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Review

Mutual Support—Modern Energy Planning Inclusive of Cooking—A Review of Research into Action in Africa and Asia since 2018

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Abstract: This paper is a review of research undertaken, and subsequent policy change enacted, in the years 2018 to 2022 regarding the integration of cooking loads and needs into modern energy planning. Building on an earlier paper which described how the dominant global approaches to tackling the enduring problem of biomass-fuelled cooking was failing, and how a new UK Aid programme (Oct 2018) would be seeking to intentionally change international energy policy towards cooking and enable a significant transition in energy use, in this paper we review whether this strategy is being adopted by researchers, governments, and the private sector across the world and whether it is likely to make a significant contribution to the fulfilment of Sustainable Development Goal 7. In particular, the call is for integrated planning of modern energy inclusive of cooking loads—the potential 'Mutual Support' that both can lend to each other. The review considers the international commitments made by donors and governments to this end, the research that positions the use of modern energy as a cost-effective proposition, the urbanisation and societal changes reinforcing such planning, and positions the review in the light of climate change and the need to reach net zero carbon by 2050.

Keywords: biomass cooking; SDG 7; grid extension; off-grid electricity; renewable energy; climate change policies; integrated planning; urbanisation; Africa; developing Asia

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1. Introduction

The aim of this paper is to review the research undertaken, and subsequent policy change enacted, in the years 2018 to 2022 regarding the integration of cooking loads and needs into modern energy planning. It looks to the fulfilment of Sustainable Development Goal 7 [1]. It builds on Batchelor et al. 2019 [2], which described how the dominant global approaches to tackling the enduring problem of biomass-fuelled cooking was failing, and how a new UK Aid programme (Oct 2018) would be seeking to intentionally change international energy policy towards cooking and enable a significant transition in energy use. The programme was purposed with reframing the problem via novel research, developing capacities to embrace emerging technologies and system models, building new actor networks, and helping to develop institutional capacities to redirect resources to the proposed strategy, i.e., to intentionally enable the transition of policies.

While this review is prompted by the development of that programme (which the authors are all directly involved in), this paper itself looks at much broader changes occurring across the energy landscape. In what follows, we draw on recently published research, as well as international statements made on clean cooking strategies, over the last 4 years (2018 to 2022), to illustrate how the global narrative around cooking seems to be shifting. Section 1 starts by reviewing the problem from an aspirational, international target-oriented point of view, illustrating how cooking is often separated out (or, worse, ignored) within the planning processes for energy by governments and international agencies. Section 2 considers the changes in the socio-economic conditions over the last four years that have started to strongly facilitate the bringing together and integration of cooking within energy planning. Section 3 reviews the field research that is supporting the design and implementation of new approaches that have been driving this process, while Section 4 looks at the challenges and barriers to a scaled uptake of cooking-inclusive integrated energy planning and the emerging responses, particularly around the addressing of financial constraints. Finally, the discussion revisits the wider geopolitics of climate change first addressed in Section 1 and the increasingly vocal calls for energy policy to more rigorously pursue net zero carbon by 2050. This new international target will be integrated to varying degrees in modern energy planning over the coming years, and the paper closes by reviewing how this might be undertaken and the issues it raises in relation to the specific case of cooking.

2. Methodology

The research hypothesis was that new data and evidence that changes the way stakeholders are thinking about clean cooking have emerged. The narrative of clean cooking is moving from 'clean' to 'modern energy' cooking services and thus is increasingly integrated with wider modern energy planning.

The review was not a full, formal systematic review. However, a protocol was applied so that the results could be repeated and the approach replicated either now or in the future. The protocol was as follows:

- Search question or objective—what evidence is there of a growing integration of cooking loads and demands in modern energy planning, and what parameters have emerged from recent research that is prompting such action?
- Inclusion/exclusion criteria—the review includes studies (both formally and informally published) and policy documents, research programmes, funding, and political statements about the use of modern energy to address the challenge of access to clean cooking for all.
- Databases—Google Scholar constrained to the years 2018 to 2022, Google and Bing search engines constrained manually to the years 2018 to 2022.
- Search strategy—key words included 'access to modern energy', 'access to modern energy AND clean cooking', 'access to electricity', 'access to electricity AND clean cooking', 'access to electricity AND cooking', LPG, clean cooking, 'off-grid', mini grids, 'solar home systems', 'ethanol' IEA, ESMAP, CCA, World Bank, COP26, crude oil pricing, 'climate change AND clean cooking'. The strategy included utilising the snowball effect for hyperlinks.
- Methodology for data extraction and analysis—collection and collation in free form digital folders.
- Declaration of interests—as the authors are involved with research covered by the review, we do not exclude our own papers.
- Time frame—review was undertaken between 1 January 2022 and 24 June 2022.

The findings were clustered around the following key concepts, and presented below in their clusters, which also provides the sequence of narrative.

- High level policy observations and aspirational changes.
- Emerging evidence and data affecting understanding of the challenge.
- Implications of new evidence and data on the key challenge.
- New evidence and data on solutions to the key challenge.

3. Findings

3.1. The Political Landscape

High-level policy observations and aspirational changes.

The literature includes a strong move within the high-level policy dialogue to reach not just clean cooking but also to ensure that the key solutions are modern energy and climate friendly.

3.1.1. Target 1—Sustainable Development Goal 7

Figure 1 summarises Sustainable Development Goal 7 and presents its breakdown of targets.

Sustainable Development Goal 7

Sustainable Development Goal 7 (SDG7) calls for "affordable, reliable, sustainable and modern energy for all" by 2030.

7.1 By 2030, ensure universal access to affordable, reliable, and modern energy services

7.1.1 Proportion of population with access to electricity

7.1.2 Proportion of population with primary reliance on clean fuels and technology

7.2 By 2030, increase substantially the share of renewable energy in the global energy mix

7.3 By 2030, double the global rate of improvement in energy efficiency

7.a By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology

7.b By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programmes of support.

Figure 1. Summary of SDG 7 goal and indicators, derived from sdgs.un.org [3].

The Sustainable Development Goals (SDG) [3] are a call for the world to respond to basic injustice where endemic poverty is a feature of society, and to ensure that people throughout the world have their basic needs met. SDG7 focuses on energy and brings to the foreground the need for a transition to 'modern energy'. In assessing the progress against this objective, it is of course necessary for the international community to show how SDG 7 is made up of key components, and such a breakdown is helpful to track the progress on each of those key components.

However, a number of papers have recently argued that the separation of 'electricity' (7.1.1) from 'cooking' (7.1.2) has led to an unhelpful separation between the planning of the two [4–7]. How then has addressing clean cooking been tackled previously and how would a focus on integrated planning that connected electricity access and clean cooking much more directly represent a change from 'business as usual'?

Regarding progress in relation to 7.1.1 'electricity', the IEA tracking report 2021 [8] states that "*Since 2010, more than a billion people have gained access to electricity. As a result, 90 percent of the planet's population was connected in 2019.*" While they lament that there are still 759 million who do not have access, the progress is nevertheless said to be encouraging. A number of publications note that this progress is fuelled by significant finance, although this is always accompanied by calls for more finance to 'finish the job' [9–11] Drawing on IEA data, Yumkella et al. (2021) [7] note that Africa has had an electricity sector investment of USD 26 billion, developing Asia 34 billion, and India 54 billion each year for the last 4 years.

However, returning to the IEA tracking report [8], it goes on to say regarding 7.1.2 'clean cooking' that "*The share of the global population without access to clean cooking fuels and technologies was 66 percent in 2019, leaving almost three billion people or one-third of the global population without access. Since 2010, the global access rate to clean cooking solutions grew annually by 1 percent, with gains mostly attributed to progress in the regions of Central and Southern Asia and Eastern and Southeastern Asia. In stark contrast, progress in clean cooking access in Sub-Saharan Africa was slower than population growth, with some countries showing little or no improvements in the clean cooking access rate*." [8].

