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Elucidating Finance Gaps through the Clean Cooking Value Chain

Olivia Coldrey [1,2,*], Paul Lant [1] and Peta Ashworth [3]

[1] Energy & Poverty Research Group, School of Chemical Engineering, The University of Queensland, St. Lucia, QLD 4072, Australia
[2] International Institute for Applied Systems Analysis (IIASA), A-2361 Laxenburg, Austria
[3] Institute for Energy Transition, Curtin University, Bentley, WA 6102, Australia
* Correspondence: o.coldrey@uq.edu.au

Abstract: The current supply of finance to enable universal access to clean fuels and technology for cooking does not match the scale of Sustainable Development Goal 7's access challenge. To date, little attention has been given to the modalities of funding the clean cooking transition at the macro level. Grounded in a review of academic and recent grey literature, this study's research objective was to provide a granular understanding of gaps in finance flows and financial instruments, mapped against the innovation cycle of companies that provide clean cooking solutions. In the context of wide-ranging barriers to the clean cooking sector's development, we found a chronic shortfall of finance for companies at the early stages of their business growth and poorly targeted public finance to support innovation and mitigate risk for later-stage investors. This is exacerbated by limited data sharing and knowledge exchange among a small number of funders. We recommend reforms to public funding for clean cooking enterprises, especially for research, development and demonstration (RD&D) and innovation, to mitigate risk for later-stage investors, as well as more effective data sharing, to help catalyse sufficient, appropriate finance through the value chain for universal access.

Keywords: SDG7; clean cooking; energy transition; energy finance; climate finance; R&D and innovation

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1. Introduction

In 2015, the international community enshrined in Sustainable Development Goal 7 (SDG7) its ambition to achieve access to affordable, reliable, sustainable and modern energy for all by 2030 [1].

With less than seven years remaining, there is a chronic shortfall of access to clean fuels and technology for cooking relative to the SDG7 universal access target, especially in developing countries. In 2020, 69% of the world's population was reported to have access, an increase of approximately only 70 million individuals compared with 2019. Progress has been hard won, with access increasing only 12% over the past decade [2]. In a business-as-usual scenario, around 2 billion people (almost 24% of the projected global population) will remain without access to clean cooking solutions in 2030 [2,3]. Since the onset of COVID-19, some estimates suggest that the number of people cooking with traditional biomass, coal and kerosene has continued to increase due to the pandemic and that around 470 million more people (approximately 5.5% of the projected global population) could be pushed into cooking fuel poverty by 2030 in a slow pandemic recovery scenario [3,4]. This means that annual increases in access of more than 3% are now required to achieve SDG7's clean cooking targets, an increase on the 2% estimated in 2010 due to the lack of progress since then [5].

The impact of the lack of access to clean cooking facilities globally is conservatively costed at USD 2.4 trillion per annum through to 2030. This figure is comprised principally

of negative health, gender and climate externalities, while the potential co-benefits of increased access span multiple SDGs [6–9].

Many barriers exist to the sustained adoption of clean fuels and technology for cooking. One set of barriers relates to finance. In absolute terms, the current supply of finance does not match the scale of the clean cooking access deficit and falls orders of magnitude short of the finance projected to be required to achieve SDG7's universal access target [10]. The scale of the challenge means that large volumes of both public and private finance are required.

The overall aim of this study was to identify and elucidate finance gaps through the clean cooking value chain and make policy recommendations to address them. This study's research objective was to provide a granular understanding of gaps in finance flows and financial instruments, mapped against the innovation cycle of companies that provide clean cooking solutions. In so doing, this study addresses a significant gap in the literature.

To date, relatively little attention has been given to the modalities of funding the clean cooking transition at the macro level. Existing literature has tended to focus on historical finance flows; investment projections to reach SDG7 access targets; and analysis of individual, typically publicly funded clean cooking projects and programs. This study sought to address this gap by analysing the demand for and supply of finance through the clean cooking value chain. This approach adds to theory and has important practical implications by mapping supply against demand, identifying the gaps that arise, elucidating the role that individual financiers play in the sector and highlighting the extent to which these roles are mutually reinforcing. This is critical to developing an understanding of whether the current actions of individual financiers contribute to a sustainable financing market for clean cooking by mitigating risk for existing and potential funders, and, in turn, informing an overall sector financing strategy.

Further, little attention has been paid to the role of finance in supporting clean cooking innovation, defined as the sequence of steps by which an idea is converted into a product or process and moved to market acceptance [11]. This is closely linked to, but distinct from, the typical stages of clean cooking enterprise growth as viewed through an investment lens. An improved understanding of the overlap between innovation, investment and company growth will, in practice, help policymakers to more accurately target their climate finance for the greatest impact, especially to catalyse private sector investment.

This study focused on supply-side finance, whose role is to facilitate the growth of enterprises that manufacture, distribute and sell clean cooking solutions, as well as support growth of the sector as a whole. Consumer finance is a separate component of overall finance for clean cooking and aims to increase access to solutions for end users by making adoption more affordable [9]. Examples include end-use subsidies and financial products, such as pay-as-you-go (PAYGo), that, while often placing a considerable debt burden on companies that offer it through their need to finance PAYGo receivables, allows consumers to make periodic payments for cooking hardware and services using mobile money. Consumer-facing finance is a critical aspect of developing a sustainable market for clean cooking because poor end-user affordability is acknowledged as a major financial constraint to the increased deployment and adoption of solutions. However, its detailed examination was outside the scope of this study.

The structure of this paper is as follows. Section 2 evaluates relevant academic and grey literature relating to finance for clean fuels and technology for cooking. In Section 3, the current state of finance for clean cooking is set out from a macro perspective. This section places investment barriers in the context of many diverse obstacles to the clean cooking sector's development. It then presents the current shortfall in supply of finance to achieve SDG7's clean cooking targets, the financing needs of companies that provide solutions and the types of financial instruments most frequently used to enable clean cooking. Against this background, Section 4 analyses investment barriers from the perspective of both funders and investees and discusses the importance of innovation funding to support enterprises through the critical, early stages of their business growth. In so doing, it highlights public finance's unique role in supporting innovation and mitigating risk for

later-stage private investment, as well as makes recommendations for improved data collection and knowledge sharing to accelerate the learning curve among clean cooking financiers. Finally, Section 5 presents conclusions, limitations of the research and potential avenues for future research.

2. Materials and Methods

This study evaluated recent literature relating to clean cooking finance, notably online reports. It incorporates results of research led by the lead author from 2018 to 2021 under the auspices of Sustainable Energy for All's (SEforALL) Energizing Finance research series and summarises relevant outcomes from SEforALL's 2019 Charrettes [12]. The latter was an intensive two-day workshop attended by clean cooking experts to address the question "What is required to create a sustainable, investable, private sector-led market for fuels for clean cooking?" The lead author conceived of and drafted this "Clean Cooking Charrette" research question.

A literature review was first undertaken to identify relevant peer-reviewed articles and grey literature on finance for clean cooking. An initial search was conducted on 29 December 2021 across two electronic databases: Scopus and Web of Science.

The databases were selected to be comprehensive, and the search incorporated articles published between January 2000 and December 2021. The year 2000 was selected as the base year to recognise the execution in September 2000 of the United Nations Millennium Declaration, from which the Millennium Development Goals, the precursor to the SDGs, were derived. The following search queries, used to identify relevant studies, consisted of keywords that are related to clean cooking, finance and investment. The search strings used were: ("clean cook*") AND ("fund*" OR "financ*" OR "invest*"); ("modern energy cook*") AND ("fund*" OR "financ*" OR "invest*"); ("clean") AND ("cook*") AND ("fuel*" OR "tech*") AND ("fund*") OR "financ*" OR "invest*"); ("clean cook*") AND ("deliver* model"); ("clean cook*") AND ("deliver* model") AND ("fund*" OR "financ*" OR "invest*"); ("improved cook*") AND ("fund*"OR "financ*" OR "invest*"); ("improved cook*") AND ("deliver* model").

