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Is clean cooking affordable? A review

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ABSTRACT

2.9 billion people lack access to clean cooking fuels and technologies. This review analyzes the literature on affordability as a barrier to adoption and consistent use of clean cooking stoves and fuels. We find diverse frameworks, definitions and metrics in use, and frequent discussions on stove price, fuel costs, microfinance, and smaller procurement quantities. We recommend that financing strategies to mitigate unaffordability be based on how low-income households actually earn, spend, and save their money, and that affordability frameworks be expanded to account for gender divides, rural/urban divides, and stove stacking behavior. Our review thus aims to reflect the nuances of a low-income household's ability to pay for clean fuels. Affordability must make sense within the lived experiences of the poor if clean cooking is to achieve universal access.

1. Introduction

Clean[1] cooking fuels are a primary focus for innovation and dissemination to meet Sustainable Development Goal (SDG) 7's call for "universal access to affordable, reliable, modern energy services" [1]. SDG 7 promotes efforts to switch to cleaner fuels as well as to cleaner-burning stoves [1].

The adoption and continued use of clean-burning stoves by the 2.9 billion people relying on traditional fuels is necessary for health, gender equality, and climate concerns [1]. The use of clean cooking fuel would help prevent up to 3.7 million untimely deaths annually that are attributed to household air pollution (HAP) [2]. HAP leads to lower respiratory infections, ischemic heart disease, stroke, cancer, and pneumonia [3]. Globally, women conduct 91 % of the household work to obtain fuel [4] and women account for over 60 % of all premature deaths from HAP because they are typically the primary cooks [5]. Children are also disproportionally affected by HAP, which causes over half of the pneumonia cases in the under-five age-group [5]. Unimproved stoves (e.g. three-stone fires or inefficient stoves that burn traditional fuels) contribute an annual 120 megatons of climate pollutants, specifically black carbon, which is the second largest contributor to climate change [6]. Household solid biomass use for cooking and heating produces ~25 % of the total annual anthropogenic black carbon emissions globally [7].

Biomass stoves range from simple firewood- and charcoal-burning devices to improved Rocket, forced-draft, and more efficient charcoal stoves. Although improved stoves produce fewer emissions than three-stone fires [8–10], a review of 19 stove types shows that even improved stoves pose a public health risk [11]. There is currently just one biomass stove that currently meets a high World Health Organization (WHO) standard (i.e. Tier 4) for cookstoves in field conditions [12,13]. BLEEN (Biogas, liquified petroleum gas (LPG), electricity, ethanol, and natural gas) fuels meet these strict health and emission standards [14].

Despite the health risks of unimproved stoves, there are widespread barriers to the adoption, and to the continued and exclusive use, of improved stoves. Notable barriers include affordability, unreliable supply, social acceptability, household education levels, household socio-economic and demographic characteristics, and low total perceived benefits [1,15–19]. Adoption and consistent use are crucial to achieving SDG 7. Even when households obtain a clean-fuel stove, they may use it but not refill the clean fuel consistently. This leads households to stack the stove with traditional, unclean stoves [20]. Benefits from reduced exposure occur under 1000–2000 $\mu g/m^3$ of particulate matter [21], and conventional stove usage must fall to under 3 hrs a week to achieve the HAP particulate matter target from the WHO [22]. The literature has evaluated numerous interventions and researchers have

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[1] The Energy Sector Management Assistance Program (ESMAP) defines clean cookstoves as "cookstoves that produce significantly less household air pollution than traditional three-stone open-fire stoves and meet a specified emissions standard" [14]. However, we refer to fuels or cookstoves as clean only if they meet the WHO's air pollution limits of $<35\ \mu g/m^3$ Particulate Matter and $<7\ mg/m^3$ Carbon Monoxide.

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List of abbreviations:

BLEEN	Biogas, LPG, electricity, ethanol, and natural gas
BPL:	Below Poverty Line
CEEW	Council of Energy, Environment and Water
ESMAP	Energy Sector Management Assistance Program
EThOS	e-theses online service (from the British Library)
HAP	Household Air Pollution
HEART	Household Energy Assessment Rapid Tool
Kg	Kilogram
kWh	Kilo-Watt hour
LILACS	Caribbean Health Sciences Literature (LILACS)
LMIC	Low- and middle-income country
LPG	Liquified Petroleum Gas
mg/m^3	: Milligram per cubic meter
MJ	Mega Joule
MMBtu	One million British Thermal Units
NDLTD	Networked Digital Library of Theses and Dissertations
NPV	Net Present Value
PAYC	Pay-as-you-cook
PAYG	Pay-as-you-go
PKR	Pakistani Rupee
PMUY	Pradhan Mantri Ujjwala Yojana
SDG	Sustainable Development Goal
USD:	United States Dollar
WB	The World Bank
WHO	World Health Organization
$\mu g/m^3$	: Micro-gram per cubic meter

suggested combining interventions to address the numerous barriers to both the initial and long-term adoption [23]. Overall, progress towards SDG 7 has been slow: From 2010 to 2017, the global population with access to clean cooking fuels and technology increased from 57 % [CI: 51, 62] to only 61 % [CI: 54, 67] [1].

In this review, we aim to isolate and better understand the concept and measurement of affordability, as it is one of the most significant reported barriers to adoption and consistent use of clean(er) cooking. A 2019 update on the progress of SDG 7 states that "*the uptake of cleaner fuels remains slow in rural Africa, in large part due to issues of affordability and supply*" [1] (pg. 6) and yet there are no widely accepted definitions or indicators to assess affordability in the context of achieving SDG 7. The specific objective is to extract meaningful definitions and explicit measurements of affordability from the vast stove program literature. We focus on affordability for the adoption and consistent use of both clean fuels and improved stoves.

We organize the review by three overarching questions: (1) What are the *main frameworks* guiding the discussion on clean cooking affordability? (2) How is affordability *defined and measured* at the household level? and (3) How are the different *components of affordability* discussed? Understanding the frameworks, metrics, and components of affordability can inform researchers and practitioners who design clean stove programs and policy to achieve universal, affordable access. In particular, our review aims to reflect the nuances of a low-income household's ability to pay for clean fuel. If stove programs are designed using metrics for affordability that reflect household realities, there could be higher rates of adoption and consistent refilling.

We emphasize BLEEN fuels that are consistent with the WHO's Tier 4 specifications but draw on the lessons learned from improved biomass cookstove projects. Adoption of BLEEN fuels is a notably different experience from using improved biomass stoves. However, studies on the affordability of these stoves can offer broad insights into affordability and expenditure patterns from the household perspective. The BLEEN fuels are also different from one another; each fuel has different implications for the SDGs regarding climate change because some have carbon-neutral sources (solar, biogas, etc.) while others rely on fossil fuels (LPG).

The intuitive definition for affordability is "*the capacity to pay for a minimum level of service*" [24](pg. 228). Ongoing affordability, as opposed to that of durable goods such as stoves, is measured as a ratio of fuel expenditure per month to overall monthly expenditure [25]. Benchmarks for this ratio have been set to indicate the affordability of electricity, heating, and water affordability in low-income settings [25]. Such benchmarks have been critiqued; recommendations of 10–20% have been called arbitrary and not universally applicable [26]. In a wider effort to grasp affordability, indices have been developed to include energy costs, efficiencies, socio-economic characteristics, and incomes (before and after essential expenditures such as rent and food) [27–30].

Affordability for clean cooking can be divided into two components: the upfront cost of the stove and the continued cost of the fuel. The upfront cost of the stove is a well-documented prohibitive cost for low-income households [20,31–33]. However, this initial cost is only half the battle. In India, the national Pradhan Mantri Ujjwala Yojana (PMUY) policy gives Below-Poverty-Line (BPL) households the regulator and hose pipe for the LPG stove for free, as well as a loan option for the stove and cylinder. Despite this, researchers found that 24 % of PMUY beneficiaries did not purchase a single refill in their first year [34]. There are also two types of affordability for the continued cost of fuel: everyday sums and occasional lump sums. Traditional fuels (wood, agricultural waste) are often purchased day-to-day, while cleaner fuels such as LPG are usually purchased on a monthly (or longer) basis. We review the multiple dimensions of stove and fuel affordability with respect to both adoption and continued use, i.e., upfront costs, and one-time and recurrent expenditures covered in the clean cooking literature.

2. Methods

The primary criterion for inclusion of the grey and peer-reviewed literatures was an improved cookstove or clean stove intervention report or commentary, published between 2000 and 2020 in a low- and middle-income country (LMIC), in which affordability was explicitly discussed. We searched through Science Direct, Google Scholar, Embase, PubMed, Web of Knowledge, the Latin American and Caribbean Health Sciences Literature (LILACS), Proquest Dissertations & Thesis, EThOS (e-theses online service (from the British Library), and the Networked Digital Library of Theses and Dissertations (NDLTD). We also searched through grey literature databases from the Clean Cooking Alliance, the Energy Sector Management Assistance Program (ESMAP), the WHO, and improved stove start-ups. We used the search terms "clean cooking" and "cookstove" with every combination of "affordability," "affordable," "ability to pay," "cost," "price." "Clean cooking affordability" produced 34,808 initial results. Finally, throughout the studies identified, we conducted hand searches from their references.