To some, this failure to tackle the clean cooking conundrum is dismissed as one of a lack of investment, noting that investment in clean cooking remains of the order of only USD 100 million each year for the last 4 years [11–14], and associated with this is the idea that the major impediment to progress on clean cooking is that there is not enough political commitment to secure the investment resources needed to adequately address clean cooking [15–17].

In their paper, Newell and Daley [5] suggest, in contrast, that the lack of progress comes not from a lack of political will towards tackling cooking, but a case of 'mutual neglect' across two key policy arenas. Despite having clearly integrated health, environmental, and economic impact, the two policy objectives of access to electricity and modern energy cooking have not been sufficiently aligned. They note, for example, that energy policy has largely overlooked electric cooking as part of broader electrification strategies, whilst clean cooking advocates often totally omit electrification from their initiatives and proposals.

It is this separation in political thinking that we argue is a major root cause of the lack of progress on clean cooking [4–7]. Almost every electrical connection to the grid could in theory be used for cooking. This might have consequences on balancing supply and demand on the grid and some connections are not yet reliable enough to be used effectively for cooking, but the use of already provided electricity infrastructures would at least give the possibility of a clean cooking experience with minimal extra investment. We recognise that the question of balancing supply and demand is important, but this could be effectively incorporated into planning processes, hence the call for integrated approaches to energy planning. If cooking loads are adequately factored into the modelling and planning of electricity infrastructure improvement and expansion (be it grid and off-grid), then the potential for scaled clean cooking with electricity becomes real. We note that in current planning scenarios, for the 759 million who currently do not have access to electricity, about half will get a full grid connection, while the balance will get modern energy through 'off-grid systems' such as mini grids and solar home systems [8]. This potentially builds in an inequality of access which makes integrating cooking for all members of every society more difficult, but as we shall see below, not impossible given recent advances in technology.

To some degree 2021 saw a shift in political aspirations about overcoming this separation. The High-Level Dialogue on Energy in September of that year issued a call which, while still isolating clean cooking as a special concern for the world, nevertheless embedded statements such as "*Prioritize access to clean cooking in national planning and policies, including energy planning, COVID economic recovery planning, and Nationally Determined Contributions to the Paris Agreement*." [18] Its overall recommendations still used language that separated electricity from clean cooking, although the tone was one of integrated planning. "*Align energy policy and investment with energy transition pathways that accomplish universal access to electricity and clean cooking by 2030*." [10] Indeed, for the first time in such a high-level document, they recommended to "*Prioritize and coordinate political commitments and financing to accelerate access to clean cooking, **building synergies with electrification efforts***." (our emphasis). Others have echoed these sentiments in international fora such as CCA [19]. Endorsed by over 25 international organisations, the Africa–Europe Foundation manifesto [20] states it clearly: "Integrate clean cooking into NDCs and national energy planning."

In early 2022, SE4All announced an Integrated Energy Planning Tool [21] and published its first analysis for Nigeria that covered both electricity and cooking in the same models [22]. The results showed that the use of electric cooking would be the least costly option, even though Nigeria is an oil producing country. In June 2022 [23], the organisation presented to the G20 Energy Transition Working Group a clear call for integration in policy planning and turned the 'mutual neglect' into a rallying call for a positive '**Mutual Support**' (hence the title of our paper) This phrase in this context is credited to Glenn Pearce Orez, Sr. Director of International Relations, SE4All.

Before moving on to explore how realistic the inclusion of clean cooking into comprehensive modern energy planning is, we need to consider another target.

3.1.2. Target 2—Net Zero Carbon

As can be seen in the preceding paragraphs, across international pronouncements on energy access, a reference is frequently made to the Paris Agreement and to the Nationally Determined Contributions. SDG7 has always had climate mitigation built into it, particularly with its emphasis on indicators 7.2 (renewable energy) and 7.3 (energy efficiency); although Newell et al. [5], in illustrating the 'mutual neglect', show that the 'cooking sector' was rarely integrated and referred to in SDG 7.2 or 7.3 reporting. However, although SDG7 does formally include these references to energy efficiency and decarbonisation (reflecting how the concept of 'sustainability' built into it the SDGs attempts to integrate social, environmental, and financial aspects of development), with the culmination of the SDGs only 8 years away, the environmental dimensions of sustainability in the form of longer-term commitments to decarbonisation and the pursuit of net zero are increasingly being brought into the foreground of global politics and policies [8].

The debate is growing as to how to further connect the transition away from biomass cooking to net zero carbon aspirations. There has been some inclusion of cooking in Nationally Determined Contributions [24], and recently the Climate and Clean Air Coalition and UNFCCC have developed tools designed specifically to ensure cooking is addressed within NDAs [25,26].

As we shall see below, tackling the problem of biomass-based cooking initially started with promoting improved combustion of biomass and then more recently added a growing emphasis on switching to other fuels. We shall see below that one such fuel switch implemented in a number of countries has been to liquefied petroleum gas (LPG), for example Morocco, Indonesia, India, Nepal. LPG fulfils the key criteria for SDG 7 offering a clean cooking experience for the user in the kitchen. However, LPG is a fossil fuel and whilst offering clear carbon savings in relation to biomass cooking, some countries that had successfully switched to LPG from biomass are now considering a switch to electricity driven by factors such as energy security, climate mitigation, price, affordability, and their drive to net zero carbon [27–29].

LPG is currently obtained from fossil fuels and the final COP 26 Pact [30] makes reference to removing fossil fuel subsidies. According to the IMF [31,32], direct fossil fuel subsidises stand at about USD 500 billion, and when externalities are included, total fossil fuel subsidisation could be as high as USD 5.9 trillion. The commitment of countries to a net zero world by 2050 (with some countries aiming at 2060 (China [33]) and 2070 (India [34])) and in particular the removal of these subsidises points to rising prices for oil, and by implication for LPG, a trend now likely to be deepened in the context of the Russian invasion of Ukraine [35]. Indeed, Parry [32] suggests that efficient fuel pricing in 2025 would reduce global carbon dioxide emissions by 36 percent below baseline levels. This and other economic changes emerging from a world concerned about climate change could push fossil fuel prices significantly higher by 2030.

Indeed, the call for decarbonisation brings to the foreground not only the emissions of fossil fuels, but the future pricing of fossil-fuel based cooking fuels. In Figure 2, Knoema [36] predict a trebling of the 2015 brent oil price by 2050, while Capital [37] suggest a similar rise, and the EIA [38] who are generally conservative about price rises, suggest a doubling by 2035 based on supply and demand even without any action on fossil fuel subsidies. During the writing of this paper, the Ukraine –Russia war increased oil prices up to USD 126 (8 March 2022 [39]), i.e., a sudden rise to the price in January 2022 that was predicted to occur in 2035.

However, these predictions are based on the scarcity of oil and the increasing costs of extracting from more difficult locations (hence the scarcity of the supply of oil created by a war that has caused the price rise), and they do not as of yet take into account the removal of inefficient subsidies as called for by COP26 [30]. These predictive prices could be doubled or tripled if 'inefficient subsidies' are removed.

These price rises will challenge the role of LPG as a transition fuel to reach SDG7 clean cooking ambitions. The danger is that modern energy planning that positions fossil fuel-based LPG as a transition fuel could also create technical lock-in that is unable to escape the challenges of rising LPG pricing.