The search strings returned 1151 articles from Scopus and 1277 articles from Web of Science. Citations were imported and managed with the Endnote reference management software. A total of 1229 results were found after duplicates were removed. A screen was then performed to remove articles considered to be out of the study's scope. These comprised those concerned with cooking in developed countries; food safety; food security; scientific aspects of air pollution or greenhouse gas emissions arising from biomass cooking; climate and environmental impacts of biomass use; technical aspects of cooking fuels or technologies; project feasibility studies and results that had no clear connection to the search strings. The remaining results were subsequently screened by their titles and abstracts. Of these, 423 were concerned with country-specific programs or interventions, 186 were related to a specific clean cooking technology (for example, cookstoves, biogas or electricity); 182 were related to health impacts and seventy-eight were related to end-use consumer behaviour. In many cases, a single article was concerned with one or more of these themes and in some cases, the search strings used generated identical results. Seventy-nine articles were related to financial products or business models relevant to clean cooking. Only eleven articles were found to interrogate macro trends in finance for clean cooking beyond a specific geography, technology solution or business model.

The literature review confirmed that published, peer-reviewed research on clean cooking finance is relatively limited, with most publications concerned with a specific country, program and/or technology. Although there has been some focus on individual financial instruments or business models to encourage the deployment and use of clean cooking solutions, these are, in isolation, difficult to apply at scale because of their limited focus.

However, several recent, important publications exist that examined finance for clean cooking from a sector-wide perspective. Notable among these are MECS and Energy 4 Impact (2022), Modern Energy Cooking: Review of the Funding Landscape; Clean Cooking Alliance

(2022), Clean Cooking Industry Snapshot 2022; Sustainable Energy for All (2021), Energizing Finance: Understanding the Landscape 2021; and ESMAP (2020), The State of Access to Modern Energy Cooking Services. Important data and findings were also contained in Global Distributors Collective (2022), Last mile distribution capital continuum: trends, gaps and opportunities, which is concerned with the adjacent but overlapping last-mile distribution (LMD) sector. This paper synthesised important findings from these publications, as well as from relevant articles and grey literature arising from the literature search.

3. Finance in Context: A Multitude of Barriers to the Deployment of Clean Cooking Solutions

Of SDG7's three core outcome and two enabling targets, access to clean cooking through increasing the proportion of the population with primary reliance on clean fuels and technology is the one most often overlooked by policymakers [1,5,13]. Clean cooking has, in large part, been neglected in national policies and development programs and has few institutional public sector champions. Progress has lagged because of lack of prioritisation and coordination at all levels, with clean cooking being an "orphan" sector that, while cutting across a broad array of policy areas, is neither owned nor prioritised by any of them for large-scale investment [6]. As a result, basic access targets do not exist in many countries. Of the approximately 128 countries that lack universal access to clean cooking, only thirty-nine have clean cooking targets, of which only nineteen aim to achieve universal access by 2030 in accordance with SDG 7.1 [3]. The lack of target setting is compounded by poor institutional leadership and a lack of integrated energy planning, which often isolates cooking policies, where these exist, from electrification programs in a way that does not recognise electricity's potential as a cooking fuel [6]. Poor policy integration combined with clean cooking advocates' omission of electrification from their initiatives has been described as a state of "mutual neglect" [14]. Clean cooking is also an invisible sector, with those groups most affected unaware of the negative health effects of "dirty" cooking. These groups also often lack a coordinated voice and are constrained by access to healthier, affordable solutions [15].

Despite the cost of inaction and acknowledgment of the co-benefits of increased access, multiple barriers exist to the widespread deployment and sustained adoption of solutions.

Figure 1 summarises a multitude of barriers relating to household characteristics; knowledge and perceptions; finance; tax; non-existent or poorly designed subsidies; underdeveloped markets; regulations; legislation; and policies that exist across the spectrum of technical clean cooking solutions [3,16–20]. The latter are presented as a simplified version of the Energy Sector Management Assistance Program's (ESMAP) Multi-Tier Framework (MTF) for clean cooking access. The World Bank and SEforALL conceived the MTF in July 2015 for defining and measuring access to energy [6,21]. Instead of assessing access through the traditional binary measure of the use of solid versus non-solid fuels, the MTF incorporates a multi-dimensional definition that encompasses the ability to source energy that is adequate; available when needed; reliable; of good quality; convenient; affordable; legal; healthy; and safe for all required energy services. Energy access is measured in a tiered spectrum, from Tier 0 (no access) to Tier 5 (the highest level of access). The six MTF attributes as they relate to cooking are as follows:

i. Cooking exposure: personal exposure to pollutants, which depends on both stove emissions and ventilation (higher tiers indicate lower exposure);
ii. Cookstove efficiency: a combination of combustion and heat-transfer efficiency;
iii. Convenience: time spent collecting/purchasing fuel and preparing the stove;
iv. Safety: severity of injuries caused by the stove over the past year;
v. Affordability: share of the household budget spent on fuel (higher tiers indicate a lower share of spending);
vi. Fuel availability: availability of the fuel when needed (a proxy for reliability) [21].

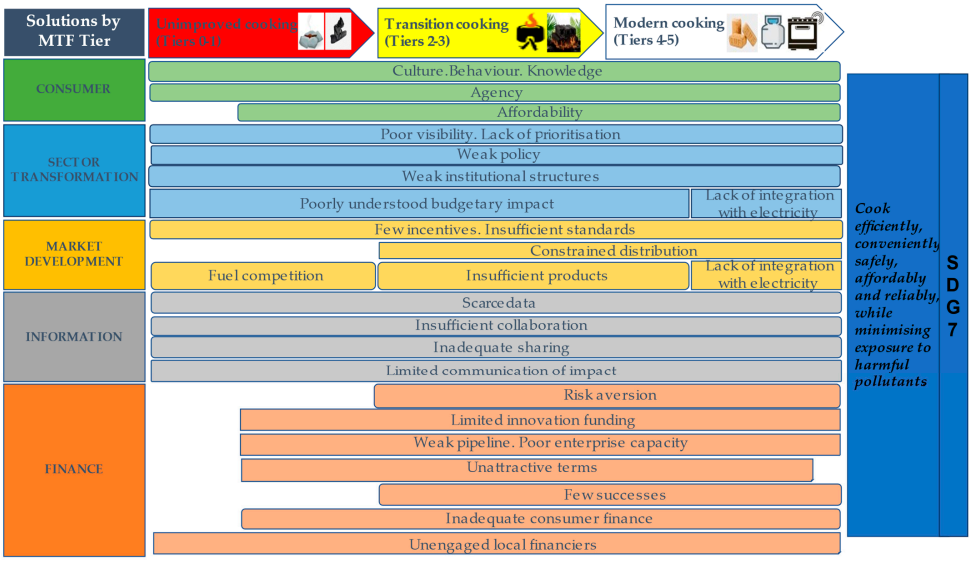

Figure 1. Summary of clean cooking barriers.

Barriers relating to finance are consistently cited as among the greatest obstacles to a reduction in cooking poverty globally [22]. Indeed, limited access to capital is cited as the single biggest barrier to scale [6]. However, finance is a necessary but insufficient condition for achieving universal access. Arguably greater challenges exist in raising consumer awareness and persuading those currently without access of the benefits of cooking with non-traditional fuels and technology; prioritising cooking in national policy; and fostering demand for, and sustainable adoption of, solutions; and knowledge sharing among market participants.