We did not include studies that discussed only health or particulate pollution. We excluded studies that focused solely on stove emissions and those dealing with affordability beyond the household (such as supply chain affordability). We excluded extreme settings such as refugee camps and post-war or post-disaster emergency shelters because these settings are not representative of normal household spending, savings, and affordability. Finally, only English language papers were reviewed. We acknowledge that, in some communities, there is no supply chain for any improved stoves or clean fuels; these communities are sometimes classified as affordability-challenged (e.g., in the water and electricity sectors [25,35]). However, we excluded studies in which unaffordability was assumed but not assessed.

We ultimately assessed 451 papers, included 172 papers for review, and narrowed these down to 114. We prioritized peer-reviewed publications and studies that offered multiple insights as we reduced from 172 to 114 papers; however, we provide a master list in Appendix A (Supplemental Materials). This selection process is outlined in Fig. 1. Out of the final 114 papers in the main text, 65 studies were peer-reviewed publications, 41 were grey literature sources, and eight were dissertations/theses. Forty-one papers covered BLEEN fuels exclusively, 13 addressed improved biomass stoves, and 60 covered some combination of BLEEN and improved biomass (see Fig. 1).

3. Results

Overall, 65 % of the first and last authors – often considered the most significant author positions in the public health and engineering-oriented literatures – of the 114 final papers were located in the global North, in particular in the USA. This was not surprising as we reviewed only English-language publications. By contrast, the case study locations of these studies were all in the Global South, in particular South Asia and sub-Saharan Africa (Fig. 2). In this, the clean cooking literature reflects the broader literature on “low-cost” energy options, wherein North-based researchers still dominate the study of significantly South-based problems.

3.1. Frameworks

Several clean cooking papers turn to energy poverty frameworks within which cooking is one among other forms of energy use, such as transport, lighting, heating, cooking and other uses. Examples include the United Kingdom’s national Fuel Poverty Strategy, in which a household is considered energy poor if more than 10 % of its net income is spent on energy [37]; variably-defined energy poverty thresholds [27,28]; the Multi-Dimensional Energy Poverty Index [29]; and Hill’s updated national index for the United Kingdom, the Low-Income-High Costs index, which assesses energy expenditure relative to a median value and also assesses whether the household’s income falls below the poverty line after purchasing energy [30]. Typically addressing multiple energy uses, these papers use the energy poverty frameworks to measure (1) energy access (electricity, cooking, etc.) [38–43], (2) the affordability of specific energy combinations for lighting, cooking, etc. [44],

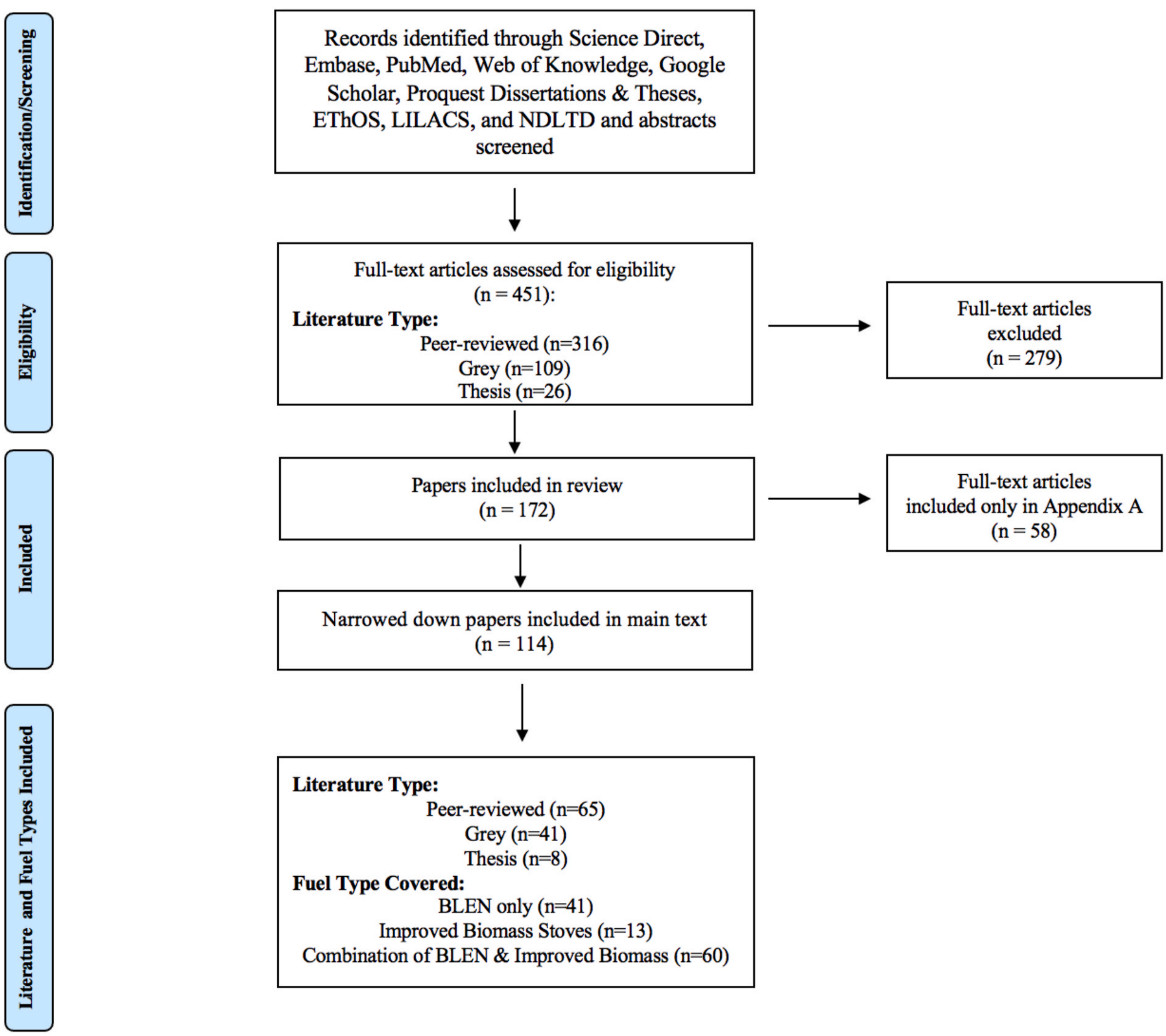

Fig. 1. Literature selection process from identification and screening to the papers included, along with the specific literature types and stove and fuel combinations systems. The primary criterion for inclusion in our comprehensive review was an improved cookstove or clean stove intervention report or commentary, published between 2000 and 2020 in a low- and middle-income country (LMIC), in which affordability was explicitly discussed. Only English language papers were reviewed. This flowchart was adapted from Moher et al. [36].

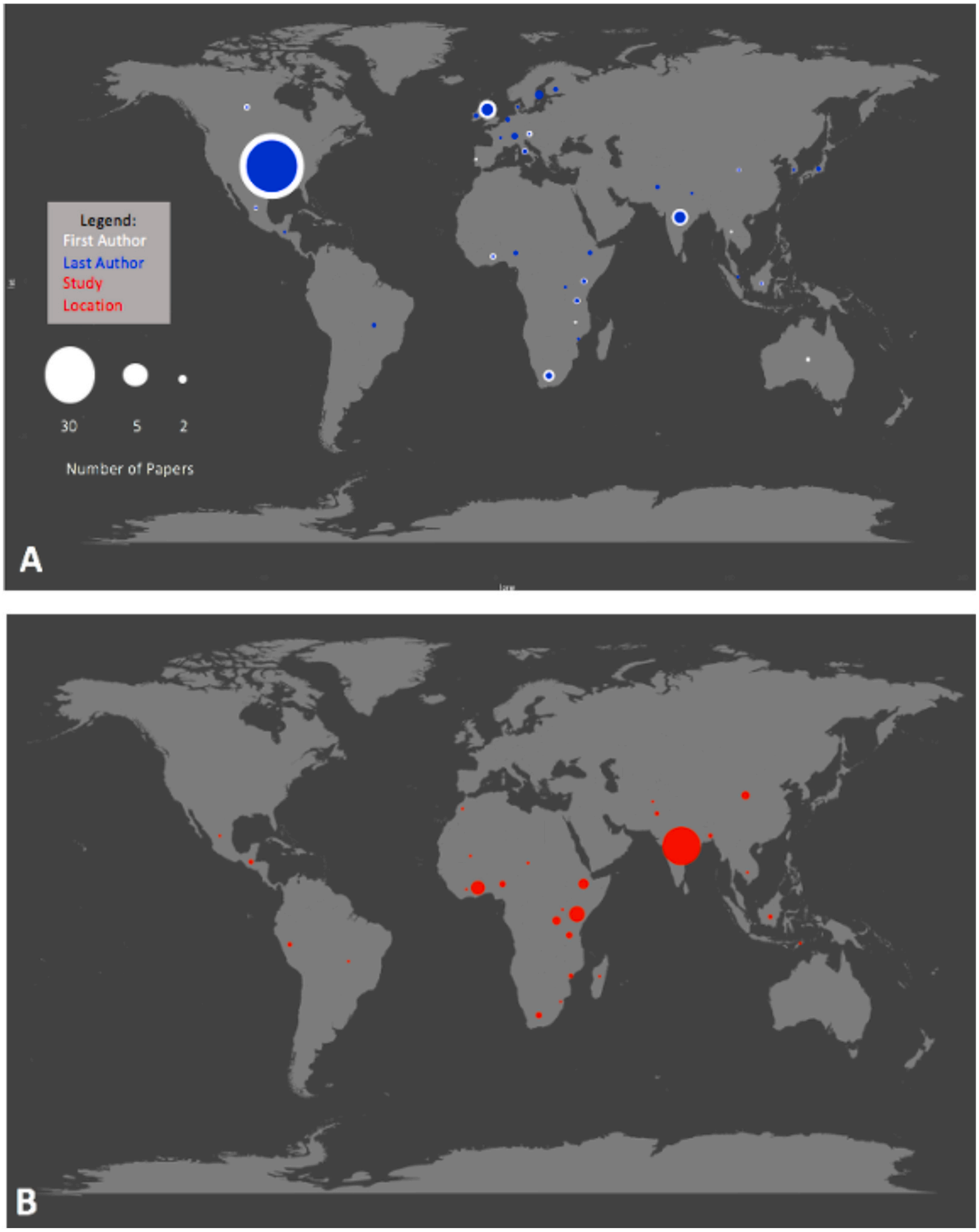

Fig. 2. Panel A illustrates the location of the first (n = 113) and last (n = 87) authors for each of the studies included in this review. If the paper included was from grey literature, we recorded the authors' location as the headquarters of the organization. Please note that difference between first and last authorship is due to single author papers and organizational reports that did not list specific authors. Panel B details the location of the study site within each paper included (n = 80). Please note that 24 studies had a global outlook or included more than three study locations. These multi-location studies were not included in the graphic.