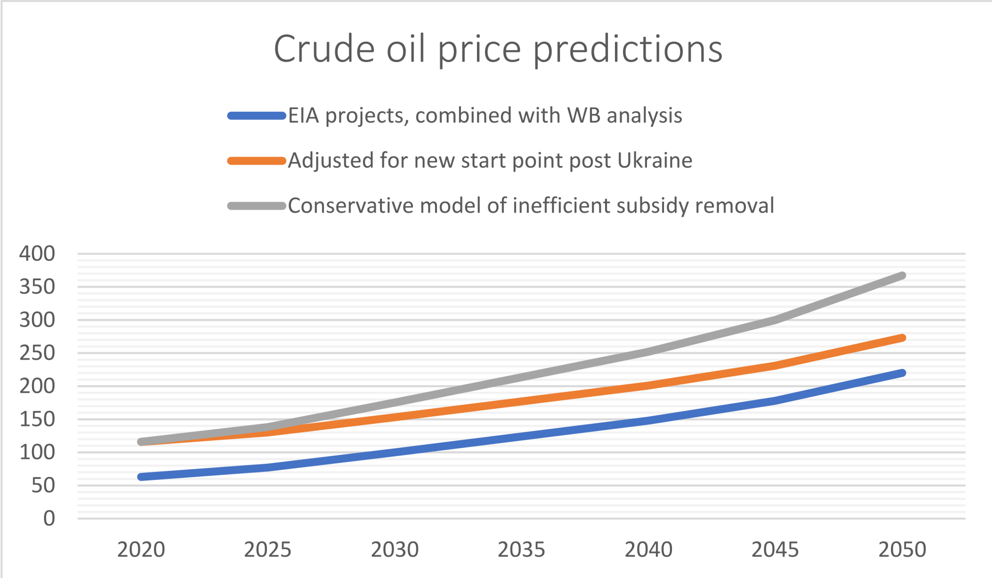

Figure 2. Authors own based on EIA long term brent oil price projection accessed through [36–38,40].

In contrast, the IEA, in their net zero scenario [41,42], suggest that the oil price will rise only for the next 8 years, and thereafter as the world decarbonises, the demand for oil reduces, and the over-supply will bring the price down. This balance between supply and demand will depend a lot on the political economy and its commitment to mitigating climate change [43].

Similarly, having challenged the fossil fuel-based LPG as a transition fuel, Čukić et al. 2021 [44], Chen et al. 2021, [45] and the IEA Roadmap [42] all draw attention to the possibility of a renewable bioLPG as a home-grown fuel. The chemically identical BioLPG can be derived from fully renewable sources and is now an emerging possibility. Chen et al. [45] show how it can be produced from feedstocks such as municipal solid waste (MSW) with suitable collection systems in place, and from biogas derived from agricultural residues. Since bioLPG is renewable, it could secure international investment and contribute to a net zero carbon world.

Some electricity generation based on fossil fuels and rising oil and gas prices based either on scarcity or removal of inefficient subsidies, will also affect electricity generation costs and tariffs. Net zero pathways for electricity will depend on increasing the use of renewable energy technology alongside emerging storage technologies, and in contrast with the fossil fuel-based generation, renewable energy prices for electricity generating equipment are reducing. They are now clearly commercially viable. Figure 3 shows the growth in solar and wind capacity procured through auctions, and the accompanying reductions in price [46–48].

More electricity will also be required to decarbonise the transport sector, and this will lead to a reduction in fossil fuel distribution (i.e., reduction in distributed fossil fuel to petrol and diesel stations) and an increased demand for renewable generating capacity (probably resulting in lower per unit costs) and expansion of transmission and distribution networks, both of which would further support a transition to electricity-based cooking.

What the exact mix of energy sources for a clean cooking fulfilment of SDG7 is, is not yet clear, but what is clear is that in the global political economy, the combination of meeting the SDG7 targets with the growing call for net zero carbon reinforces the idea that **clean cooking needs to be properly integrated into modern energy planning creating a 'Mutual Support'.**

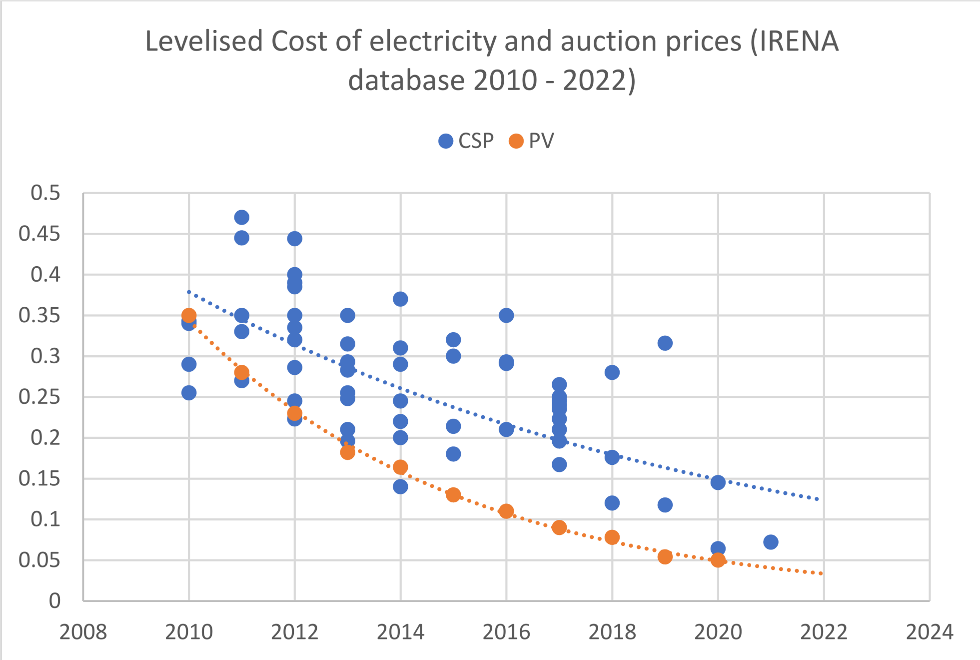

Figure 3. Authors own derived from IRENA database [46,47].

SDG7 is only an interim target and is now only 8 years away. Beyond 2030, we should also note that the population is set to increase by 2 billion people by 2050 [9,49], and that the majority of these people will be added to countries where clean cooking access is limited. Price 2021 [50] notes that inward migration combined with this population growth will mean that there will be considerable urbanisation in those countries, and that in itself affects the nature of the clean cooking strategies that will succeed and strengthens the need for integrated modern energy planning. Even in the unlikely event that SDG 7.1.2 is reached by 2030, the strategies employed to continue meeting the demand for affordable sustainable cooking for all will need to accommodate significant population growth post 2030.

3.2. A Brief History of Clean Cooking

This paper started by noting that the monitoring indicator on SDG 7.1.2 suggested the world was failing in its promise to deliver access to clean cooking to 3 billion people. Papers [2,4,5] all pointed to international calls for a different approach, something other than 'business as usual' in the clean cooking space. "If we are to witness the kind of progress expected on electricity, **clean cooking must be placed on a par with electricity access on the policy agenda**." [51]. The International Energy Agency/World Bank SE4All 2017 Global Tracking Framework of 2017 [52] stated that "the number of people who still use traditional, solid fuels to cook rose slightly to 3.04 billion, indicating that efforts to advance clean cooking **are not keeping up with population growth**". In addition to the SE4All report, ESMAP and GACC [53] concluded that "the 'business-as-usual' scenario for the sector is encouraging" (without major new interventions, about 180 million households globally will gain access to, at least, minimally improved cooking solutions by the end of the decade) "but will fall far short of potential".

So what was 'business as usual' prior to 2018 and how does the reference to and focus on electricity form a disruptive and ground-breaking additional clean cooking strategy for accelerated scaled response?