The multifaceted barriers to access and sustained adoption do not exist in isolation and are not mutually exclusive. On the contrary, they are interconnected and reflect the challenges and slow progress to date. Further, there is no single, homogenous clean cooking market. Rather, individual market characteristics are highly localised and context-dependent, creating a unique set of challenges in each [9]. Improving access to clean cooking requires a sound understanding of local socio-economic and livelihood conditions that potentially affect the sustained adoption of solutions [20,23,24]. This may help to explain why very little evidence exists on how to achieve large-scale transformation of the world's cooking system. To date, most evaluations of clean cooking technologies and fuels have been based on small-scale and experimental studies, which are difficult to generalise for large-scale transition programs as envisioned by SDG7 [25].

Taken together, barriers to clean cooking access and adoption make financiers less likely to fund projects and companies that provide solutions. This is because financiers perceive the policy, market and consumer risks of doing so to be less likely to generate a return on their investment, whether measured in financial terms or through positive social or environmental impact [26]. In other words, the many barriers that exist within clean cooking markets create actual and perceived risk for financiers, limit their participation in those markets and, therefore, hinder the development and growth of companies that deliver solutions.

3.1. A Chronic Shortfall of Finance

In the context of many demand and supply side challenges, delivering universal clean cooking access by 2030 requires a step change in the volumes of capital allocated to the sector. The projected amount differs according to the basis of individual forecasts but is, by any measure, a very large number. The International Energy Agency (IEA) estimates that an annual investment of USD 8 billion will be required to achieve full clean cooking access by 2030 [27]. ESMAP estimates the cost of transitioning to universal access to modern energy cooking services (MECS)—those at Tiers 4 and 5 according to the MTF—by 2030 to be

USD 148–156 billion annually based on current policies [6]. From the perspective of LMD companies, including clean cooking companies, an estimated forty-fold annual increase in finance for clean cooking is required to achieve universal access [28]. The LMD sector is distinct from the clean cooking sector inasmuch as companies that operate within it distribute a range of products, not only clean cooking solutions. However, there is overlap in the funding challenges experienced because the companies tend to operate in the same markets, which are marked by relatively poorly developed infrastructure, often in remote locations, and serve customer groups with typically low incomes and limited financial resources.

Viewed through a climate lens, large volumes of projected energy sector investment are required to meet the increasing demand for energy from a growing global population while remaining consistent with a target to limit global temperature rise to 1.5 °C by 2050. One estimate puts this at USD 480 billion annually to 2030, over and above total energy investments otherwise foreseen in a baseline scenario of countries' energy- and climate-related policies as of 2015 [29]. At the same time, developing countries want and need a clear path to finance and implement the climate commitments they have formalised as Nationally Determined Contributions under the Paris Climate Agreement [30]. There is increased political attention being given to clean cooking as a cross-cutting development challenge and, with that, a likelihood that the sector will be required to absorb greater volumes of climate finance than it is capable of. In November 2022, at the 27th session of the Conference of the Parties of the United Nations Framework Convention on Climate Change (COP27), the government-appointed UN Climate Change High-Level Champions, with the Clean Cooking Alliance (CCA), recognised clean cooking as one of the "2030 Breakthroughs"—specific tipping points across major sectors of the global economy—and set a shared target for governments, donors and the private sector to expand access to clean cooking for 2.4 billion people through at least USD 10 billion in innovative finance each year [31].

However, the volume of finance allocated to clean cooking businesses and projects consistently and conspicuously falls short of all these projections. At the enterprise level, CCA tracked USD 61 million in investment to thirty-two clean cooking companies in 2020 [32]. From a broader, country-level perspective, in twenty countries across Sub-Saharan Africa and Asia that together are home to more than eighty percent of people globally without clean cooking access ("High Impact Countries (HIC)"), finance commitments for clean cooking, from both public and private, international and local sources, averaged approximately USD 130 million per annum between 2015 and 2019. In 2019, the HICs were Afghanistan, Bangladesh, China, the Democratic People's Republic of Korea, the Democratic Republic of the Congo, Ethiopia, Ghana, India, Indonesia, Kenya, Madagascar, Mozambique, Myanmar, Niger, Nigeria, Pakistan, the Philippines, Uganda, Tanzania and Vietnam [10]. These finance commitments were highly concentrated geographically; several Sub-Saharan African countries with ninety percent or more of their populations without clean cooking access received no or minimal commitments during the period [10].

Exacerbating the shortfall, much planned investment and funding have been delayed or face structural barriers to their deployment. For example, in the period between 2002 and 2018, approximately half of the energy projects in HICs that had funding committed to them were delayed. The multiple reasons for delay included poor initial project planning, a mismatch between the types of finance provided and the risk profiles of the projects to which it was committed, and often poor institutional delivery capacity [33].

3.2. Financing Needs through the Business Growth Cycle

As a precursor to understanding how the finance that has been committed to clean cooking, however inadequate, is currently allocated, it is instructive to examine the financing needs of the businesses that manufacture, distribute and sell clean cooking solutions. Ultimately, these businesses are the conduits through which solutions are made available to end-use consumers, either directly or through large-scale, typically donor-funded programs. Therefore, their viability is fundamental to a sustainable clean cooking sector.

Figure 2 presents a generalised model of the clean cooking system, which sees the system as a set of primary and support activities. Primary activities are those that occur through the value chain that brings clean cooking solutions from inception to end use, while financial investment is one of several support activities.

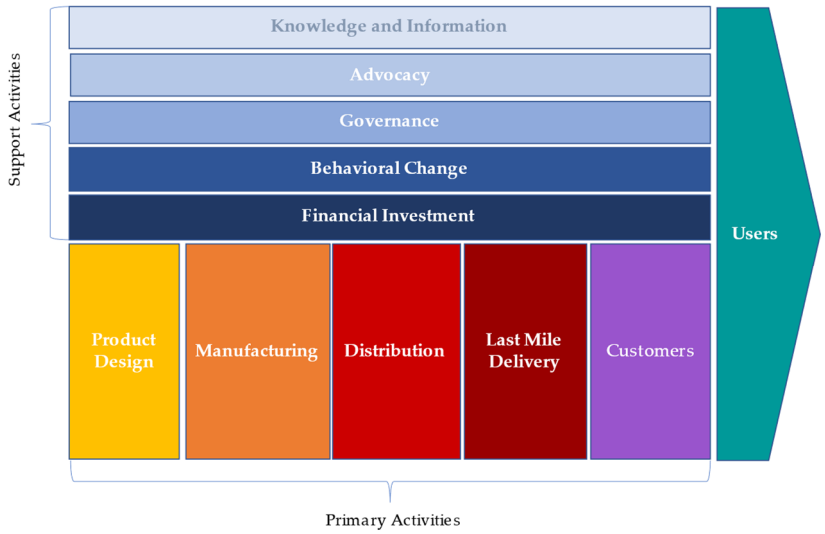

Figure 2. An adapted version of Porter's Value Chain to frame the cooking poverty sector. Source: Biser Kaluz, A.-M.; Thomas, D.; Hodges, J.A.; Ghaffari, L.; Rossano, N.; Schott, P.C.; Guo, Z., Killed by Breathing—Addressing Cooking Poverty: Current State, Gaps and Challenges, and Proposed Solutions to Achieving SDG 7.1. 2021. An Independent Study within the Sustainability Management Program, Columbia University, New York, NY, USA.

Clean cooking companies are involved in producing and distributing a wide range of solutions. For example, CCA's Clean Cooking Catalog identifies 476 different kinds of cookstoves used in household cooking [34]. The companies' capital structure and financing requirements are influenced by their individual business models. In this regard, MECS and Energy 4 Impact distinguish between "tool-only" and "tool & fuel" businesses. Tool-only companies are those that sell clean cooking hardware only. By contrast, tool & fuel companies typically sell hardware to consumers at low cost, accompanied by a fuel purchase contract. Their aim is to recover the cost of hardware through margins on the sale of fuel over the medium-to-long term (at least three years). Profitability depends on reaching a certain scale of fuel use, which is, in turn, a function of hardware sales volume. In some cases, tool & fuel companies have entered strategic partnerships with larger fuel companies to leverage the latter's distribution networks [22].