and (3) if the provision of energy is compromising other essentials (water, sanitation, transport, telecommunications, etc.) [45]. These evaluations are used to make policy recommendations and decisions at the national and zonal levels [40,41,46,47], and one study argues that different frameworks should be used simultaneously to obtain a fuller picture of energy poverty [48]. Though we cannot extract metrics specifically for cooking affordability from these all-purpose frameworks, they serve as a reminder that overall energy affordability goes well beyond the kitchen.

With respect to frameworks specifically for clean cooking affordability, we found four approaches: a Multi-Tier Framework from ESMAP, a Developing World Consumer Segmentation framework also from ESMAP, one from India's Council of Energy, Environment and Water (CEEW), and the Energy Ladder. ESMAP created a Multi-Tier Framework, one of which is specifically for clean cooking. Tiers range from 0 to 5 (5 signifying the best access) with associated indicators of indoor air quality, efficiency, convenience, safety, affordability, quality, and availability. The affordability indicator is defined as the levelized cost for both the primary cookstove and the primary fuel at less than 5 % of household income, but is not specific about whether the income measure is for disposable, net, or gross [14]. If the household's levelized cost meets that criterion, then it is designated as within Tiers 4 or 5 for affordability. A household's overall tier is determined as the lowest out of the seven aspects included. This framework can be used for measuring, monitoring, and evaluating progress towards higher-quality cooking energy. In their 2015 technical report on "The State of the Global Clean and Improved Cooking Sector," ESMAP created a second framework, "Developing World Consumer Segmentation," in which eight different types of cooking fuel consumers are described and an affordability characteristic is assigned to each. For example, a "Poor Wood Purchaser" represents 96 million people globally, has high fuel expenditures relative to income, has low awareness of available clean fuels, and cannot afford modern energy [49].

India's CEEW defines affordability as a binary variable of either affordable or unaffordable based on whether expenditure on all types of cooking fuels (not including the stove) is less than 6 % of the household's total monthly expenditure [50,51]. The CEEW's affordability framework for clean cooking access includes multiple fuels, acknowledging the reality of stove and fuel stacking [51].

Many papers implicitly tie the affordability of cleaner fuels to higher income, leaning on the assumption of the original Energy Ladder. The Energy Ladder visually represents how, as households increase their income, they move up the rungs of the cooking energy ladder – from using biomass and agricultural waste to improved biomass stoves to LPG to (finally) electricity [52]. However, it has been compellingly argued that a multiple fuel model is more appropriate as biomass (or less efficient) stove usage persists even with rising incomes [20]. Despite this challenge to the linear Energy Ladder, the idea that income is the primary determinant of the use of modern energy persists [20]. Many studies continue to use the Ladder— while acknowledging its faults—and treat income as a proxy for clean fuel affordability. Overall, these four frameworks take four different approaches to affordability, incorporate different measurement methods and count different costs towards "affordability" (Table 1). The only universal consideration was income, either as a general spectrum (Energy Ladder) or by percentile group. Table 1 illustrates how these elements vary across frameworks in the literature.

3.2. Definitions and measurements

The field of clean cooking contains several definitions of affordability (see Fig. 3, panel A). Affordability is generally understood as what households would be able to pay for their cooking energy supply [53–56]. Some literature does not measure affordability directly but defines it indirectly via its correlates. For example, studies have suggested that household size, educational background, employment status, or the socio-economic status of households lead to different affordability scenarios [31,57,58]. One study gave a more concrete definition that

Table 1
Elements of clean cooking affordability frameworks in the literature.

Element of Framework	ESMAP	ESMAP's Developing World Consumer Segmentation	India's CEEW	Energy Ladder
Sets a Clear Threshold	x		x	
Includes Net Present Value, Lifecycle Costs, or Levelized Costs	x			
Considers Multiple or Stacking Fuels			x	
Considers Income	x	x	x	x
Considers only Stove Cost				
Considers only Fuel Cost			x	x
Considers Stove and Fuel	x	x		
Considers Different Consumer Groups		x	x	
Binary	x		x	
Spectrum		x		x

listed the tangible cost of inputs (stove cost, cash fuel cost) plus the time value of fuel collection, which is monetized based on the average hourly wage) [59]. Another combined socio-economic factors (cash income, household expenditure level) and product-specific factors (stove price, fuel prices) (see Fig. 3, Panel A) [60]. Ability to pay was the most common definition, but it is diversely measured, and often concretely understood only by its associated metrics in particular instances.

3.2.1. Metrics

Several reviewed studies do not define affordability as a concept, but simply suggest metrics to quantify it. The literature offers multiple metrics in the form of capital costs, indices, ratios, thresholds, per unit metrics, proxy indicators, and social costs. Examples of specific equations, metrics, etc. used to calculate clean cooking affordability can be found in Appendix B. Per unit variables were the most common metric type, but there was little consensus, confirming that affordability is an intuitively understood but unevenly quantified concept.

3.2.1.1. Price. Several studies focus on the price of the stove, often suggesting price ranges that could be considered affordable for particular socio-economic segments [33,61–63]. Prices that were "unaffordable" for the mass market ranged from 15 to 50 United States Dollar (USD) [62–64], when projected household earnings were 3–10 USD per day or 200–500 USD per month, depending on the study. Other work suggested affordability limits for initial stove costs at ~10 USD [65–67], but even a 3–7 USD range is arguably too high for many [68]. A World Bank (WB) report synthesizing multiple studies proposed that 70–90 % of the consumers in Sub-Saharan Africa could afford a stove at 3–7 USD, while fewer than half could afford a 15–40 USD stove [64]. Another claimed that reducing the cost of the cookstove or a price support was the key to making it affordable [69]. Some studies focused on the levelized cost of the fuel and the stove, spreading the initial cost over time [50,70,71]. These papers recommended that stove costs hover around ten dollars [65–67], but the difference between 3 USD and 10 USD for a low-income household could be several days of income. Authors occasionally specified whether these claims referred to middle-income countries [65], or to rural households [72,73] or BPL households [72, 73]. Only one study included the stoves' net present value (NPV) in the affordability calculations [74]. Overall, equating affordability with initial stove price, or even with monthly fuel price, ignores the larger context of the household's budget. Differing household budgets and therefore affordability constraints affect uptake and continued use.

3.2.1.2. Indices. The literature includes many clean cooking affordability indices that have been used to capture multiple dimensions of affordability. For an assessment of Ethiopia, the Household Energy Assessment Rapid Tool (HEART) created a rank (1–6: 6 having the highest associated costs) composed of various metrics for capital and recurring costs as well as fuel efficiency (Appendix B) [75]. Fuel-specific continuous variables, e.g., 0 to 1, have also been proposed, to indicate completely unaffordable and completely affordable respectively. The index is one minus the ratio of expenditure on specific cooking fuels to income [76], thus acknowledging the reality of fuel-stacking. These indices taken together provide a spectrum of multiple quantifiable components in the attempt to reflect overall affordability.