In the period up to 2010, the focus of 'clean cooking' in the least developed economies was predominantly on seeking to improve the efficiency of biomass combustion [54]. In theory, if biomass combustion is improved, less biomass is used and stoves provide greater efficiencies for cooking. At the same time, higher efficiency means less particulates, helping to mitigate household air pollution to the point where it does not affect the health of the cook. By about 2010, research had shown that 'improved cookstoves' could be classified in tiers, and that tier 2 and 3 stoves did indeed offer an improved combustion efficiency, but research began to emerge about the lower particulates still being in the danger zone for health [55], and that there was limited time and health saving for the cook when using these lower tier stoves. When a chimney was introduced, the particulates lowered for the cook, but increased for the children playing outside.

Even though they were not set until 2015, it is against this backdrop that SDG7 was shaped, and clean cooking was monitored with the indicator 7.1.2. Clean cooking access was and continues to be defined under SDG7 as having an 'improved cookstove', a tier 3 or higher stove. "*The definitions of clean and efficient are aligned with the interim performance guidelines in the ISO International Workshop Agreement (IWA). For this report, stoves and fuels that meet Tier 2 for efficiency are considered efficient and those that meet Tier 3 for indoor emissions are considered clean for health* [56]".

During the last three decades, some stronger economies had scaled the use of LPG. Brazil started in 1937, and by 2001 had scaled use. However, in 2001, subsidies were removed and that caused a crisis [57]. In 2004, Indonesia used policy instruments to substitute kerosene use with liquefied petroleum gas (LPG) and by 2007 the uptake of LPG had moved from 10.5 percent to 47 percent of households. [58] India had started to encourage LPG use by policy reforms in 1991 and by 2015, 56% of households were using it [59,60]. Gould et al. [61] discuss how Ecuador promoted LPG from 1980 onwards, achieving a drop in firewood use from 70% to less than 10% over four decades. It is worth noting for the context of this paper that all of these gains were achieved by heavily subsidising the switching to and use of LPG combined with making polluting fuels more expensive initially and then very difficult to obtain at all, i.e., pushing people away from polluting fuels and simultaneously pulling them towards LPG.

Around 2010, donors, experts, and policy planners who had been focused on ICS in least developed economies started to publicly focus more on fuel switching. This was to get a cleaner kitchen experience to address the shortfalls of lower tier ICS, and fuels such as LPG, biogas, and ethanol which were classified as tier 5 rose up to the agenda, and did indeed offer the hope of a near particulate free kitchen experience for the cook. Donors and actors in the sector also pointed to the gender aspects of cooking, and the time used and safety experienced for collecting wood featured heavily, with the hope that tier 5 fuels could release time and improve safety for women.

A key article captured this general move and the shortfall being seen in the tracking of SDG7.1.2 and emerging in the research and evidence. [62] The article caused a stir among proponents of clean cooking (with some judging it as unfair journalism). In a response to the article, a statement made by the World Bank recognised that.

"*that there is no one-fits-all-solution and local innovation and contextualized solutions are critical for long-term sustainability of programs. The cooking technologies supported by World Bank programs include biomass cookstoves, biogas, ethanol, LPG, and natural gas. In all cases, the fuels and technologies used are selected based on local context, resources and needs*." [63] They reaffirmed that clean cooking is a critical issue that the development community cannot simply retreat from because certain approaches have not produced the results that were initially promised. They acknowledged that the clean cooking community needed to regroup, "*and put our collective strength behind a new, concerted effort on modern energy cooking service—one that is built on scaling up approaches that have been proven to work, mobilizing new resources where needed, and targeting those resources for maximum impact*." [63].

What is significant about this response is the list of fuels that is quoted. While their publication [64] did discuss electricity, it tended to dismiss it as too expensive, and it lamented the basic infrastructure suggesting it was mainly too weak to consider electric cooking seriously as a steady cost-effective supply of energy for household level cooking. It is worth noting that the document draws on cooking cost data from hotplates in 2012.

The decade from 2010 sees the rise of two energy efficient appliances for electric cooking. Induction stoves are said to be efficient because they create heat in the pot by magnetic induction, and therefore, unlike hotplates, there is no loss of heat from the heating element to the pot [65,66]. A good fitting pot to a hotplate can indeed do an equivalent heat transfer, but it needs a pot sized for the plate. Both hotplates (resistive or infrared) and induction can also gain some efficiencies by automating the control of some parts of the cooking process (e.g., defined heat levels, and cooking timers). Recent research has pointed to the electric pressure cooker (EPC), which has two additional reductions of energy loss. The first is an air gap insulation which mitigates radiant heat coming from the pot during a 'long cook' of beans or stews, which can also be found in rice cookers and slow cookers [67,68]. The second is its automated use of pressure to reduce the time required to cook long cooking food like bean stews [69–73]. The EPC also has a well-fitting pot, automation, and timers.

The energy efficient electric pressure cooker (EPC) was introduced to the global market in 2010, and Instapot, the now leading supplier of such EPCs, report sales of a few hundred to developed economies in those first few years [74]. It is not until 2015 that sales rise substantially and they become more common in developed economies. The marketing surrounding them focused on convenience and time, and not on energy efficiency, and so it is only from 2015 onwards that new research points to their potential as an energy efficient appliance for LMICs [75–77]. Indeed, Instapot themselves recently undertook an energy efficiency study to position their products in Europe [78].

The timing here is important since, prior to this, it was not that the clean cooking sector was ignoring energy efficient electrical appliances, it was that many of the most culturally relevant types of energy-efficient appliances did not really exist until the start of the last decade (it should be noted that energy efficiency in the kitchen of developed economies was improving, with the kitchen energy use in 2020 being half that of 1970. Rice cookers and kettles are energy efficient but are seen as task-specific and microwave ovens are very energy-efficient but mainly used for reheating food rather than cooking from raw materials. The task specific energy efficient products have been around since the 1950s but the point of the recent research is pointing to the most culturally relevant types of energy-efficient appliances). As Newell et al. [5] present, the fuel switching discussion with its incomplete awareness and data on energy efficient electric possibilities, barely included electricity as a way of fulfilling SDG 7.1.2 even though significant gains were being made on SDG 7.1.1.

It was in this context that the UK Aid programme described by Batchelor et al. [2] was designed, and the language around 'modern energy cooking services' as something other than business as usual was strengthened. The programme talks about leveraging the gains in electricity provision to include clean cooking.

3.3. A Growing Focus on Modern Energy Cooking Services and Changes in Evidence and Data Collection

Emerging evidence and data affecting the understanding of the challenge.

Given the above discussion about how the sector has been politically influenced over the last few years, and given that there is a growing focus on modern energy cooking services, this section reviews changes in evidence and data collection that strengthen the focus.

3.3.1. Making the Statistics Worse but for the Better

As the ESMAP puts it, ESMAP regrouped and put a concerted effort into clarifying what modern energy cooking services might look like. In the state of modern living [79], they sought to redefine what it meant to have access to modern energy cooking. They found that "four billion people around the world still lack access to clean, efficient, convenient, safe, reliable, and affordable cooking energy". Using their Multi Tier Framework data (see below), they identified that in order to get access to tier 4 or tier 5 cooking solutions, the world would need to find USD 150 billion a year between now and 2030. USD 39 billion could be public sector finance, while USD 11 billion would be private sector installing downstream infrastructure, and the balance would be the expenditure of households on the purchase of stoves and fuel. Despite the emerging research on electric cooking, the assumption of the ideal scenario was that the shift to modern energy cooking would primarily be met by 70% LPG use across all countries. Their scenario that allowed for tier 3 solutions required USD 10 billion a year. They have since used their basic model to create an online planning tool for high level use by nations to consider paths for integrating modern energy planning with higher tier cooking solutions [80].

Ref. [81] illustrates that to date, transitions have been from wood to LPG to natural gas (where available), with electricity being considered as a supplement to the primary fuel. However, this is challenged by the changing prices of oil-based products and the drive to net zero as described above.