Regardless of the business model, it is typical for different financial instruments to support different stages of a business's evolution. As applied to the clean cooking sector, MECS and Energy 4 Impact describe four stylised stages of company growth, with the company's funding strategy and needs changing through its lifecycle and progressing along an S-curve. A company's progress through the growth cycle may be linked to an innovative technology or business model.

At the early "seed" stage of their development, clean cooking companies depend heavily on founder equity and grants. At the end of this stage, a company may have identified a positive unit economics business model as a precursor to scale. When it enters its early growth stage, the core management and operations teams are expanded and hurdles relating to technology scale-up, distribution network and hardware are encountered. Consumer credit processes are developed and recruitment efforts are expanded. Early growth companies begin to attract equity from venture capitalists, private investment funds and impact investors. In its late growth stage, a company's cost structure is driven by the number of repeat customers. A need for new investment comes from geographic expan-

sion and product and customer experience improvements in existing markets. Funding at this stage is likely to include a solid equity base, short-term revolving debt, working capital to finance inventory and term loans to finance end users. Concessional funding and results-based financing (RBF), that is finance, usually in the form of grants, provided to companies or institutions on achievement of pre-agreed, verified results, may be available, implicitly from public sources; however, most capital inflows are likely to come from commercial sources. At maturity, a company enjoys sustained profitability. At this stage, it has optimised its capital structure in terms of leverage to make appropriate returns for equity investors. From a whole-market perspective, there is consensus around business models within the market, dominated by a few actors in each technology. In a mature market, the financing landscape is likely characterised by occasional large equity raises involving strategic and private equity and long-term debt from commercial lenders [22].

Capital requirements for tool-only and tool & fuel businesses are similar until the late growth stage of their respective evolution. Tool-only companies' main requirement is for working capital for inventory and receivables and possibly capital to fund manufacturing, while tool & fuel companies need significant working capital and capital for fuel distribution [22]. In all cases, grants can be useful for emerging cooking companies to test their product market fit and can also help larger, more established companies explore entry into new markets or pilot new products. In 2020, clean cooking companies used grants for each of these purposes [32].

In the adjacent and to some extent overlapping LMD sector, the Global Distributors Collective (GDC) mapped funding for companies through a four-stage business growth trajectory: proof of concept, starting operations, growth and accelerated growth. It found that fundraising needs are similar for all early-stage LMDs, then vary depending on a company's trajectory. All companies require early-stage capital to invest in basic commercial infrastructure and face growing working capital needs to fund inventory and consumer financing solutions. Faster growth companies, defined as those with average revenue growth exceeding USD 440,000 per year of operation that are typically focused on quick geographic expansion and whose growth is primarily equity-funded, require a balanced mix of equity and working capital, while companies on a slower growth trajectory are focused on business sustainability and mostly need working capital [28].

3.3. Who Funds Clean Cooking and How?

A relatively small number of capital providers service the sector. SEforALL categorises these as international governments (including bilateral development finance institutions (DFI)), multilateral DFIs, domestic governments, commercial finance (venture capital, private equity and impact investors), multilateral climate funds, philanthropic foundations and carbon markets [10]. Figure 3 shows total finance commitments of USD 133.5 million for clean cooking by source, instrument, use, consumer sector and MTF Tier that were tracked to HICs in 2019.

Historically, there has been little diversity in the financial instruments used to encourage clean cooking. In 2019, SEforALL and CPI tracked grants (including non-repayable grants, as well as those paid on achievement of pre-determined results, or "results-based" grants); project debt (both concessional and commercial) and project equity, where creditors and equity investors, respectively, rely on a project's cash flow for repayment; balance sheet financing; and other instruments, such as crowdfunding, for clean cooking projects in HICs. SEforALL and CPI did not track disbursements and policy-induced revenue support mechanisms, such as feed-in tariffs or other public subsidies. Secondary-market transactions, such as the reselling of stakes, were only tracked if they did not constitute double counting with other areas of the data collection [10].

From the inception of SEforALL and CPI's tracking exercise, commencing with 2013 data, grants have played an important role. For example, in 2019, the volume of grant funding commitments to clean cooking in HICs amounted to USD 69 million of the total USD 133.5 million tracked and, in 2018, accounted for USD 60 million of a total USD

131.5 million [10]. This highlights a trend of donor-funded clean cooking programs relying on short-term (grant) funding to address a long-term challenge [35]. Figure 4 shows the breakdown of financial commitments for clean cooking in HICs between 2013 and 2019 by financial instrument.

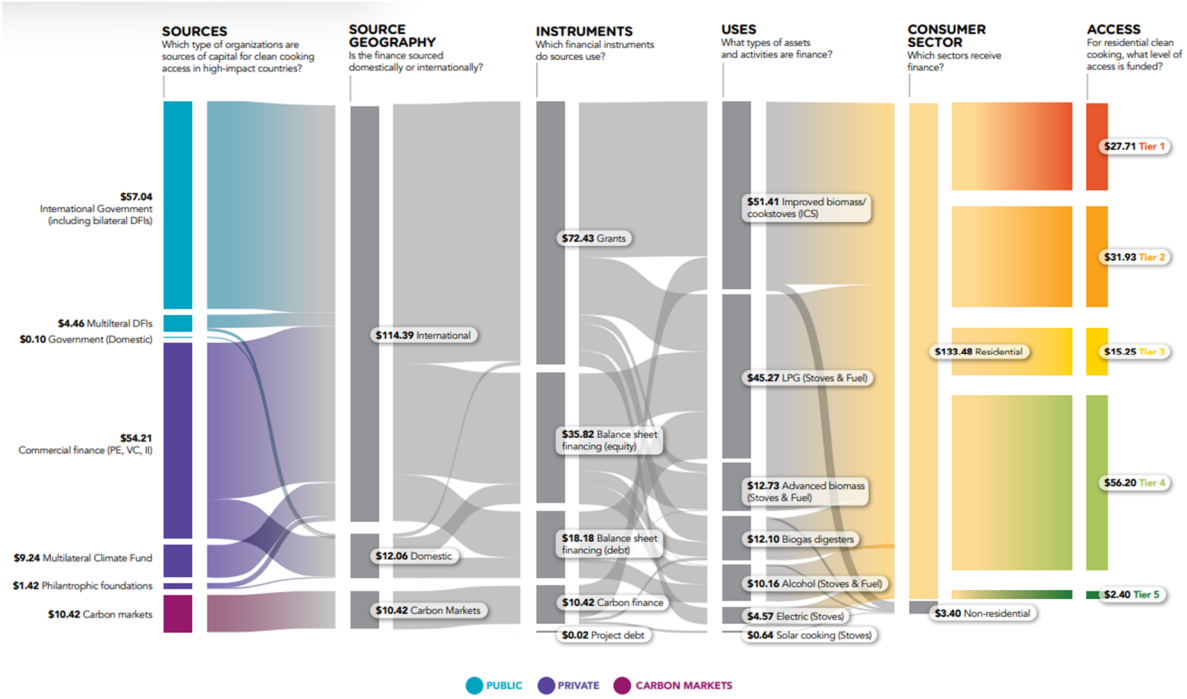

Figure 3. Tracked finance for clean cooking in high-impact countries in 2019 (million USD). Source: Sustainable Energy for All and Climate Policy Initiative, Energizing Finance: Understanding the Landscape 2021.