3.2.1.3. Ratios. Ratios are commonly used in the literature to measure affordability for clean cooking: The ratios are fractions of cooking technology and fuel expenses over income or expenditure. These ratios vary from spending on a specific cooking energy source over total expenditure (i.e. share of expenditure on firewood, charcoal, electricity, or kerosene in the household budget) [44,77,78] to total energy expenditures over income that do not single out cooking energy [79,80]. The components of the numerator vary: only in one case study of Ethiopia did the authors explicitly acknowledge that the lifespan of the

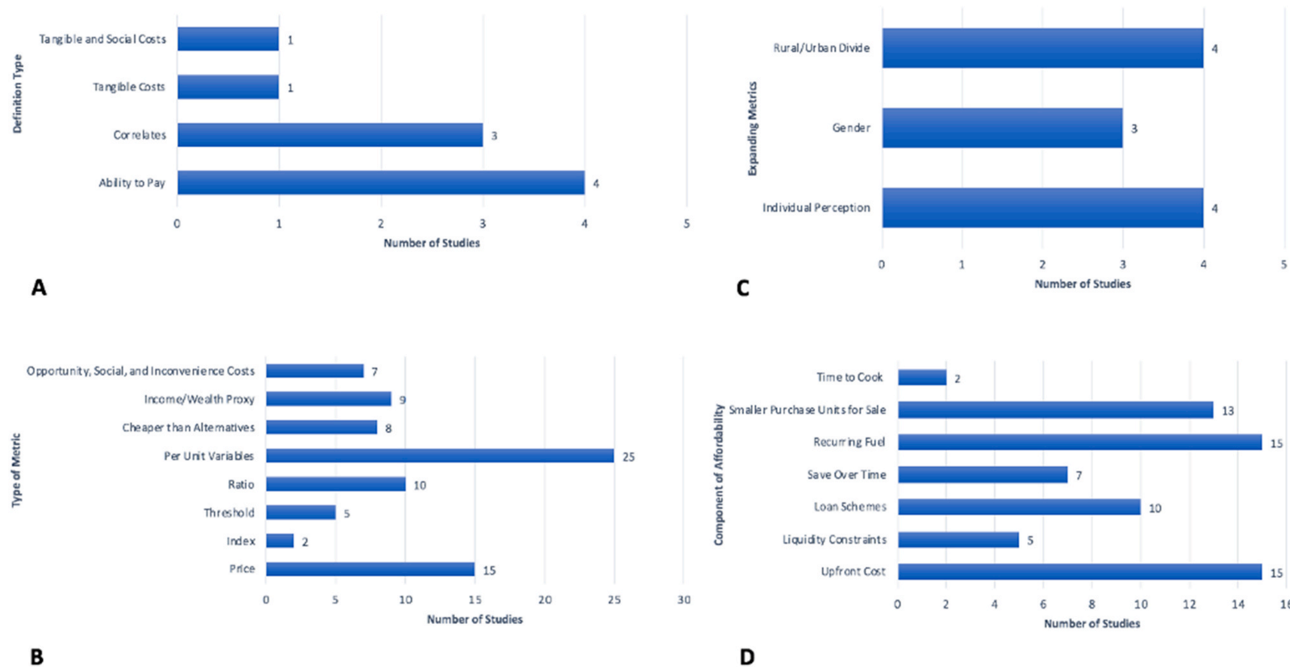

Fig. 3. Panel A shows the number of case studies that use different types of definitions for affordability (n = 9). Panel B depicts the frequency of each type of metric to quantify affordability in clean cooking (n = 81). Income or wealth proxy refers to studies that directly related affordability to income. Per unit variables are metrics for affordability such as cost per day or cost per meal. Affordability ratios and threshold ratios were commonly used (e.g., 6 % of household income). Affordability indices are weighted sums of multiple components to rank stoves and fuels. Panel C illustrates how many studies suggested including aspects beyond metrics (n = 11). These include gender inequalities, rural and urban differences, and perceptions of affordability (i.e., whether households feel that they can or cannot afford an item that technically is within their budget). Finally, Panel D reports studies that addressed different components of affordability (n = 63). Time to cook acknowledges that more efficient fuels may be less suited to meals with longer cooking times. Smaller purchase units refers to the ability to buy smaller (and therefore less expensive) quantities of fuels. Save over time refers to efficient stoves (although initially more expensive) that allow the household to save money over time on fuel costs. Loan schemes refer to studies of microfinance programs to overcome the upfront cost of stoves.

fixed assets, depreciation rate, and corresponding discounting of future costs and expenditures were not considered [81]. The denominators also vary: Some reports distinguished between total income and disposable income in the ratio's denominator [82,83]; others used residual income after payment for non-energy essentials [84]. Another study defined the denominator as total household expenditures as opposed to income [17]; this follows a broader strand in development economics in which expenditure data are considered more reliable than income data. These works reveal that seemingly small differences in the numerators and denominators of affordability ratios can have large implications for what is deemed affordable.

3.2.1.4. Thresholds. Affordability ratios have been the basis for several affordability thresholds. In India, a study found that a single LPG refill was on average 6 % of monthly spending, not accounting for any other energy needs [17]. This 6 % is also the country's affordability threshold [51]. Another study argued that cooking energy costs must be less than 10 % of the household's annual expenditure [85]. In South Africa, the national threshold for energy affordability (beyond just cooking) has been set at 10–15 % of income [86]. A study on energy security in India noted that 11–13 % of monthly expenditures for poorer households was a high burden, especially when wealthier households were paying 6–8 % [87]. In a Kenyan study, households with a total expenditure under 10, 000 Kenyan shillings per month (~93 USD/month) were found to be spending a third of their income on fuel [88]. While thresholds are intuitively understandable as measures of affordability, the literature remains scattered around a range of numbers, but also shows the unequal cost burdens across socio-economic strata.

3.2.1.5. Per unit metrics. Affordability has also been quantified by per unit metrics in the literature, ranging from dollars per capita per meal, costs per unit of time (month, year, etc.), and costs per unit of energy. Case studies in Ethiopia, India, and China have considered the per capita expenditure on each cooking fuel type as a metric for affordability [81, 89,90]. Some studies consider fuel expenditure per day [91,92], fuel cost per month [93,94] or total costs per year [32,95] (which may include investment, fuel cost, useful life of system, efficiency, and total fuel purchased) [71,96]. In LPG studies from South Africa, Brazil, and Kenya, a clean fuel study from Ghana and Uganda, and India's CEEW report, fuel efficiency was taken into account to produce cost per fuel unit rather than cost per fuel weight [50,86,97–99]. Efficiency also affects cost per meal metrics of affordability [100,101]. Affordability in terms of cost per unit (e.g., per unit energy, per capita, per month, etc.) was the most common metric (see Fig. 3, Panel B); however, it simplifies affordability because it excludes household income. Within per unit metrics, cost per unit of energy was the most common approach as it allowed researchers to compare different types of fuel (see Fig. 4). LPG's higher energy density prohibits researchers from comparing fuels using cost per weight metrics [99].

Some studies evaluate affordability of different fuels by comparing each fuel's per unit metrics and implicitly define a fuel as affordable if its per unit metrics are cheaper than the alternatives in use. For example, studies compared different types of fuel by monthly fuel expenditure [102,103], price per Kilo-Watt hour (kWh) [104] (or Mega Joule (MJ)) [50,98], or price per one million British Thermal Units (MMBTu) [105]. Many have argued that any transition to modern fuel must be at the same cost, if not cheaper, than the (traditional) alternative [106,107]. There is consensus around comparing clean fuels to traditional alternatives, but not on the method to compare the cooking stoves plus fuels.

3.2.1.6. Proxies. Proxy metrics arose in the literature, and these metrics commonly equate affordability with another household characteristic.

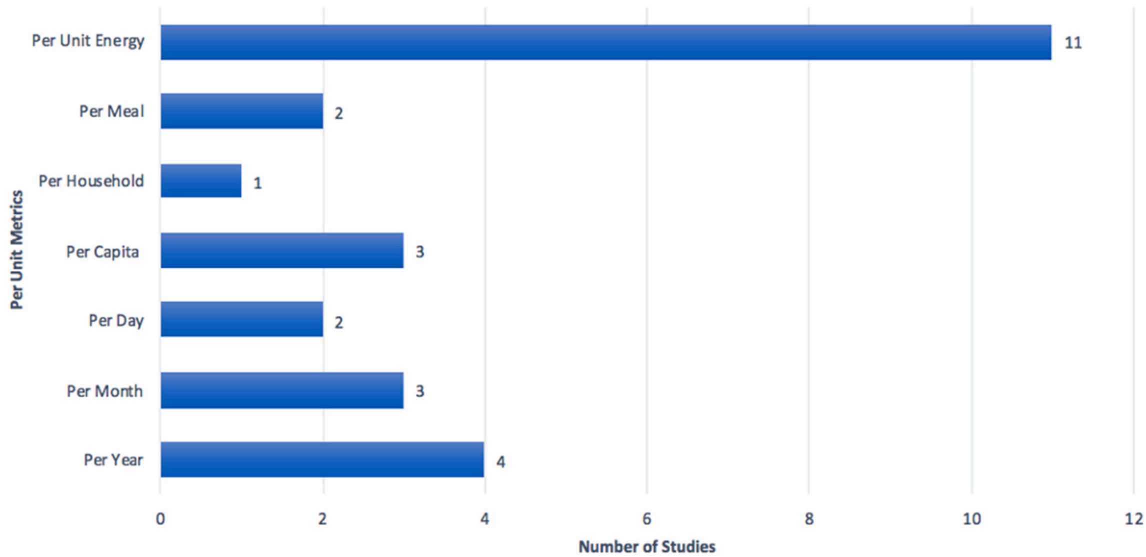

Fig. 4. This bar chart represents the frequency of different types of per unit metrics for affordability in the literature (n = 26). Overall, per unit energy was the most frequently cited metric type for clean cooking affordability.

Econometric analyses of the determinants of stove choice rely on income or wealth, not as a ratio denominator, but as a proxy for affordability [108–111]. Riley states that, "*a solution is considered affordable if yearly cost minus income is less than zero and hence no subsidy is required*" [112] (pg. 313). Others noted income cutoffs below which certain clean cooking fuels would not be affordable. For example, studies in Rwanda, Pakistan, and Kenya set income limits of 100,000 Rwandan francs, 32,857 Pakistani Rupees (PKR), and 350 USD per month as cutoffs for affording clean energy, biogas, and LPG respectively [113–115]. In an econometric model of LPG consumption by India's PMUY recipients agriculture on owned or leased land, labor (e.g. daily wage) and salaried employment were all included as proxies for affordability [116]. The econometric literature, commensurate with the Energy Ladder literature, generally treats affordability as directly correlated with income or wealth.