3.3.2. Confirming the Need through Systematic Reviews

At the same time that the case for higher tier alternatives has been strengthening (both gas and electric), further evidence has been accumulating about the limitations of current dominant narratives/strategies. In the period in question of 2018 to 2022, a number of systematic reviews have been published, which reinforce much of the push back on biomass Improved Cookstoves. Pope et al. (2021) [82] synthesise evidence of in-field measurements, across 50 studies, which concluded that "*Only studies of clean fuels consistently achieved post-intervention kitchen PM2.5 levels at or below the health-based WHO interim target level 1 (WHO-IT1) of 35 μg* m^{-3}." However, they point out that although the cleaner fuels used exclusively hit the WHO-IT1 target, most studies experienced stacking and ambient air pollution which pushed the exposure over the target. They noted that none of the Improved Cookstoves (ICS) were at or below the target.

UNESCAP 2021 [83] concluded that clean cooking interventions did indeed reduce fuelwood consumption, fuel collection time, and cooking time, but the review did not detect any significant impacts on pneumonia, ARI, blood pressure, or hypertension. The review also suggested that interventions often lead to short-term adoption, but struggle to achieve sustained long-term use. They noted that the majority of the evaluation literature focuses on improved biomass cooking stoves. This makes it challenging to assess the effectiveness of other technology and fuel solutions such as LPG, LNG, biogas cooking stoves, and electric cooking stoves. Nevertheless, they note that the broader development literature and historical evidence suggest that the impacts of LPG, gas, and electric cooking solutions have lower emissions, and therefore greater health benefits.

While [84–86] do identify mild health benefits on blood pressure from ICS, they all question the comprehensive effects of ICS on health.

Accordingly, ESMAP (2021) [87] conducted a review of the literature to understand what might drive and hold back a transition to modern energy cooking services. They noted that key factors included education levels and wealth status; peer influence and trust in stove information source; competition with existing fuels and technologies; and program design features, including technology, training, and after sales support. These findings supported a consumer-focused review [88].

3.3.3. Beyond Just Primary Fuel Data

One of the other challenges, and to some degree 'neglects', of the current cooking sector is that of fuel stacking. It has been acknowledged that the 'energy ladder' does not represent how people use different fuels. While the richer do tend to use more modern energy and cleaner fuels for cooking, they often do so overlapping with the use of previous lower tier fuels. This is neglected in the national data collected on cooking. The survey questions utilised are often about the 'primary cooking fuel'. This can lead to the situation where LPG is used for 60% of the menu, but the old wood or charcoal stove is lit for the other 40%, which is reported as a household using LPG, and yet such household is still experiencing life threatening household air pollution [89,90].

To some degree, ESMAP address this by introducing the Multi Tier Framework [91]. In addition to classifying cookstoves according to their emissions, the MTF takes into account the convenience, safety, affordability, and fuel availability when creating a new tier structure. These added parameters allow for a more nuanced understanding of the household's situation. For instance, the calculation of the health effects of emissions can now take into account the kitchen design—is the cook outside or within a small windowless kitchen? The latter being much more harmful than the former. New sets of data utilising the MTF have been published over the last 4 years [92–97].

However, the MTF still does not directly address the fuel stacking issue, creating instead a more detailed picture of the primary stove. Another criticism of the MTF is that of its separation of the electricity module from the cooking module, the end result being a set of diagnostics which do not integrate the data and continue to present the two issues of 'modern energy (i.e., electricity) and 'clean cooking' separately. The presence of a kettle or even a microwave in the list of electrical assets is overlooked when analysing and constructing the diagnostic for clean cooking. Refs. [98–100] present analyses of the same data but with an emphasis on connecting the two modules. Using people who use a single fuel exclusively, they are able to unpack the role of stacking and show that a wider use of electricity for partial cooking is already taking place.

3.3.4. Beyond Boiling Water

The other shift that occurred during this period was a move away from defining the efficiency of a cooking appliance by the time taken to boil water and considering the way the cook might use it in real life. Methods such as the Water Boiling Test (WBT) [101,102] defined how much energy might be used to bring a fixed amount of water to temperature, and measured the input energy, giving an overall efficiency. However, cooking tasty food is not just about boiling water (and holding it at heat). The controlled cooking test (CCT) [103] introduced using stoves in almost real-life conditions to monitor how much energy is used to cook a defined meal (in a defined quantity). Since cooking culture varies between contexts, the CCT varied depending on where it was carried out—and was primarily used to compare stoves and fuel within that context. The Kitchen Performance Test (KPT) [104] takes this one step further and gives the appliances to households and asks them to use it and measures the change in fuel consumption after the introduction of the new device.

The Cooking Diaries methodology [105] monitors not just the energy consumption, but also the number of heating events, what food is cooked with which fuel, and whether that weekly menu changes from the baseline. The method can be applied in an intensive form with respondents noting their answers on paper or through online forms with the assistance of enumerators, or in a lighter fashion through a WhatsApp bot that prompts the user when the energy meter signals that the appliances are being used [106].

3.3.5. Beyond Oil-Based Fuels—Wider Possibilities for Modern Energy Cooking

Clean and with minimal kitchen emissions alternative fuels include ethanol, biogas, bioLPG, and possibly in the future, hydrogen.

We have seen above that through the climate change lens, COP26 called for the removal of inefficient subsidies, and this will likely have a strong impact on the price of LPG (although this is something that is increasingly recognised by the LPG industry itself [107,108]).

An alternative tier 5 experience can be achieved by utilising biogas. Biogas is versatile and country-specific policies in many countries include it as part of waste management, renewable energies, and climate change [109]. A key constraint of biogas use is a lack of distribution infrastructure. Small units can be installed for utilising agricultural waste and the gas used in the kitchen for a tier 5 experience, but the units are fixed and have to be near the user. There are innovations for considering novel technologies for small-scale and low-cost biogas clean-up into biomethane, and compression into small bottles, suitable as a clean cooking fuel [109]. The paper [109] concludes that where competing fuels command a high price, a bioCNG system could be viable even at small scale; however, its viable affordable use would very much depend on the context.

Ethanol-based stoves can also offer a tier 5 experience. Koko Networks has pioneered refilling ethanol fuels via an automated teller, and this possibility has seen considerable growth in Kenya [110]. In the longer term, there is discussion about green hydrogen as a mechanism for leveraging renewable energy into a distributed cooking fuel [111].

3.4. Modern Energy Cooking and Socio-Economic Impacts

Implications of new evidence and data on the key challenge.

Building on the above discussion about the growing focus on modern energy cooking services and changes in evidence and data collection, this section reviews gives insights into the socio-economic impacts of such a transition.

3.4.1. Deforestation

Once again, a lack of data and incomplete picture are sources of frustration for the planning processes. The continued dominance of biomass cooking in low- and middle-income countries undoubtedly contributes to deforestation—but by how much? The ProPublica article [62] cited studies that called into question how much wood collection for cooking was sustainable, but it also challenged the idea that most was not sustainable, and instead stated that most was indeed sustainable. These statements were based on [112] and referred to data collected in 2009. Since 2009, however, most key countries in Africa have doubled their population, and given the persistence of biomass cooking, it is not surprising that countries such as Uganda have moved from 15% forest cover in 2006, to 9% forest cover in 2016 [113], with a likely 6 or 7% coverage in 2022 [114]. As the population is set to grow at the same pace, how much longer before a critical tipping point is reached where land cannot recover, and a shortage of wood presents as huge price increases in wood and charcoal?

Ref. [112] also clearly showed the link between urbanisation and deforestation and [115] showed the red net loss of biomass surrounding areas of higher population in Kenya. This is logical but reinforces the idea that if urban and peri urban populations continue to use wood and charcoal, the surrounding agricultural and forest lands cannot sustainably supply the cities and towns.