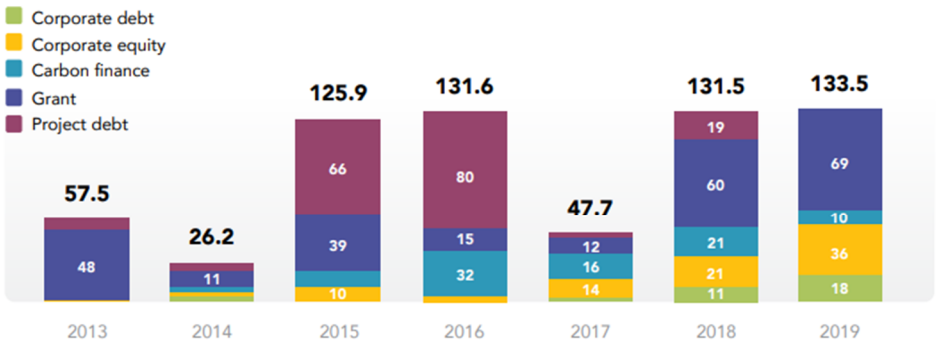

Figure 4. Clean cooking commitments in high-impact countries by financial instrument, 2013–2019 (million USD). Source: Sustainable Energy for All and Climate Policy Initiative, Energizing Finance: Understanding the Landscape 2021.

In contrast, CCA noted the declining role of grants in directly funding clean cooking enterprises, with grants in 2020 making the smallest contribution to corporate funding each year since 2016 and representing only fifteen percent of the total investment in companies between 2016 and 2019 [32]. This has important implications for companies seeking to progress through the early stages of their business growth inasmuch as grant funding, typically provided by the public sector, has a critical role to play in supporting research,

development and demonstration (RD&D) and early-stage innovation as a precursor to scale, as explored further in Section 4.

A promising trend has been an upwards trajectory of equity finance commitments for clean cooking in HICs between 2013 and 2019, as well as equity investment in enterprises [10]. CCA found that equity was the most common type of finance for clean cooking companies in four of the five years between 2016 and 2020 and amounted to fifty-nine percent of total finance for companies in 2020 [32].

The predominance of grant and, increasingly, equity funding may be attributed to the immaturity of the legacy clean cooking sector, with its limited number of technology solutions dominated by improved biomass cookstoves (ICS) [22]. Indeed, these continue to be the dominant sources of clean cooking sales revenue. While only eleven of thirty-two companies tracked by CCA are biomass stove manufacturers, as distinct from manufacturers of other technologies, they accounted for three-quarters of all sales revenue between 2014 and 2020 [32].

Carbon financing—revenue derived from the sale of verified emissions reductions arising from the use of a clean cooking solution—is proving to be an increasingly important source of finance. While relatively modest and fluctuating volumes of carbon finance commitments to clean cooking projects were recorded in HICs between 2013 and 2019, clean cooking company revenue from carbon credits in 2020 increased 21-fold to USD 11 million from USD 500,000 in 2017 [10,32].

Debt finance commitments for clean cooking in HICs remained consistently low between 2013 and 2019 and the number of companies globally reporting receipt of debt funding has declined each year since 2016 [10,32]. This is a notable deficit because short-term debt, especially working capital, and longer-term debt facilities are critical components of clean cooking companies' funding mix.

Together, the data indicate a modest increase in volumes of committed finance for clean cooking over time, as well as a transition from grants to more commercial financing. The diversity of investment vehicles and funders has also increased, with investment funds, family offices, foundations and commercial lenders all now active [22]. Similarly, clean cooking investment in the LMD sector has grown at a rate of twenty percent year-on-year [28].

However, in view of the total addressable market of people living in cooking poverty, progress in increasing volumes of finance and diversification of funders and recipients is considered very slow. The enormous imbalance in the supply of finance against that which is projected to be required to achieve universal access strongly implies a shortfall of finance for the sector that spans the entire value chain. CCA noted that while investment in the clean cooking companies it surveyed increased at a compound annual growth rate of twenty percent year-on-year from 2014 to 2020, at that rate it would be 2036 before investment in the sector exceeds USD 1 billion [32].

4. Discussion

In a mature financial market for clean cooking, sufficient finance would be available to meet companies' needs at every stage of their growth in a form appropriate to each stage. However, despite the number of people who lack access globally, the sector is characterised by few investors, a limited number of companies that have not achieved significant traction and few successful investment exits [22]. This is borne out in the data on how few clean cooking companies worldwide have reached scale.

Most corporate funding has been concentrated in a small number of scalable modern cooking businesses [22]. It is estimated that in 2020, there existed 450–500 fully dedicated manufacturers and distributors in the cookstove operations chain globally, with around ten percent of enterprises collectively responsible for over forty percent of stove sales. Very few businesses have reached sales volumes that enable economies of scale [6]. Sector financiers themselves consider only 10–20 companies investible and scalable [22]. CCA confirmed this in 2020 when it found that six companies accounted for eighty-two percent of revenue,

while seven companies raised more than ninety percent of total investment. Four of the seven were also among the eight companies that received ninety percent of investment capital in 2019 [32].

Recent major investments in 2021–2022 in companies devoted wholly or partly to delivering clean cooking solutions continued to underscore the concentration of investment. These comprised a USD 5.5 million senior secured loan to BBOXX from the AfricaGoGreen Fund for Renewable Energy and Energy Efficiency Investment (AGG); HomeBiogas' completion of a NIS 310 million initial public offering; a USD 6 million investment in XpressGas, comprising USD 3 million equity from Investisseurs & Partenaires and a USD 3 million debt facility from the Belgian Investment Company for Developing Countries; a USD 15.6 million investment in Sistema.bio, comprising a mix of equity, debt, and nondilutive capital from KawiSafi Ventures and AXA IM Alts; and debt finance facilities to C-Quest Capital, comprising USD 6.4 million from the FMO Access to Energy Fund and an undisclosed amount from BIX Capital [32].

The focus of most investment in a small number of late-growth-stage companies relative to the number of companies operating in the sector highlights two issues. First, the multiple barriers to investment as expressed by financiers and companies alike. Second, a very small proportion of enterprises (according to the above figures, five percent or less of active clean cooking businesses) survive past the proof of concept stage of the innovation cycle. The latter, combined with the declining volume of public funding, especially in the form of grants, suggests poor effectiveness of public finance in two major respects. In the first instance, limited sustained innovation funding at the beginning of the business growth cycle, where risks are highest and the private sector most reluctant to invest. In the second instance, limited use of public financiers' expansive mandates to mitigate risk for private capital.

4.1. A Broad Spectrum of Investment Barriers

From the perspective of potential investors in enterprises that provide clean cooking solutions, financiers cite a lack of proven, viable business models; lack of investible pipeline; potential investees' lack of profitability (compounded by very limited publicly available data) and lack of operational history; and poor consumer affordability as the greatest barriers to scale [22]. Financiers' overall risk aversion may be underscored by business models in the sector evolving too rapidly to enable investors to suitably assess risk [6]. In the adjacent LMD sector, financiers cite LMDs' lack of a strong funding pitch, lack of financial literacy and poor data collection as key pain points in a company's early growth stages [9,28].

For their part, clean cooking companies rank consumers' lack of ability and willingness to pay for solutions, poor access to finance and lack of financial support as the greatest obstacles to scale. Specific fundraising challenges include a perception that funders have a low-risk appetite; the shortage of early-stage grant capital; the high cost of debt and short loan tenors; lack of working capital; the length of funder due diligence processes; lack of energy know-how among local financiers; and a shortage of equity. In summary, no single issue dominates clean cooking companies' fundraising challenges. It is a broad spectrum that spans the entire innovation chain [22].