3.2.1.7. Social and opportunity costs. Affordability metrics sometimes include opportunity or social costs. Social costs typically comprise both the individual costs and the resulting externalities imposed on the society from producing or consuming the good [117]. The WB defines a "*total annual social cost*" (pg. 4) of cooking activities for an individual household including both opportunity and social costs, with social costs defined at the societal level [71]. The WB quantified social costs as the value of natural resource damage and the value of pollutant times the health impact of that pollutant, to which household-level costs such as stove, fuel, etc. are added [71]. Other studies mentioned (but did not calculate) the need to evaluate opportunity costs including health, storage, labor, and value of time [32,74,118–121]. The expansion of affordability metrics to include opportunity costs beyond stove, fuel and other financial costs is an attempt to quantify intra-household dynamics and, in particular, the invisible work of women cooks.

3.2.2. Expanding metrics: Perceptions, values and social divides

There is a substantial literature on household perceptions of affordability when debating the value of quantifiable metrics. Some researchers ask the households whether or not they felt they could afford the stove or fuel e.g. Refs. [57,79,109,122] Affordability was argued to be "*a black box in some ways*" [109] (pg. 100) because monetizable inputs such as price, income, wealth, and competing expenses are well understood, but how households perceive these costs or value the benefits is not [109]. Discussion of perceptions of affordability pushes the literature beyond monetized metrics.

Researchers within this expanded view have argued that affordability cannot be analyzed at "the household" level, but rather within the context of gender, power, and capacity. For example, candidate determinants of affordability include not just income, but also regularity of income, access to loans, installment payment possibilities, and women's autonomy [123]. Affordability is not uniform across gender as women "*are on average poorer and less able to access credit*" [124] (pg. 29). A report from South Asia on gender equality and energy development argued that "*affordability requirements should address the special needs of women and integrate gender criteria*" [125] (pg. 1). Differences in affordability for rural and urban households have also been noted. Metrics of affordability reveal differences in relative poverty that expose a deep rural-urban divide in access to clean cooking [81,90,126,127]. Only a handful of studies have addressed ways to expand beyond the household-based metrics traditionally used in the literature (Fig. 3, Panel C). This work demonstrates that there are real concerns about intra-household power and capacity differences, but these concerns are expressed but rarely incorporated into the clean cooking discussion.

These varying definitions, metrics, and contexts for affordability within clean cooking speak to its nuances and its place-specific nature. Despite these nuances, diverse geographical locations, and varying fuels covered in this review, several common definitions, metrics, and themes did emerge. The literature contains numerous proxy measurements to quantify a seemingly intuitive concept; however, these results also reveal that a price, a ratio, or a metric alone cannot tell us if clean fuel or stove is or is not affordable. Metrics are one piece of a larger puzzle; other aspects to consider are household spending patterns overall (as opposed to total expenses), the components of cost (upfront and recurring) within affordability, and intra-household power relations.

3.3. Disaggregating affordability: Spending patterns and components of cost

The most commonly cited component of affordability of clean cooking is the upfront cost of the stove, which was universally discussed in papers on LPG stoves, more efficient charcoal stoves, biomass gasifiers, biogas, and induction stoves (Fig. 3, Panel D). LPG requires the cylinder, the regulator, the pipe, and finally the stove; biogas requires the generating plant; and induction stoves require a connection to an electric grid or to household solar power [128,129]. Although improved charcoal stoves are cheaper than LPG, biogas, or induction, even these seemingly more affordable stoves face barriers to adoption. The prohibitively high upfront cost was noted for all stove types and in multiple study locations in Latin America, Africa, and Asia [20,31–33,53,75,95,98,129,130]. This barrier was mentioned even in contexts where the initial cost is partially subsidized. For instance, a government subsidy in China covers a third of the upfront cost of a biogas plant, yet the remaining upfront cost is still a barrier [131]. The same is true for Peru's and Côte d'Ivoire's subsidies for LPG stoves [132,133]. India's PMUY policy offers the initial connection (hose & regulator) for free to BPL households. However, the households remain responsible for purchasing the stove and initial cylinder, with a loan if needed, which is a barrier [134]. LPG stoves and biogas plants (biodigesters) are often critiqued for their high prices; however, the overall literature suggests that affordability is a challenge regardless of stove type [135].

Liquidity constraints are often the major challenge for households to afford the stove. Some studies mentioned that highly variable cash incomes make the stove's purchase price unreachable. Poor households have little to no access to credit, which forces them to save in advance (which is difficult) or reduce consumption of other necessities (which is also difficult). This aspect was routinely mentioned for LPG, biogas, and improved biomass stoves [15,74,75,136,137]. These discussions imply that affordability cannot be captured as a monthly concept; at the lowest-income levels, it is a day-to-day struggle.

Several studies discuss (un)affordability under variable and uncertain cash flows, suggesting that financial institutions or governments provide financing schemes to spread out the upfront cost. Studies and reports have suggested microloans [122,138,139] for LPG stoves as well as payment in monthly installments [31,33,122,140,141]. These steps also require upfront cash, albeit less than full cost, at around 7–8 USD when subsidized [31,78]. The Clean Cookstove Alliance notes that microfinance institutions have increasingly served as commercial distributors in an effort to accommodate variable cash flows [142]. Spreading out the LPG refill cost is also being considered [17,134,143]. Nonetheless, many households clearly struggle to afford the refill, and many staggered payment plans could still be unaffordable.

Discussions of affordability note the potential for households to save money on recurring fuel costs. Some improved biomass stoves require less fuel, allowing households to recoup the stove cost within a short payback period. Improved biomass stoves have lower recurring fuel costs than traditional stoves, as most use the same or less biomass. Therefore, studies from Africa and Asia justify the higher upfront cost by household savings on weekly fuel costs, and, after the payback period, savings on cooking expenditure overall [56,68,119]. However, these studies do not account for the very short time horizons over which poor households have to make financial decisions [144,145]. They also do not pertain to rural households that collect firewood for free [146]. The use of biogas for cooking could lead to money saved in recurring fuel cost because the necessary input to serve a household is the waste of 3–4 cows or pigs, assuming that the households have animals already [58,84,102,104]. Additionally, one study noted that households may save on fertilizer (i.e., the household can use the slurry to fertilize their fields) [84]. However, others caution against these hypothetical savings with biogas as the households may have to invest in new appliances or purchase water to maintain moisture in the manure [122,128]. Furthermore, households may value on-hand liquidity (forgoing the upfront cost of a more efficient stove) rather than future savings on recurring fuel costs even if the latter is less expensive in aggregate [93,119,144].

The Clean Cooking Alliance explicitly separates affordability into two categories, dubbed "*tool and fuel*" [142] (pg. 3). Reports note that households are often unable to pay for either the more expensive fuels and the stove e.g. Refs. [31,64,81,109,142]. The need to address both types of affordability is evident in recent studies on India's PMUY policy [143]. India's 2019 LPG sales data revealed that removing the capital cost does not result in more refills [34]. Other PMUY evaluations noted that, even with the capital cost subsidy and an LPG refill subsidy, households remained vulnerable to drop out [17,134]. An evaluation of PMUY in six states found that households given the free connection consumed less LPG than non-PMUY households, even when controlling for socio economic status and age of connection [116]. Beyond India, Ghana's national LPG program gave out the stove and cylinder for free, while Peru's national voucher program subsidized LPG fuel costs; however, households struggled to refill in both programs [147,148]. This situation is not unique to LPG; an evaluation of a biomass pellet company in Rwanda found that the recurring cost of processing firewood into pellets was "*stressful and limiting*" [13] (pg. 38). The only studies without recurring fuel cost as a barrier were those that provided an improved biomass stove for free, because the inputs remained equal to or less than the previous situation [149,150] (Fig. 3, Panel D).

The literature also examines the timing of fuel purchases, patterns of consumption, and the procurement of small quantities of modern fuels to match purchases with households' cash flows. The advocacy for smaller quantities was almost as frequently referenced as the total cost of the stove and fuel (Fig. 3, Panel D). This method differs from microfinance schemes by altering the supply chain rather than the household's finances. Studies in Kenya, India, and Pakistan discuss the daily (or even meal by meal) procurement of traditional fuels in small quantities, compared to the monthly paid-up costs for LPG or kerosene [31,91,93,151]. Studies from Ghana, Kenya, India, and Sri Lanka all mentioned that smaller units of fuels for sale would be more affordable [59,81,115,152,153]. These discussions particularly focused on providing smaller LPG cylinder refills of 5 kg or even 1 kg compared to the typical 14.2 kg cylinder [152,153]. Reports noted that firewood and charcoal could be bought in very small quantities [118,151]. However, a gasifier study in Kenya found high rates of daily fuel consumption with Pay-as-you-cook (PAYC) model (also called pay-as-you-go, (PAYG)), which allows households to buy fuel incrementally at their discretion [99]. This new technology adjusts the stove to the household's behavior rather than force the household to adopt different, arguably impossible, consumption habits [99]. Within the campaign for smaller quantities, scholars have argued that this may lead to the poor paying higher per unit prices for energy [94,154]. The smaller quantities are more "affordable" in the short run, but not necessarily in the long run, because smaller quantities are cheaper per purchase but buying in bulk is less expensive overall. This nuance reveals the tradeoffs embedded in making affordable cooking more available.