While [112] is a key referent point for many who discuss these matters, their work was constrained by the data available. They calculated changes in above-ground biomass. When a tree is killed, the roots decay, releasing climate-relevant emissions. In dry soil, this tends to be CO2, but in mangrove swamps this becomes methane, a more potent climate change forcer. Recently, some authors have also argued that the loss of the next twenty years of carbon capture is important and relevant. While a new tree planted or wild wood encroachment can 'replace' the tree that was killed, their carbon sequestration is small at the start of the seedling's life and takes 10 to 20 years to get back to significant carbon capture [116–119]. Such authors note that we do not have twenty years to recapture carbon, and the loss of the coming twenty years of capture in the mature tree that was killed is significant to nature-based solutions for climate change.

3.4.2. Health and Economic Impacts

Whilst combatting deforestation and addressing climate change are important motivations for policy interventions that seek to tackle the continued dominance of biomass cooking, until very recently it has been health concerns that have been the most-often cited motivation for pursuing clean cooking priorities. As other motivations have received greater attention (whilst existing solutions have been found lacking), it is interesting to note how different objectives are co-articulated within the most recent policy interventions and how these relate to different fuel mixes and overall strategies. In [44], the authors describe how the National Master Plan of Rwanda is seeking to promote LPG scale up using three scenarios to analyse the situation—a business as usual, an intervention scenario, and a policy scenario. They argue that the policy scenario would save 404,000 Disability Adjusted Life Years (DALY) as well as a 7660 reduction in premature deaths. They translate the health savings including labour time and productivity, as USD 19.5 million of economic benefits. They also point to the 'not cutting down' of 243 million trees which would have its own impact on carbon capture—which has been discussed above.

A key tool is now available from the WHO, which assists in the calculation of benefits from changing to modern energy cooking [120]. Eight market assessments were conducted in 2021 and presented the benefits of switching a proportion of charcoal users to modern energy in the form of electricity. [121–128] The papers take account of the mix of generating technologies in the country's specific grid, since some like Kenya have significant renewable generation already, while others such as Benin are reliant on fossil fuels. When such benefits are considered at the global scale, the ESMAP modelling suggests that USD 1.4 trillion would be gained in health benefits, USD 0.2 trillion in climate mitigation, and USD 0.8 trillion in benefits to women and girls.

3.4.3. Raising the Profile of Clean Cooking in Urban Areas

In the last 4 years, there has been a growing recognition that population growth, urbanisation, and deforestation are intricately linked. The combination of these has shifted some of the focus away from getting clean cooking in remote rural areas (which has dominated previous strategies) to ensuring that those in urban centres which already have access to infrastructure can access clean cooking solutions.

Urbanisation, of course, also suggests a transition in cooking and eating habits. Urbanisation often accompanies changes in eating patterns. Households with adults in full-time jobs rarely cook lunch, and even sometimes miss breakfast. They also eat out more and buy more pre-cooked foods and [129] shows how this is increasing particularly in developing Asia.

Price et al. [90] re-analyse MTF data to show the linkages between the two and link it in particular to the increasing urbanisation of the world. A key change to the environment is urbanisation. While rural areas were the priority 20 years ago, urbanisation means that tackling urban poverty is now urgent. The next 20 years will be dominated by increasing urbanisation, and the fact that cooking with polluting fuels in urban areas is detrimental to health, local environment, surrounding environment, and the economy, clean air policy will rapidly rise up political agendas for governments globally.

Price et al. [90] tie their research to fuel stacking behaviours, and we shall revisit these phenomena below. However, in terms of policy environment, they note the persistence of biomass in urban contexts. They analyse the MTF data for urban populations in Cambodia, Myanmar, and Zambia and show that a diverse set of practices is widespread in the urban areas of these three countries, a behaviour commonly called fuel stacking. To transition households to cooking exclusively with modern fuels, the stakeholders of Ockwell et al. [130] will have to engage in situated realities and explore how stacking behaviours relate to cultural, economic, and policy landscapes in each context.

3.4.4. Displacement Settings

A body of literature that seeks to bring the energy needs of displacement settings more to the foreground is also emerging. Landscape reports and papers such as [131,132] are complimented by online training sessions such as [133], which notes how the idea of bespoke temporary displacement camps set in the rural areas is being overtaken by long-term camps being neighboured by host communities and the need for both to be engaged in the energy discussions, and by the fact that 65% of the displaced are in urban settings.

Bisaga and To [134] echo the challenges described above noting that there have been interventions for improved cooking solutions in displacement settings but also note that very few have involved modern energy cooking. They blame this absence on there being limited availability, affordability, and lack of business models that suit those complex humanitarian settings, with many interventions focusing on the short-term and addressing the need through grants. The number of displaced people surpassed 80 million in 2020, with close to 90% having little or no access to adequate cooking fuels and technologies.

The longevity of being displaced is quoted, with the mean duration of exile as experienced by refugees standing at between 10 and 15 years. Data are not clear on the proportions in each category; however, in 2019 an estimated two out of three IDPs and 60% of refugees were in urban or semi-urban areas. It is possible to provide modern energy cooking services in urban areas. Research on access to MECS among displaced populations in urban areas has been scarce and the legality and status of the displaced can be a significant barrier.

3.4.5. Institutional and Small Business Cooking, and Pre-Processing Food

Most of the above focuses on the domestic settings, although [90,129] suggest that there is a growing need for clean cooking in retail settings (restaurants and street vendors). There are also institutions that provide food for their clientele, whether that be schools with school feeding programmes, health clinics and hospitals for patients and staff, or factories or private sectors with many staff members [135]. There may also be need for pre-processing food to reduce the energy consumption within the final kitchen [136,137]. In each of these cases, bulk cooking may be required, and there is a thread of research looking at larger modern energy-efficient cooking appliances that might be substituted for biomass-based options [138,139].

3.5. Building the Evidence Base

New evidence and data on solutions to the key challenge.

Given these landscape changes, recent years have seen a growing cohort of researchers considering the cost effectiveness of energy-efficient electrical cooking appliances. In this section, we review some of the emerging studies that confirm the possibilities of mutual support between gains in access to electricity and clean cooking.

3.5.1. Electricity as a Cost-Effective Option for Cooking

Cowan (2008) [140] did compare cooking real meals across different fuels, but that comparative research on electricity was extremely rare before 2018. Since then, there have been a number of studies that have illustrated the cost effectiveness and practical possibility of cooking with electricity. ESMAP (2020) [75] presented, in five case studies with modelling based on field data, a comparison of the current and projected costs to the consumer of a range of electric cooking (eCooking) solutions with the costs of cooking with other widely used fuels in each context. Leach et al. [141] also tackles the question head on. They present a suite of models that represent the technical, economic, human, and environmental benefits and impacts of delivering electric cooking services, with a life-cycle perspective. Cases on urban grid-connected households in Zambia, mini-grid connected households in Tanzania, and for off-grid Solar Home Systems in Kenya all evidence the viability of electric cooking.

Their conclusion is that electric cooking can be cost-effective at a household level (i.e., a wise use of household finances), but they also bring in the value of the externalities such as the reductions in human and ecological impacts. A major barrier may be the upfront cost, but consumer financing can unlock eCooking for low-income HHs [13,142–146]. The resulting impacts can be used for results-based financing [14].

Within this discussion of cost effectiveness and affordability, there are reviews of the capacity of the grid to supply the electricity. Within that, they draw a distinction between grid, mini grid, and off grid solar home systems.

3.5.2. Grid

This is a double-edged question—does the grid have the capacity [147], and would the connections be strong enough to cope with the higher power draw of a cooking device [148,149]? There are grids that have been rapidly expanded and in doing so have delivered a less than ideal service to their consumers. Ref. [147] identify the least-cost electrification solution, usually a combination of standalone systems (SAs), microgrids (MGs), and grid extensions (GEs). Ref. [148] conclude that "*Low Voltage networks (assuming* *sufficient electricity generation exists) have a strong capability to support electric cooking loads without exceeding substation capacity and voltage drop constraints, and can already support cooking appliances at low power ratings (e.g., 300W rice cookers) for 100% of users connected under the same substation*."