Together, these barriers are borne out in the difficulty clean cooking companies have in securing finance at all stages of their development in the context of an overall huge shortfall. However, even if sufficient volumes of finance were available, questions remain as to whether it is allocated at the early stages of the clean cooking innovation cycle in such a manner that anticipates risks later in the cycle, seeks to help mitigate them and ensures a healthy pipeline of viable businesses for later stage investment. Further, it is important to consider whether the institutions that supply finance are organised in such a way to be able to effectively deploy it and enable businesses that require finance to efficiently access it. To answer these questions, it is useful to examine in more detail the nature and flows of finance through the clean cooking enterprise value chain, with a focus on the early, innovative stages of a business's lifecycle.

4.2. Surviving Proof of Concept

A sustainable clean cooking sector depends on a critical mass of businesses moving through the early stages of the innovation cycle to commercial operation and, ultimately, maturity. However, it can take many years to bring an innovative idea to market, with energy technologies typically operating within highly regulated environments. Importantly, conventional drivers of technology push through the innovation cycle from RD&D, as well as market pull from end-use consumer demand, can be reinforced or inhibited by feedback between different stages of the cycle and by the influence of framework conditions, such as government policy and the availability of risk capital [36]. Further, just as critical as a technology or business model's progression through the innovation cycle, concerned as it is with problem-solving of a technical or marketing nature, are the bridges between the various stages of the cycle. These are associated with mobilising interest, resources (including financial resources) and market constituents and are geared towards satisfying the various stakeholders of the technology or business model at each stage, without whom its value is not recognised [37].

Commercialisation of new technology, defined as the process of moving a technology from laboratory to market acceptance and use, thereby becoming part of mainstream economic activity, is expensive and time-consuming [11]. By way of example, it is possible to summarise the progress of a solar photovoltaic (PV) technology through the innovation cycle into four phases. Phase 1, comprising fundamental research and new concept development, requires continuous, long-term (minimum 10 years) funding, which is largely provided by a host research institution backed by government funding. Typically, strategic industry investors have little interest in funding innovation at this stage, as intellectual property arising from it has little or no value. The demonstration and evaluation of new concepts during phase 2 continue to require medium-to-long-term funding and, as the work becomes more applied in nature, is more reliant on capital-intensive facilities. Intellectual property arising out of this phase is still of minimal value, resulting in difficulty in attracting private investors. Therefore, public grant funding is essential to help advance technologies through this phase. The development of commercially relevant technology during phase 3 is highly innovative and generates the most intellectual property, which is typically jointly owned by the developers. Strategic industry involvement is essential to ensure that research outcomes are commercially relevant and preferably lead to pilot production. Government funding that fosters collaboration between research institutions and industry is valued in this phase. Lastly, phase 4 of a PV technology's development, as it moves to large-scale manufacturing, involves minimal innovation and intellectual property creation. However, the high capital intensity of this phase can raise significant financing challenges [38].

Similarly, business model innovation is a process that occurs over time. It entails a set of deliberate actions that are undertaken by managers and entrepreneurs to change the components and architecture of a business model in an innovative way with the aim of gaining a strategic advantage [39].

Against this background, it is instructive to highlight the role of public finance in pushing new technologies and business models through the critical, early stages of the clean cooking innovation cycle and, by extension, creating viable opportunities for later-stage private investment.

Early-stage funding is important to support technology development, proof of concept and pilot demonstration. While some founder equity may be available at this stage, accelerating energy innovation hinges critically on public investment and institutions for RD&D [40]. This reflects long timeframes to commercialisation, a commensurate lack of value in intellectual property and, therefore, a relative lack of interest from private sector strategic and financial investors. As concepts are proven, early-stage private investors (for example, strategic industry investors, angel investors and early-stage venture capital) demonstrate an increased willingness to invest in new ventures, especially as intellectual property begins to emerge as an asset. At this stage, greater scope for public and private

sector co-funding emerges. Once a technology or business model is more developed and risks are retired, the capital intensity required to scale increases. Consequently, while early-stage technology and business model innovation can be supported by relatively modest amounts of capital from the public sector and equity investors, the substantial amounts of capital required to scale mean that all but the most highly capitalised companies must seek significant amounts of finance, often from multiple sources. In blended finance structures, this can include government-backed financial instruments to increase confidence among, and encourage the participation of, private sector investors. Blended finance is the use of catalytic capital from public or philanthropic sources to increase private sector investment in developing countries to realise the SDGs [41].

Applying these dynamics to the clean cooking sector, Figure 5 shows a stylised progression of a clean cooking company through its innovation cycle following a typical S-curve. This is overlaid with considerations of consumer, sector transformation, market development, information and finance risk, and the financial instruments currently most used in the sector.

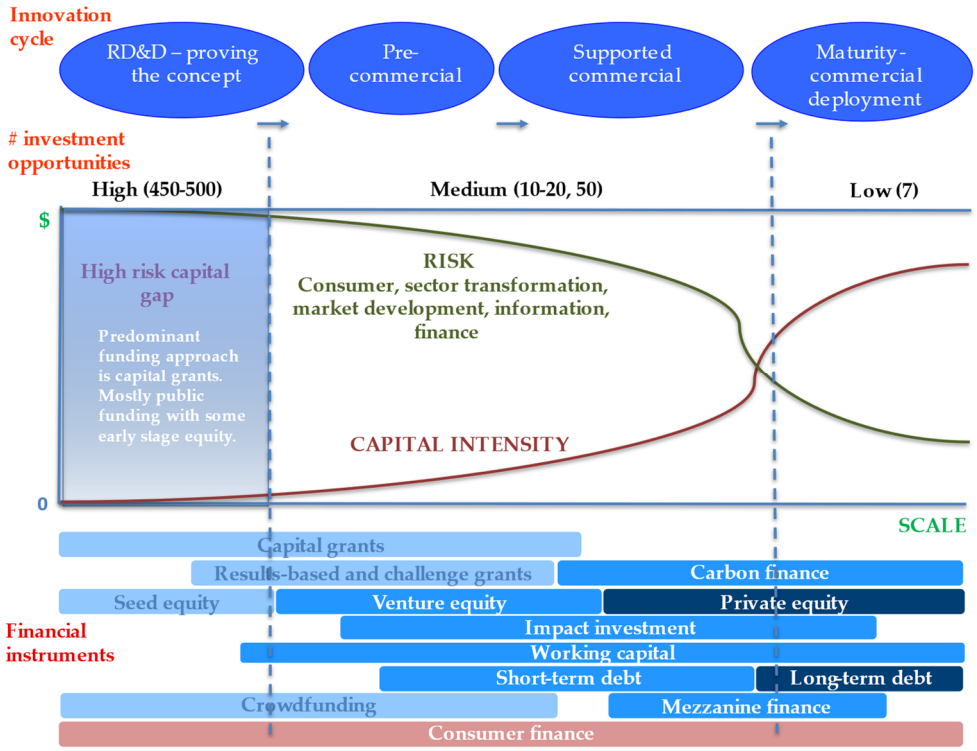

Figure 5. Clean cooking finance through the innovation cycle. References: ESMAP. The State of Access to Modern Energy Cooking Services. 2020. World Bank: Washington, DC, USA; MECS and Energy 4 Impact, Modern Energy Cooking: Review of the Funding Landscape. 2022; Clean Cooking Alliance. Clean Cooking Industry Snapshot. 2022.

The data show a relatively high number of enterprises, and by extension, investment opportunities at the beginning of the cycle, where risks associated with new ventures are highest and, therefore, where clean cooking funders that seek a return are most reluctant to commit funding. In 2019–2020 combined, almost nine out of every ten dollars going into clean cooking companies sought some return on investment [32].

This is reflected in financiers' risk perceptions. Viewed through an equity investment lens, most are interested in funding enterprises in their early or late growth stage, followed by mature and then seed companies [22]. Risk aversion has also driven existing investors towards familiar investees rather than high-potential new ventures [6]. Similarly, in the LMD sector, start-up capital and small working capital loans can be difficult to secure in the early stages of company growth, creating a funding "valley of death". These companies are

often unsophisticated, struggle to identify suitable funders and are unable to communicate their value proposition using language that resonates with investors [9,28].