A final aspect of affordability is related to the time it takes to cook a specific food with a specific fuel. In Mexico, households reported that cooking tortillas on the LPG stove is time-consuming, and therefore using LPG for that specific food is not economic [20]. Another study in Guatemala found that corn is cooked twice for corn flour, so households claimed that cooking corn is only affordable with wood [137]. Thus, BLEEN stoves, once adopted, may continue to be stacked if staple foods are inconvenient or "too" expensive to cook with purchased fuels, in spite of policies that strive to mitigate affordability challenges.

4. Discussion

In summary, this review found that although there are many commonly cited definitions, metrics, and cost components to define clean cooking affordability, none appears dominant. Broad energy use frameworks do not provide guidance for cooking energy specifically, which leaves researchers and practitioners to develop their own definitions. The numerous metrics currently in use prevent researchers from comparing clean cooking options or defining a common language around affordability. On the other hand, the variation in the research mirrors the complexity of affordability with respect to incomes, cash flows, other essential consumption, fixed and operating costs, alternative options, and individual perceptions of what is affordable. Our key policy-relevant finding is that there is a frequent mismatch between how low-income households earn, save and spend, and how cleaner stoves and fuels have to be purchased. Low-income households often earn day by day and may procure fuel day by day, or even meal by meal; cleaner fuels often must be purchased in larger quantities. The clean cooking affordability frameworks, definitions, metrics, and discussions, in general, do not adequately reflect how spending habits could affect affordability at different time scales. We interpret these results and offer policy recommendations below.

4.1. Interpretation of results

We now turn to areas that we wish to understand better to converge to a more common understanding of clean cooking affordability, and to monitor progress on SDG 7. We discuss the implications of different payment schemes and offering smaller quantities of fuel for purchase, and the need for affordability metrics to reflect spending patterns, stacking behaviors, and intra-household dynamics.

The lack of comparable metrics across stove and fuel types that reflect the household's fuel consumption patterns makes it challenging to design (and administer) affordable cooking programs. Metrics of price per kg of fuel, per unit energy, or per month mean little to households trying to make it through the week or even day. The literature suggests that PAYG, PAYC, and microfinance schemes for fuel refilling may be effective ways to address the day-to-day reality of variable household incomes. However, microfinance schemes in their current form rarely resolve affordability challenges [62,141] and innovative PAYG and PAYC programs need further evaluation [99]. We conclude that the clean(er) cooking literatures should prioritize metrics and measurement of affordability that reflect the shorter time spans on which household income streams operate.

Studies often suggest that the fixed cost of the stove should be amortized over months; however, the struggle to refill subsidized LPG at monthly intervals reveals that even monthly payments are often too large for poor households to plan for. *Portfolios of the Poor* [144] refers to the "Triple Whammy" of low-incomes, irregular and unpredictable cash flows, and lack of financial tools, all of which make it difficult to save for future lump sums, even on a monthly basis. Smaller cylinders or smaller procurements of LPG are promising but could end up costing the household more in the long run. Affordability metrics and discussions should take into account these short-run and long-run tradeoffs and their implications for household finances. The household itself may think of these tradeoffs as acceptable, because their planning is dominated by the management of current cash flows, but policy makers should take these into account as they evaluate metrics of affordability (and equity).

Metrics for affordability should reflect the spending habits of low-income households if cost comparisons are to be used to induce behavior changes towards BLEEN fuels. Cost per household member or per meal may be more useful information for households when comparing stoves or fuels [81,89,90,100]. However, these metrics do not capture how often, or how large, a lump sum is necessary to purchase these fuels. The levelized cost, NPV or life-cycle costs of the stove and fuels [50,70,74,120,121] are helpful for governments investing in solutions, but poor households are rarely planning for a five-year stove lifetime. Households dealing with small and uncertain incomes may not actively consider the discount rate for durable purchases, but they fully understand their current spending priorities. In effect, higher discount values should be incorporated into the definition of affordability for low-income households, given the uncertainty of the households' income streams. NPV is also relevant as the end of life scrap value; low-income households often look to sell off any asset in difficult times [144,155]. Overall, affordability metrics and definitions must more accurately reflect patterns of consumption that are driven by uncertain and irregular incomes, acknowledging that purchasing modern fuels often do not match poor households' liquidity constraints, spending patterns, near-term economic considerations, or perceptions of what is affordable.

4.2. Policy recommendations

Based on our review, we advocate for an expanded affordability framework and for financing schemes that mirror the day-to-day realities of the poor, and we advocate for an expanded affordability framework that acknowledges socioeconomic stratification, gender, and the rural urban divide.

The conclusions of our review imply that current microfinance programs should be adjusted to alleviate affordability problems. These programs focus on the upfront costs, most often providing microloans for the stove set up or offering timed payment plans in an effort to increase the affordability of the stove set up (e.g., ESMAP with the Modern Energy Cooking Services outlines this as a key strategy to make electric cooking affordable [156,157]). However, many households, although not all, suffer from the "Triple Whammy" [144]; they may receive seasonal incomes [155], and procure fuel day by day. Low, unpredictable, and irregular incomes, and the lack of financial tools suggest that microfinance should be re-designed towards day-to-day affordability (i.e. daily or weekly payments), potentially for the upfront cost and the monthly recurring cost. Micro-saving programs may actually be a more effective means to accommodate household spending patterns for either the upfront or recurring cost. These could be voluntary or committed programs that provide dedicated accounts at more realistic intervals that match households' current spending. Poor households do save, although it is difficult, and loans could still be beneficial. Future research could fruitfully investigate integrated products of loans and savings to address both components.

Although the Energy Ladder is used as an (imperfect) affordability ladder, households do not abandon a type of fuel as income increases [20]. Affordability metrics often single out specific fuels, when, in reality, a poor household rarely uses only one fuel. Stacking may be less economic as the less efficient fuels can be purchased on a day-to-day basis but cost more per unit energy, increasing a household's daily costs [14]. Multiple fuel users have been found to spend more—even double—compared to firewood-only users [20], while other firewood users may only collect (i.e. have no financial costs) [146]. Stacking remains a persistent phenomenon. Therefore, we advocate for metrics of affordability that reflect the entirety of the household's cooking fuel use, rather than their primary one, and for conceptualizing affordability beyond the (theoretically) lowest-cost option.

The prevalent forms of stratification for socioeconomic status are also inadequate for understanding affordability disparities. Characteristics such as income, education, household size, or employment status, do not necessarily make modern fuels more affordable as they do not reveal any other factors about the household's financial situation. The evidence against linear fuel switching has shown that income or wealth are not proxy metrics for affordability, as we have only a partial understanding of how ability to pay changes stacking behaviors. Income or wealth indices reveal that households may have the option to stack, but do not accurately predict fuel use.

Gender is a complicating factor for affordability metrics when households are the unit of analysis, which they most often are. Some researchers, NGOs, and governments advocate for subsidies to be targeted to vulnerable groups, such as those with female heads of households [49,158,159]. For example, PMUY targets women through its reimbursement process, which is a direct transfer to a female member's bank account within a BPL household. But targeting may not be enough; a mixed method study in India found that women are not the primary beneficiaries of access to electricity, even when appliances are affordable [160]. Although we address cooking energy and not electricity, the same possibility should be considered in analyses of what is affordable or what "the household" is able to pay. In reality, the woman, even if she is the primary cook, may be unable to exercise her ability to pay even if she has a bank account in her name, and even if the stove and fuel are affordable by the metric in use. We therefore advocate for a gender-disaggregated model of the household [161] in which members have diverse views on what is affordable with respect to stoves or fuels, and in which the final decisions to purchase and to refill are made jointly (though not necessarily equally).

Gender differences compound rural-urban differences to increase the perception of unaffordability for modern fuels. The biggest affordability concern with respect to rural households is the competing availability of free or very cheap biomass. Unclean fuels are "*ancient and traditional, [and] are essentially free*" [146] (pg. 2); this is a significant deterrent of exclusive LPG or other BLEEN use [116]. As discussed, there is a large body of literature that compares affordability metrics across traditional and modern fuels. However, a definition of affordability as cheaper than alternatives is not useful when faced with free collection, as households may not "count" the labor costs associated with the collection. In particular, the labor of women or children may be given an implicit value of zero [162]. Households sometimes express surprise when asked to assess the social costs associated with collected firewood and charcoal [163]. Gender disparities mean that the burden of unaffordability, and possibly the very understanding of affordability of clean fuels, is disproportionately borne within the household.

In general, under a definition that equates affordability with being cheaper than current alternatives, the only truly affordable cooking fuel would have to be free, at least in rural areas. Like other health interventions (condoms, bed nets, etc.), policy makers must find ways to incentivize the continued use of the product, not simply give it out and assume use [66]. Clean cooking fuel is a crucial health intervention [164] and an understanding of stove and fuel affordability, grounded in household financial realities, could lead to more effective avenues to incentivize the transition.

An approach to affordability that does not consider food, rent, or other non-discretionary expenses because of the desire to establish a general threshold, is at best partial. When cooking fuel is unaffordable, households have to make difficult decisions between other essentials and cooking fuel [165]. In this context, Fig. 2 reveals the disconnect between the location of the case studies and the authors of these evaluations. Northern researchers are often trained to look for "generalizable" results, but the study residents are dealing with a host of financial pressures to obtain many essential services—only one of which is cooking. Thus, the meaning of "affordable" can never be completely free of its place-based characteristics and constraints.