3.5.3. Mini Grid

Ref. [150] discuss the balance of load profiles and tariff rates in mini grids, based on field work in Tanzania. Such a balance is necessary to recover their investment costs. In Kweka et al. [151], the paper illustrates the dynamics of adding energy-efficient appliances, specifically electric pressure cookers, to mini grids providing electricity to very remote communities on the lake shore of Tanzania. They go on to show how the use of the EPC reduced time not just in the fuel gathering, but in the preparation and actual cooking times as well. In Nepal, Clements et al. [152] build on their field data on Micro Hydro Power (MHP) to model the effectiveness of adding cooking loads to them. The model showed that a payment structure based on electricity consumption rather than a flat tariff could increase the income of a case study community in Eastern Nepal by 400%, although it increased monthly payments for certain households from NPR 110 (USD 0.93) to NPR 500–1100 (USD 4.22–9.29) which could present difficulties. Keddar et al. [153] consider the aspect of reliability. Could a mini grid actually support a scaled uptake of electric cooking on energy-efficient devices? They model the grid with and without eCooking loads and conclude that mini grids characterized with 50 mm2 and 16 mm2 CSA distribution and service cables, respectively, adequately support high levels of eCook penetrations without causing any serious network constraint issues that would require network reinforcement. Lombardi et al. 2019 also demonstrated the effect of cooking loads on a mini grid [154].

3.5.4. Off Grid Solar Home Systems

Van Buskirk et al. [155] position their research from a household point of view rather than community mini grid. It has long been thought that since Solar Home Systems had such challenges as to innovate a simple lighting system that could replace kerosene lamps that to cook on such a system would be financially out of reach. Refs. [156,157] present a very cheap solar electric system, one that is adaptable to include storage or not storage, and more importantly they show in the paper how they can work with a household to start with a simple lighting system and upgrade it to eCooking through an 'earn and grow' system. Refs. [158–160] propose a similar system, while Pesitho [161] are demonstrating such systems in displacement settings.

3.5.5. Confirming the Energy Efficiency

There is now a substantial body of literature confirming the efficiency of energy-efficient electrical cooking appliances in lab and field settings. As briefly discussed above, emerging research and advocacy literature tend to side step the task-specific appliances such as kettles and microwaves (with the exceptions of [162,163]), to focus the rice cooker and electric pressure cooker which both have control and insulation for long duration cooking [67,69–73], and the induction stove and infrared hotplate, which when fitted to bespoke pots are good for short duration cooking (e.g., frying) [65,66,69], the intention being to replace a wood or charcoal stove across the whole of the households regular menu.

The energy efficiency of such devices has been supported with a significant body of evidence from lab tests [164–176] and field tests in households [76,156,177–190] all conducted within the target years.

The literature notes that electric pressure cookers can fry, and while there were some early statements that the appliances, due to their deep pot, could not cook 'chapati', it has now been shown that it can. An emerging energy-efficient appliance is the air-fryer, which has begun to get traction in emerging markets and yet has had limited testing to date. Electric pressure cookers also now have the option of a fryer lid [78].

3.5.6. The Socio-Cultural Dimension

There is more limited evidence that modern energy cooking fits the socio-cultural contexts of everyday cooking. Much of the above technical literature makes a point of ensuring that tasty food is cooked, which is acceptable in different cultural contexts. However, Leary et al. [191] discuss the broader contexts of what might make modern energy cooking using energy-efficient electrical appliances attractive to the consumer—time, convenience, cleanliness (as in, not getting clothes dirty). They refer to Puzzolo et al.'s [192] systematic review, which identified drivers and barriers for clean cooking but did not include electrical cooking appliances per se as the core data were collected before this recent change in research and action. Nevertheless, Leary et al. use the seven domains identified by the systematic review to assess the challenges and strategies of modern energy cooking. They note that that the uptake of eCooking can be hindered by (often false) perceptions around cost, taste and safety, the high cost, and the steep learning curve for new appliances. This is supported by evidence from [193–195]. The lack of awareness/availability/after-sales service for energy-efficient appliances and the reluctance of male decision-makers to authorise appliance purchases was also thought to be a barrier.

Scott et al. [196] present research on consuming foods and modern eating habits. In wider society in urban settings, the choice of foods varies and there is more pre-preparation. They show that innovative food products that take less energy to cook can clearly have a substantial impact on the amount of cooking energy used in the household kitchen. Kelkar [197] brings in the gender dimension focusing on how much agency women have to choose what they cook with. Such socio-cultural barriers may prevent scaled uptake of electrical cooking, although this should not prevent planners integrating cooking with the planning of electrical networks—the Mutual Support.

3.6. Finance for a Scaled Uptake

Finally, for this section, as briefly discussed above, this alternative and additional strategy of leveraging the gains in electricity to include clean cooking, strengthens old options for financing and opens new possibilities. The literature focuses on three aspects of financing.

3.6.1. Mitigating Upfront Expenditure by the Consumers

Most of the modern energy cooking solutions have a slightly higher cost for the basic equipment and the supposition of most of the literature is that consumers will need credit facilities to be able to obtain the equipment. [145–147,149–151] Work has been undertaken on linking financial inclusion and its emphasis on money management to cleaner cooking. Pay as You Go solutions, including utility led on bill financing, has become common in solar home systems, and has been applied to biogas and LPG roll out [132,198]. The PAYG system allows the consumer to obtain the equipment and begin to use it, paying an amount each week or month, sometimes depending on their usage or sometimes at a fixed rate. It is effectively a credit facility managed by the supplier.

3.6.2. Mitigating the Actual Total Cost of the Equipment to the Consumer

In parallel with the above mitigation of the upfront cost to the consumer, there are emerging opportunities for mitigating the total cost to the consumer. Since transition to clean cooking has health, environment, and economic benefits, it can be seen as a public good, and therefore government subsidies can seem justified. The most famous of these is the Indian PMUY which not only offered subsidy of the equipment and the LPG, but encouraged 'middle class' citizen voluntary donation of their subsidies to poorer households. On the whole, the programme has been considered a success, although there are emerging reports that the poor still cannot afford to refill the cylinders, and that the USD 5 to USD 8 billion the Indian government spends on this is a burden on the government budget—indeed, in 2020 the scheme was suspended. [199–204] There is much to learn from such a scheme to ensure that integrated modern energy planning inclusive of clean cooking can anticipate and adapt to changing national and global contexts.

Schemes other than direct subsidies can mitigate equipment costs and are being tried by international agencies. The Clean Cooking Fund, an aspiration by the World Bank to utilise USD 500 million for clean cooking activities, has and will use results-based funding based on co-benefits to guide its programmes [205]. Other work such as BGFA [206] echoes the use of RBF for promoting modern energy cooking.

There has also been a potentially significant shift in how carbon finance might be used with modern energy cooking [14]. Improved biomass cookstoves have accessed carbon finance previously, but it has had a chequered history. Payments were made on the sale of the improved cook stove and stories emerged of people not using the new stove and reverting to their old traditional stoves. The only way of monitoring such effects was relatively expensive house-to-house visits. The consequence has been that policy actors have felt that the emission savings attributed to the carbon schemes were not very accurate and, if anything, inflated. With the use of higher tier stoves and modern energy appliances, the opportunity presents itself to remotely monitor. Metered supplies and PAYG allow for a direct link between use of the equipment and data flows, giving more accurate and timely data on actual use. The new protocols are being tested now and are in the public domain [207,208].