Critically, the risk aversion of private financiers in the early stages of business growth has not been met with a commensurate assumption of risk and volume of targeted public finance to help push promising new ventures through this essential stage of the innovation cycle. On the contrary, there is a dearth of RD&D funding to support the development of new clean cooking technology, ventures and pilot demonstration activity. This is underscored by the diminishing role of grants in funding clean cooking enterprises, where grants have traditionally been the financial instrument most likely to support RD&D. In 2020, grants represented the smallest amounts of capital flowing to clean cooking companies, with an average of USD 400,000 per company. Further, the number of companies reporting having received grants declined from thirty-six in 2014 to nineteen in 2020 [32]. These data suggest an increasing concentration of grants into fewer companies over time, while the amount of grant funding per company has also declined. From the point of view of the innovation cycle, the implication is that ever fewer companies are receiving the early-stage capital required to test new ideas and prove business models as a precursor to private investment and scale.

Aside from company-level RD&D, several structured clean cooking RD&D programs exist or have existed but, with some exceptions, these have tended to be time-limited and focused on cookstoves, as distinct from the full range of modern cooking solutions [6,22]. A promising development is a planned innovation fund under the auspices of Pillar 2 of ESMAP's USD 500 million Clean Cooking Fund. The innovation fund is envisaged to support "technological, business, policy, and financing innovations closely aligned with country and regional investment projects" and "co-financing of pilots and technology transfer for projects" [42]. Notwithstanding these initiatives, current sector-wide clean cooking RD&D efforts are said to lack focus [9].

Exacerbating the diminishing share of innovation funding is evidence that the sector's traditional reliance on grant-based funding and subsidies does not in fact reduce the risk of debt or equity financing for private financiers, which are concerned with the profitability of businesses net of any grants they receive. Poorly designed grants and subsidies are at best unsuccessful and, in a worst-case scenario, can distort markets and sustain enterprises with sub-optimal business models [9,25].

The very small proportion of clean cooking businesses that become investible and scalable in the eyes of financiers bears this out. This speaks to an overall failure of early-stage funding for the sector to properly target key risks to business and sector growth [6]. It, in turn, contributes to an incomplete supply-side financing value chain and an inefficient process of financial resource aggregation and transfer to clean cooking solutions providers. These companies' ability to access commercial finance depends on their ability to demonstrate profitability in both the short and long term. This, in turn, arguably requires sustained public investment in innovation to put meritorious ideas on a path to success and, crucially, attract follow-on private sector funding.

4.3. Expanding Public Finance for Innovation and Risk Mitigation

In 2009, developed countries agreed to jointly mobilise USD 100 billion each year by 2020 to support developing countries in taking climate action. They reaffirmed and extended this commitment through 2025 under the auspices of the 2015 Paris Climate Agreement [43]. However, the annual goal has never been met [44]. Further, while the public sector can potentially play a powerful role in catalysing private sector finance by reducing constraints and underwriting risk, the volume of private capital mobilised through public climate finance did not exceed USD 15 billion in any year (2016–2020) for which comparable data are available [45,46]. As is widely acknowledged, public finance alone will not achieve the world's emissions reduction targets and by implication, the SDGs that were established to help do so [26]. Rather, the role of public finance should be to make judicious, targeted

investments to prove a climate-friendly business or project's investment readiness, catalyse co-investment and ultimately promote self-sustaining private finance markets.

Private investment in clean cooking markets can be leveraged through more and better targeted public funding for innovation to help nurture more companies through proof of concept and thereby improve the investment pipeline for later-stage commercial financiers. In this regard, an analogy may be drawn with decades-long public funding for the development of solar PV technology and the impact of that funding on PV deployment.

The cost of PV modules has declined ninety-nine percent since 1980. R&D and improvements in cell efficiency are the major contributing factors, accounting for almost a quarter of the decline between 1980 and 2012 [47]. As a result, the cost of electricity from utility-scale PV fell eighty-five percent in the decade to 2020 and it is now the lowest cost source of electricity generation in history [48,49]. Annual investment in off-grid solar companies, whose consumer profile overlaps significantly with that of people without clean cooking access, was between USD 300 and 350 million between 2016 and 2020 [50]. Investment into the off-grid solar sector in 2014 was USD 74.5 million, a similar amount to that seen in clean cooking companies in 2020 [32].

As clean cooking companies move through the early stages of the innovation cycle, their RD&D efforts need not be limited to technology development and business model improvement. On the contrary, an approach that prioritises the practical and strategic needs of end users should be adopted to create the greatest potential for sustained adoption of solutions. The energy-related needs and concerns of the world's poorest people, and therefore those most likely to experience cooking poverty, are rarely integrated into energy innovation efforts, are understudied and are poorly understood [51]. Research efforts should therefore be channeled to better understand end-use consumer preferences and other demand-side barriers. For example, a wide variety of customer segments exist for cookstoves based on characteristics and price points and it is critical that RD&D efforts aim to develop and foster solutions that consumers find useful and attractive. Notably, research has found that consumer-facing subsidies to incentivise adoption often do not match consumers' needs and preferences, which are better understood by cooking companies themselves. As a result, policies that use indirect subsidies to support company RD&D, manufacturing and marketing tend to be more successful than blanket consumer-facing subsidies in creating sustained adoption [9].

To the extent that fledgling companies do not secure the finance necessary to develop their business models to viability, they will not contribute to a later pipeline of potential investees; these are precisely the issues cited by financiers as the greatest barriers to scale. As a result, public finance has a critical role to play in supporting RD&D and innovation, whether related to technology development, business model improvement or consumers, that are necessary to nurture promising new ideas through to bankability and scale. This is entirely consistent with SDG7.a's target to enhance international cooperation to facilitate access to clean energy research and technology, while progress could be assessed by reference to indicator SDG7.a.1, which measures international financial flows to developing countries in support of clean energy research and development [13]. While competition and the attractiveness of growing clean cooking markets will of itself incentivise RD&D investment, greater strategic engagement in the RD&D process by public funders will arguably accelerate a business's progress through this crucial phase of the innovation cycle [9].

Beyond innovation funding, public financiers are uniquely placed to promote new financing solutions and co-funding efforts, especially through assuming greater risk and anchoring blended finance structures.

Clean cooking companies that have endured through the difficult, early stages of their business growth encounter a range of obstacles that prevent them from becoming one of the handful of businesses that have attracted significant funding to scale. Part of the reason for this is a lack of catalytic public finance for businesses in their growth stages, as well as a lack of structure around co-funding and risk sharing among public and private funders.

In June 2019, SEforALL convened a set of charrettes in Amsterdam, Netherlands, to identify impactful but pragmatic solutions to accelerate progress on SDG7. One of four charrettes was grounded in the question: "What is required to create a sustainable, investable, private sector-led market for fuels for clean cooking?" Twenty-seven experts from developed and developing countries, who represented organisations spanning the full value chain, were invited to participate in this "Clean Cooking Charrette". They were asked, collectively, to bring forth solutions with the potential to disrupt the sector's status quo and enable transformative progress towards the achievement of universal access to clean fuels and technology for cooking by 2030 [12].

One such solution was a proposal to create a Clean Cooking Market Catalyst (CCMC) that seeks to address the fragmentation and inefficiency of current donor-funded programs and projects by aligning providers of public finance on a common vision and approach to prove the viability of, and to scale, the clean cooking market. The CCMC was envisioned as a USD 1 billion, grant-funded platform that would offer a suite of financial products across the development and finance continuum of clean cooking, enabling quick decision-making and a high risk tolerance. With a prioritisation on "clean" fuels, the platform would offer equity for 15–20 select companies languishing in the "valley of death", to demonstrate scalability and create confidence in the sector; a catalytic finance window to foster innovative business models and technology solutions; an RBF window that would pay for verified social, health and gender impacts of deployed solutions; and a debt fund for consumer finance and company working capital, with a possible guarantee window [12].