The field of clean cooking could learn from the extensive literature on affordability in other sectors such as water [25,35,166], electricity [25], and housing [167]. These literatures often critique generalizable thresholds for affordability and have developed approaches that consider affordability within the context of a minimum "basic needs" consumption level and a minimum budget [35,166]. Comparisons to other affordability literatures could act as reality checks to the conversation in clean cooking, but we recognize that generalizing across sectors is also problematic. Fundamental differences arise in e.g., calculating a basic-needs basket of energy [168] vs. basic-needs volumes of domestic water [35]).

It would be useful to have a comprehensive framework for affordability of clean cooking that would serve as a guide, rather than as a blueprint, for clean cooking programs and research. Without a set of principles underpinning the concept of affordability, interventions may continue to promote self-identified "affordable" cooking fuels. ESMAP and India's CEEW provide the first steps towards a guiding framework but could be built on in the under-researched areas we have uncovered. An expanded framework could differentiate affordability criteria for (1) female-led households, (2) multi-gender households with differential bargaining powers, (3) rural versus urban communities with different default options, (4) different essential expenses regimes (e.g. where schools are free versus where all schools are private), and (5) different time scales of affordability (e.g., daily or weekly affordability ratios, rather than the typical monthly time frame) – all the while taking into account stacking behavior, which seems likely to continue. A comprehensive framework that acknowledges these significant differences could be more informative, and so hold institutions, policymakers and researchers more accountable in their work on clean and affordable energy for all. By construction, therefore, such a framework cannot lead to "generalizable" ratios and thresholds.

5. Conclusion

This review finds that affordability metrics for clean cooking should be reimagined to reflect the uncertain and irregular nature of low-income households' income streams, the persistence of fuel stacking, and non-discretionary expenses such as food and water. Our results reveal scattered, and sometimes over-simplified, conceptualizations of affordability that do not reflect actual fuel procurement patterns, actual income patterns, or persistent stacking habits. Components of affordability remain unevenly grounded in the spending patterns of the poor. Affordability in practice is variable, as are the low, irregular, and unpredictable incomes of the poor. Incorporating the day-to-day realities of households and their ability to pay for modern fuels in affordability metrics is challenging, but necessary, to encourage universal adoption and sustained use.

We find that clean cooking affordability should neither be equated solely with income or socio-economic characteristics, nor simplified to a cost comparison of alternative fuels. Gender divides, rural/urban divides, and households' perceptions of what is affordable are important aspects of clean cooking affordability. Microfinance strategies should be expanded to address not only loans for the stove, but also savings or savings-and-loan combinations for fuel refills and the upfront cost. This expanded microfinance programming would allow for the procurement of fuels in small quantities (i.e., daily or weekly saving schemes or payment schedules), matching the way that poor households tend to earn. Microsaving schemes may be more useful than microcredit alone to encourage consistent use of clean fuels. Finally, affordability frameworks should not pursue universal thresholds if it compromises authentically addressing the financial struggles within the kitchen. This reality must be acknowledged when developing SDG 7-compatible financing strategies that reflect the lived experiences of the poor.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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This paper is dedicated to Dr. Kirk Smith whose life's work was instrumental in creating the field of indoor air quality, cooking fuels, and health impacts. We honor his enormous intellectual contributions as well as his abiding concern for the poorest households. Dr. Smith passed away on June 15, 2020.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rser.2021.111537.

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References

[1] IEA, IRENA, UNSD, WB, WHO. Tracking SDG 7: the energy progress report 2019. 2019. Washington DC.

[2] Bailis R, Ezzati M, Kammen DM. Mortality and greenhouse gas impacts of biomass and petroleum energy futures in Africa. Science 2005;308:98–103. 80-.