There are also opportunities for the upfront cost to be mitigated by charitable donation and in particular crowd funding, both for the support of emerging supply firms but also of NGOs that work with the people [150].

Direct subsidies are not the only way to mitigate the cost of the equipment. The supply chain can experience favourable customs exemptions which reduce the import taxes as evidenced in the solar industry [209–212]. Localising manufacture has always been a strength of the 'business as usual' improved cook stoves, and one of the barriers to the use of higher tier appliances has been the need to import them (and the subsequent use of foreign exchange). A number of local constructs are emerging that create jobs and mitigate this reliance on the global supply chain.

3.6.3. Mitigating the Cost of the Fuel

While the upfront cost of the equipment or appliance seems a large household purchase and can be mitigated by such actions as described above, it is the cost of the fuel that far outweighs that initial purchase. A 10 years' worth of fuel (LPG or charcoal) in an urban setting is of the order USD 1440, so if a USD 50 or USD 100 appliance can save 20 or 30% of household expenditure, then on a financial basis it would seem worthwhile to obtain it [67–69]. However, it has been the case that household decision making is not necessarily guided by monetary concerns [213].

The cost of the fuel depends on several factors. The efficiency and therefore consumption of the fuel in equipment or appliance, the cost per quantity of fuel, and the way(s) the equipment is used. However, once again, due to the public good and the benefits of the fuel switch, many governments have already implemented direct subsidies for the cost of LPG as stated above, and most places also have lifeline tariffs for the electricity [214–218]. Lifeline tariffs enable the utility to charge a different tariff for the first quantity of electricity units (ranging from <15 to >100 kWhs), and then have a standard tariff (or blocks of tariffs) thereafter. In some locations where the lifeline is generous (e.g., 100 kWh), it could be possible to cook with energy-efficient appliances and be within the lifeline rate. However, for most locations, and since cooking utilises significantly more energy than, for example, lighting, rates for use with cooking are pushed into the standard tariff. Uganda [219] and Nepal [220] have recently introduced a 'cooking tariff' which may set a precedence for mitigating the cost of electricity for cooking.

It may be important to note that many utilities in Africa struggle to be profitable [221]. However, as argued above in the first section, the push to SDG7 access for all, and the decarbonisation of forging ahead to net zero targets, will only give more flexibility and strengthen electrical networks. The danger is that excess generation is created without increasing demand, preventing pay back of loans for the generation—utilising finance currently paid by householders to use charcoal that deforests, to clean electric cooking is potentially a win-win [143].

4. Discussion

As can be seen from the range of literature quoted above, action and progress on a new strategy to clean cooking has taken root in research and policy communities. There is still a long way to go to reach SDG7, and in what is now a very short time. Taking net zero carbon seriously as a target and component of this work creates an added dimension which has yet to be sufficiently taken into account.

Consensus seems to be gathering around the core idea that modern energy planning needs to be integrated with clean cooking ('Mutual Support'). Treating electricity and clean cooking as different sectors has not been helpful to tackle the enduring problem of clean cooking.

Modern energy infrastructure, even when dependent on fossil fuel, is an investment that can be leveraged to make gains in modern energy cooking services. The existing fossil fuel extraction, import, and distribution infrastructure for transport and industrial fuels, provides a backdrop against which LPG cylinder distribution can support LPG usage. Many African policy makers would argue that Africa has made minimal contribution to climate change and should use gas resources to fuel its economic growth, thus generating energy by fossil fuel and using LPG as a 'transition fuel' for clean cooking [222]. While that argument has some merit, the issue may be that as decarbonising comes to the foreground of economic planning, and as transport in particular shifts to electric vehicles, there are threats that a reliance on LPG could lead to technological lock in a world of increasing crude oil prices.

As we have noted many times throughout this paper, electricity investment, access, and infrastructure has grown considerably over the last 10 years. While approximately half of the generating capacity added has been fossil fuel-based, an equivalent amount of renewably generated energy capacity has also been added. Additionally, over the last 10 years the cost of that renewable technology has dropped significantly, opening the way for auctions to add renewable energy to the grid without subsidy and at a commercially viable cost. Some arguments remain over the efficiency and effectiveness of utilities managing the grid, the legacy of coal-fired power stations in Asia, and the need for a fossil fuel base generating capacity (particularly for Africa); nevertheless, all countries have made a commitment to decarbonise where possible. The intentions for an increasingly decarbonised grid in all these countries is there as a political goal (even India at 2070), and combinations of commercial and climate finance could see the basic infrastructure grow further.

Whether such infrastructure is one national grid, or a combination of grid and off-grid technologies is a matter of debate. There are grids that have been rapidly expanded and in doing so have delivered a less than ideal service to their consumers. The electricity can be intermittent, and the local transformers and wiring can be inadequate for the increased demand load of cooking equipment. However, this just reinforces the idea that cooking could have been considered at the planning stage, and that the extension of the grid infrastructure would have been future proofed for the breakthroughs in energy-efficient cooking equipment that have emerged over the last decade. Similarly, we saw that a number of agencies believe that off-grid approaches are needed for 500 million of the 670 million that do not currently have access to electricity, but we have also seen that an off-grid approach can also include clean cooking with electricity. If mini grids are planned to include cooking, then the additional loads from cooking can actually be a demand that helps developers make profit and cover the ongoing costs of the mini grid. We have seen that even individual solar home systems can be made to deliver a cooking experience, at a price point that is effective in some markets.

All this is about an integrated planning approach with a suitable 'future think' that will address these issues. Indeed, modern energy planning inclusive of cooking loads need not avoid biomass concerns. We have seen that deforestation (due to cooking needs, not due to shifts to agriculture) is clustered around higher populations, particularly urban and peri urban centres. Leveraging the modern energy infrastructure within urban spaces could lead to alleviating the pressure on forests, and effectively be a nature-based solution for climate change. However, if such an approach is part of the integrated modern energy planning, then that could leave more remote lower populated rural areas to manage their biomass more effectively and create a sustainable use of biomass. There is then still a role for tier 3 and 4 stoves to reduce biomass consumption in these remote areas. There is a need for updating net biomass loss, as the key work Bailis was published in 2015 and was based on 2009 data, and only took into account above ground carbon. Below ground and loss of carbon sequestration are two data gaps that need to be filled. We should also note that use of tier 3 and 4 stoves still creates health risks—it is here that the Multi Tier Framework data could help in the planning, evidencing how many people cook outside (reducing their particulate intake), and how many cook in windowless kitchens (maximising their and possibly their children's intake). Biomass could be a part of integrated energy planning, as long as it is considered a transition fuel to access modern energy cooking services (the danger of a biomass technical lock in is considerably less than fossil fuel dependency).

5. Conclusions

In summation, there is a need for those working in the policies and planning of modern energy to consider cooking loads as a part of their remit. For too long, there has been a mutual neglect between the electricity sector and the cooking sector. The answer, the call, is then for '**mutual support**' integrated modern energy planning to be inclusive of cooking loads.

To execute this requires multi agency and cross-government working, which keeps in mind both the Sustainable Development Goal (SDG 7) and the aspirations for a decarbonised world. As decarbonisation changes the economies of the world and the global price and availability of fossil fuels, governments will need to plan for such changes. They will need to consider what is viable in the longer term and perhaps avoid making investments in 'transition fuels' if that has the potential to create technical lock in.

Over two billion people will be added by 2050 to the world, and the majority of those will be in countries that currently cook with biomass. The majority will also be in urban and peri urban locations, which will inevitably participate in modern energy infrastructure gains. This review suggests that many authors, researchers, policy makers, and international advocates are referring to the need to leverage the aspirations of a modernising population to utilise clean energy in order to reach a decarbonised economy, a healthy cooking experience, recover sustainable biomass growth through (agro) forestation, and improve gender dynamics by releasing women's time and decision making.

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