In its emphasis on a greater assumption of risk by public funders, the CCMC concept aligns with the IEA's assertion that concessional finance provided by public financiers has a key role to play in helping to de-risk commercial participation [3]. It is also consistent with MECS and Energy 4 Impact's recommendation to expand the availability of concessionary, first loss capital to catalyse commercial debt at later stages of clean cooking company growth and that of the GDC to create new or adapted debt mechanisms to free up companies' working capital [22,28].

As is the case with innovation, public funding, including through DFIs, has a unique role to play in anchoring blended finance funds and facilities, as well as assuming early-stage risk, by fulfilling the promise of public funders' typically expansive funding mandates.

4.4. Improving Data and Knowledge Sharing among Financiers

Closely related to investment barriers concerning investees and pipeline are poor data availability and knowledge sharing among clean cooking funders. Siloed, fragmented data on markets, enterprises and customers are some of the biggest obstacles to attracting capital to the sector. With incomplete data, financiers are less effectively able to define markets, develop investment strategies, conduct due diligence and close investments [22,28]. When looked at through the lens of the business growth cycle, scarce data means that financiers have less visibility into which clean cooking solutions are working and, therefore, to target resources to promote the scale-up of demonstrably successful strategies. Specifically, a dearth of rigorous, context-specific evidence on the success of different business models acts as a barrier to growth for clean cooking enterprises, particularly in their early stages [9]. ESMAP notes that most sector data come from academic journals, with very little from non-journal sources, such as international organisations, non-government organisations and the private sector. The effect is that the results of much valuable fieldwork are not finding their way into the synthesis of evidence [25].

In contrast, improved collaboration and sharing of market-oriented data among funders can help them, in aggregate, form a more complete picture of potential investees and a truly integrated view of the sector. This should in turn result in better investment decision-making and a more efficient process of financial resource aggregation and transfer to businesses.

Sector financiers are overwhelmingly in favour of greater data sharing and knowledge exchange. More than eighty percent of clean cooking funders want an online data portal

as a collaborative effort with other stakeholders [22]. Similarly, the LMD sector calls for greater collaboration among funders through improved data sharing, for example, through the creation of an investment portal, as well as investment readiness and data tools to increase LMD companies' visibility and help them showcase their performance [28].

Notwithstanding the demand, to date, no attempt has been made to create a dynamic, open-access portal as a repository of sector data. However, the idea was foreshadowed by the SEforALL Clean Cooking Charrette participants, who envisaged a platform that would provide accurate and timely data to help drive informed decisions by investors, enterprises and governments to allocate resources and funding to viable and scalable clean cooking solutions. The platform would optimise existing data while making it more accessible and usable, for example, through the visualisation of MTF household survey data. Additional data would be collected and evidence derived on the impacts of cooking practices on health, climate and gender equality, with transparency around measurement and metrics. Consumer preference data would also be captured, as would data on next-generation solutions to identify and test the scalability of promising ideas and business models [12].

The demand from sector stakeholders for a data portal need not be met by creating a whole new infrastructure. Rather, existing platforms conceived of and sponsored by public international institutions with an interest in climate and energy could be leveraged to achieve the same objective. For example, the Climate Investment Platform (CIP) or the Global Atlas for Renewable Energy could incorporate a clean cooking data window. The CIP was jointly announced by the United Nations Development Programme (UNDP), the International Renewable Energy Agency (IRENA) and SEforALL in coordination with the Green Climate Fund (GCF) at the UN Secretary-General's Climate Action Summit in September 2019. It convenes governments, financial institutions, project developers and the private sector to increase financing for climate action and help countries reach their climate goals, with its first focus being the clean energy transition [52]. IRENA's Global Atlas for Renewable Energy, informed by data from over fifty international research institutions, is an online platform intended to assist policymakers and investors to find renewable energy resource maps for locations across the world. It aims to close the gap between countries that have access to the necessary data and expertise to evaluate the potential for renewable energy deployment in their countries and those that do not [53]. Cross-sectoral collaboration on clean cooking data capture and sharing through, for example, the CIP or the Global Atlas for Renewable Energy would have the benefit of better integrating clean cooking with broader energy transition and related investment initiatives.

DFIs also have the motivation and resources to play a key role in knowledge sharing by facilitating the development of best-case practices, as well as investing in rigorous monitoring and evaluation of different business models and strategies with the objective of generating adaptable evidence that could be made freely available [9]. In this regard, Pillar 2 of ESMAP's USD 500 million Clean Cooking Fund is a global platform for knowledge, innovation and policy coordination. This is intended to incorporate a "knowledge platform for publishing and sharing analytical products, promoting cross-country learning and exchange, and taking stock of knowledge gaps and opportunities" [42]. A logical extension of this concept could include dynamic data of the kind envisaged at the Clean Cooking Charrette.

5. Conclusions

The incremental progress made in increasing volumes of finance for clean cooking since SDG7 was established, combined with financiers and companies alike articulating major barriers to investment and scale, make it clear that a business-as-usual approach to financing the sector will not result in the achievement of SDG7's clean cooking targets. This study's contribution involved analysing recent data on finance flows and financial instruments for clean cooking through the lens of the company innovation cycle. In the context of wide-ranging barriers to the clean cooking sector's development, we found a chronic shortfall of finance for companies at the early stages of their business growth

and poorly targeted public finance to support innovation and mitigate risk for later-stage investors. This is exacerbated by limited data sharing and knowledge exchange among a very small cohort of active financiers relative to the size of the clean cooking access problem. Interrogating financing through the enterprise value chain enables investors and other stakeholders to see the investible landscape "whole" and, in turn, to pinpoint major funding gaps. In practice, this can help to promote singularity of purpose among the funding group. Ideally, it would prompt greater risk tolerance and agility on the part of public funders, especially for RD&D and at the earliest stages of the innovation cycle where risks are highest and private sector financiers most reluctant to invest. Combined with improved coordination and data sharing among existing and potential new funders, this could help mitigate financing risks and catalyse much-needed private investment in clean cooking.

Some limitations of the research should be acknowledged. First, data collection was limited to peer-reviewed articles in Scopus and Web of Science and recent grey literature relating to finance for clean cooking. The database searches revealed a modest volume of published, peer-reviewed research on clean cooking finance at the macro level relative to publications concerned with a specific country study, program and/or technology. These results were supplemented by a small number of important, recent studies in the grey literature. Future studies could expand the data collection to incorporate recent conference proceedings, as well as practitioner surveys that build on and extend the grey literature's findings. A second limitation of this research concerns its lack of analysis of consumer finance. This is a crucial aspect of the clean cooking transition, especially to address chronic affordability challenges, and its detailed investigation at the global level, to supplement country-level studies, is therefore a strong candidate for future research.

While an analysis of finance gaps through the clean cooking value chain can highlight deficiencies in the volume and type of capital available, addressing them presents significant implementation challenges. In view of this study's findings regarding the importance of public funding for innovation and risk mitigation, a first promising avenue for further research is to consider the institutional innovation required to more efficiently and effectively deliver public finance to accelerate the clean cooking transition. Second, clean cooking financiers' calls for enhanced cooperation in data sharing and knowledge exchange invite an investigation of what may be achieved through improved coordination to accelerate the sectoral learning curve in clean cooking financing transactions. This could occur by reference to the off-grid solar sector, whose funding challenges, consumer profiles and distribution challenges overlap significantly with clean cooking. Third, the poor representation of local financial institutions in overall finance for clean cooking suggests wide scope for research into what is required to build capacity among this cohort to enable their robust participation in clean cooking markets.

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