[3] World Health Organization. Burden of disease from household air pollution for 2016: summary of results. 2018. Geneva.
[4] Clean Cooking Alliance. Women and Gender n.d. https://www.cleancookingalliance.org/impact-areas/women/index.html.
[5] World Health Organization. Burning opportunity: clean household energy for health, sustainable development, and wellbeing of women and children. 2016. Geneva.
[6] Clean Cooking Alliance. Climate, environment, and clean cooking. 2019.
[7] Bond TC, Doherty SJ, Fahey DW, Forster PM, Berntsen T, Deangelo BJ, et al. Bounding the role of black carbon in the climate system: a scientific assessment. J Geophys Res Atmos 2013;118:5380–552. https://doi.org/10.1002/jgrd.50171.
[8] Ezzati M, Mbinda BM, Kammen DM. Comparison of emissions and residential exposure from traditional and improved cookstoves in Kenya. Environ Sci Technol 2000;34:578–83. https://doi.org/10.1021/es9905795.
[9] Bailis R, Ezzati M, Kammen D. Greenhouse gas implications of household energy technology in Kenya. Environ Sci Technol 2003;37:2051–9. https://doi.org/10.1021/es026058q.
[10] Maccarty N, Ogle D, Still D, Bond T, Roden C, Willson B. Laboratory comparison of the global-warming potential of six categories of biomass cooking stoves. 2007.
[11] Garland C, Delapena S, Prasad R, L'Orange C, Alexander D, Johnson M. Black carbon cookstove emissions: a field assessment of 19 stove/fuel combinations. Atmos Environ 2017;169:140–9. https://doi.org/10.1016/j.atmosenv.2017.08.040.
[12] Champion WM, Grieshop AP. Pellet-fed gasifier stoves approach gas-stove like performance during in-home use in Rwanda. Environ Sci Technol 2019;53:6570–9. https://doi.org/10.1021/acs.est.9b00009.
[13] Jagger P, Das I. Implementation and scale-up of a biomass pellet and improved cookstove enterprise in Rwanda. Energy Sustain Dev 2018;46:32–41.
[14] Angelou N, Bhatia M. Beyond connections: energy access redefined. 2015. Washington DC.
[15] Heltberg R. Factors determining household fuel choice in Guatemala. Environ Dev Econ 2005;10:337–61. https://doi.org/DOI: 10.1017/S1355770X04001858.
[16] Deshmukh S, Jinturkar A, Anwar K. Determinants of household fuel choice behavior in rural Maharashtra, India. Int Proc Chem Biol Environ Eng 2014;64:128–33.
[17] Gould CF, Urpelainen J. LPG as a clean cooking fuel: adoption, use, and impact in rural India. Energy Pol 2018;122:395–408. https://doi.org/10.1016/j.enpol.2018.07.042.
[18] Ahmad S, Puppim De Oliveira JA. Fuel switching in slum and non-slum households in urban India. J Clean Prod 2015;94:130–6. https://doi.org/10.1016/j.jclepro.2015.01.072.
[19] Shafer M. Stupid stoves: why rebranding won't solve the clean cooking alliance's problems. Next billion 2019. https://nextbillion.net/stupid-stoves-clean-cooking-alliance-problems/. [Accessed 30 July 2020].
[20] Masera OR, Saatkamp BD, Kammen DM. From linear fuel switching to multiple cooking strategies: a critique and alternative to the energy ladder model28. Pergamon; 2000. https://doi.org/10.1016/S0305-750X(00)00076-0.
[21] Ezzati M, Kammen D. Indoor air pollution from biomass combustion and acute respiratory infections in Kenya: an exposure-response study. Lancet (London, England) 2001;358:619–24. https://doi.org/10.1016/s0140-6736(01)05777-4.
[22] Johnson MA, Chiang RA. Quantitative guidance for stove usage and performance to achieve health and environmental targets. Environ Health Perspect 2015;123:820–6. https://doi.org/10.1289/ehp.1408681.
[23] Furszyfer Del Rio DD, Lambe F, Roe J, Matin N, Makuch KE, Osborne M. Do we need better behaved cooks? Reviewing behavioural change strategies for improving the sustainability and effectiveness of cookstove programs. Energy Res Soc Sci 2020;101788:70. https://doi.org/https://doi.org/10.1016/j.erss.2020.101788.
[24] Bartl M. The affordability of energy: how much protection for the vulnerable consumers? J Consum Pol 2010;33:225–45. https://doi.org/10.1007/s10603-009-9122-9.
[25] Fankhauser S, Tepic S. Can poor consumers pay for energy and water? An affordability analysis for transition countries. Energy Pol 2007;35:1038–49. https://doi.org/10.1016/j.enpol.2006.02.003.
[26] Healy JD, Clinch JP. Quantifying the severity of fuel poverty, its relationship with poor housing and reasons for non-investment in energy-saving measures in Ireland. Energy Pol 2004;32:207–20. https://doi.org/10.1016/S0301-4215(02)00265-3.
[27] Foster V, Tre J-P, Wodon Q, Bank W. Energy prices, energy efficiency, and fuel poverty 1. 2000.
[28] Tennakoon D. Energy poverty: estimating the level of energy poverty in Sri Lanka. 2008.
[29] Nussbaumer P, Bazilian M, Modi V. Measuring energy poverty: focusing on what matters. Renew Sustain Energy Rev 2012;16:231–43. https://doi.org/https://doi.org/10.1016/j.rser.2011.07.150.
[30] Hills J. Getting the measure of fuel poverty: final report of the fuel poverty review. n.d.
[31] Singh R, Wang X, Ackom E. Energy access realities in urban poor communities of developing countries: assessments and reccomendations. 2015.
[32] Bounds M. Ethanol as a household fuel in Madagascar. Warwickshire 2012.
[33] Global Alliance for Clean Cooking. Igniting change: a strategy for universal adoption of clean cookstoves and fuels. 2011.
[34] Kar A, Pachauri S, Bailis R, Zerriffi H. Using sales data to assess cooking gas adoption and the impact of India's Ujjwala programme in rural Karnataka. Nat Energy 2019;4:806–14. https://doi.org/10.1038/s41560-019-0429-8.
[35] Gawel E, Sigel K, Bretschneider W. Affordability of water supply in Mongolia: empirical lessons for measuring affordability. Water Pol 2013;15:19–42. https://doi.org/10.2166/wp.2012.192.
[36] Moher D, Liberati A, Tetzlaff J, Altman DG, Group TP. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 2009;6. e1000097.
[37] Boardman B. Fuel poverty: from cold homes to affordable warmth. London: Belhaven Press; 1991.
[38] Bhanot J, Jha V. Moving towards tangible decision-making tools for policy makers: measuring and monitoring energy access provision. Energy Policy 2012;47:64–70. https://doi.org/https://doi.org/10.1016/j.enpol.2012.03.039.
[39] Akande SO, Sanusi A, Mohammed N. Determinant of energy poverty in rafi local government area of Niger state. Nigeria 2018.
[40] Khandker SR, Barnes DF, Samad HA. Are the energy poor also income poor? Evidence from India. Energy Pol 2012;47:1–12. https://doi.org/https://doi.org/10.1016/j.enpol.2012.02.028.
[41] Phoumin H, Kimura F. Cambodia's energy poverty and its effects on social wellbeing: empirical evidence and policy implications. Energy Pol 2019;132:283–9. https://doi.org/https://doi.org/10.1016/j.enpol.2019.05.032.
[42] Zhang D, Li J, Han P. A multidimensional measure of energy poverty in China and its impacts on health: an empirical study based on the China family panel studies. Energy Pol 2019;131:72–81. https://doi.org/https://doi.org/10.1016/j.enpol.2019.04.037.
[43] Nathan HSK, Hari L. Towards a new approach in measuring energy poverty: household level analysis of urban India. Energy Pol 2020;111397:140. https://doi.org/https://doi.org/10.1016/j.enpol.2020.111397.
[44] Maliti E, Mnenwa R. Affordability and expenditure patterns for electricity and kerosene in urban households in Tanzania. n.d.
[45] McInnes G. Understanding the distributional and household effects of the low-carbon transition in G20 countries. 2017.
[46] Moses T. Multidimensional energy poverty in Nigeria: a national and zonal level analysis. Br J Adv Acad Res 2014;3:83–92.
[47] Crentsil AO, Asuman D, Fenny AP. Assessing the determinants and drivers of multidimensional energy poverty in Ghana. Energy Pol 2019;133:110884.
[48] Villalobos Barría C. Energy poverty measures and the identification of the energy poor: A comparison between the utilitarian and multidimensional approaches in Chile Empiric Analysis of Determinants, Trends and Composition of Monetary and Non-Monetary Welfare Distributions View project n.d. https://doi.org/10.13140/RG.2.2.34219.39203.
[49] Ramana Putti V, Tsan M, Mehta S, Kammila S. The state of the global clean and improved cooking sector. 2015. Washington D.C.
[50] Jain A, Choudhury P, Ganesan K. Clean, affordable and sustainable cooking energy for India possibilities and realities beyond LPG. New Delhi: CEEW Report; 2015.
[51] Jain A, Agrawal S, Ganesan K. Rationalising subsidies, reaching the underserved improving effectiveness of domestic LPG subsidy and distribution in India. 2014.
[52] Smith K. The biofuel transition. Pac Asian J Energy 1987:13–32.
[53] Butera FM, Caputo P, Adhikari R, Facchini A. Analysis of energy consumption and energy efficiency in informal settlements of developing countries: the Challenge of Energy in Informal Settlements. Rev Literat Latin Am Afr. [n.d].
[54] Mangula MS, Kuzilwa JA, Msanjila SS, Legonda I. Indicators of energy access in rural areas of Tanzania: an application of confirmatory factor analysis approach. Indepen J Manag Prod 2018;9:1068–78. https://doi.org/10.14807/ijmp.v9i4.797.
[55] McDonald DA. The bell tolls for thee: cost recovery, cutoffs, and the affordability of municipal services in South Africa. 2002.
[56] Nguyen TTPT. Women's adoption of improved cook stoves in Timor-Leste: challenges and opportunities. Dev Pract 2017;27:1126–32. https://doi.org/10.1080/09614524.2017.1363160.
[57] Adebisi SA, Johnson FO. Predictors of clean cookstoves adoption by households in lagos state. Nigeria 2019;7.
[58] Karanja A, Gasparatos A. Adoption and impacts of clean bioenergy cookstoves in Kenya. Renew Sustain Energy Rev 2019;102:285–306. https://doi.org/https://doi.org/10.1016/j.rser.2018.12.006.
[59] Benbekhaled, Nancy Coop, MI, Koffi Ekouevi, UI, World Bank mehdi El Guerchi TI. Why women in the developing world want LPG and how they can get it. [n.d].
[60] Takama T, Tsephel S, Johnson FX. Evaluating the relative strength of product-specific factors in fuel switching and stove choice decisions in Ethiopia. A discrete choice model of household preferences for clean cooking alternatives. Energy Econ 2012;34:1763–73. https://doi.org/10.1016/j.eneco.2012.07.001.
[61] Menghwani V, Zerriffi H, Dwivedi P, Marshall JD, Grieshop A, Bailis R. Determinants of cookstoves and fuel choice among rural households in India. EcoHealth 2019;16:21–60. https://doi.org/10.1007/s10393-018-1389-3 LK - https://ucelinks.cdlib.org/sfx_local?sid=EMBASE&sid=EMBASE&issn=16129210&id=doi:10.1007%2Fs10393-018-1389-3&atitle=Determinants+of+Cookstoves+and+Fuel+Choice+Among+Rural+Households+in+India&stitle=Ecohealth&title=EcoHealth&volume=16&issue=1&spage=21&epage=60&aulast=Menghwani&aufirst=Vikas&auinit=V.&aufull=Menghwani+V.&coden=&isbn=&pages=21-60&date=2019&auinit1=V&auinitm=.
[62] Envirofit. Cooking in one million kitchens: lessons learned in scaling a clean cookstove business. 2015.
[63] Puzzolo E. Cooking with ethanol: a stakeholders' perspective. 2014.
[64] Clean and improved CookIng in sub-saharan Africa: a landscape report Africa renewable energy access program (AFREA). 2014. Washington D.C.

[65] Budds J, Biran A. What's cooking? A review of the health impacts of indoor air pollution and technical interventions for its reduction. 2001.
[66] Smith KR. What's cooking? A brief update. Energy Sustain Dev 2010;14:251–2.
[67] Sovacool BK, Drupady IM. Summoning earth and fire: the energy development implications of Grameen Shakti (GS) in Bangladesh. Energy 2011;36:4445–59. https://doi.org/https://doi.org/10.1016/j.energy.2011.03.077.
[68] Kammen DM. Cookstoves for the developing world. Sci Am 1995;273:72–5. https://doi.org/10.1038/scientificamerican0795-72.
[69] Rai K, McDonald J Cookstoves. Markets: experiences, successes and opportunities. 2009.
[70] Jolomi N. Model for marketing LPG in Nigeria (Warri as a case study). North-West University; 2008.
[71] Toman M, Bluffstone R. Challenges in assessing the costs of household cooking energy in lower-income countries. 2017.
[72] Mann PAG. Achieving a mass-scale transition to clean cooking in India to improve public health. UK: Oxford University; 2012.
[73] Improved cookstoves and better health in Bangladesh. 2010. Washington D.C.
[74] Ekholm T, Krey V, Pachauri S, Riahi K. Determinants of household energy consumption in India. Energy Pol 2010;38:5696–707. https://doi.org/10.1016/J.ENPOL.2010.05.017.
[75] Beyene GE, Kumie A, Edwards R, Troncoso K. Opportunities for transition to clean household energy in Ethiopia application of the WHO household energy assessment Rapid tool (HEART). n.d.
[76] Reddy BS. Access to modern energy services: an economic and policy framework. Renew Sustain Energy Rev 2015;47:198–212. https://doi.org/10.1016/J.RSER.2015.03.058.
[77] Andadari RK, Mulder P, Rietveld P. Energy poverty reduction by fuel switching. Impact evaluation of the LPG conversion program in Indonesia. Energy Pol 2014; 66:436–49. https://doi.org/https://doi.org/10.1016/j.enpol.2013.11.021.
[78] Nexant ILPG. Market assessment study for Mozambique. 2005.
[79] Tait L. Towards a multidimensional framework for measuring household energy access: application to South Africa. Energy Sustain Dev 2017;38:1–9. https://doi.org/https://doi.org/10.1016/j.esd.2017.01.007.
[80] Pachauri S, Spreng D. Measuring and monitoring energy poverty. Energy Pol 2011;39:7497–504. https://doi.org/10.1016/J.ENPOL.2011.07.008.
[81] Kebede B, Bekele A, Kedir E. Can the urban poor afford modern energy? The case of Ethiopia 2002;30.
[82] Jiang L, Yu L, Xue B, Chen X, Mi Z. Who is energy poor? Evidence from the least developed regions in China. Energy Pol 2020;137:111122.
[83] Dlamini L. The perception of clean cookstove technologies in rural Swaziland. University of Witwatersrand, [n.d].
[84] Rosyidi SAP, Bole-Rentel T, Lesmana SB, Ikhsan J. Lessons learnt from the energy needs assessment carried out for the biogas program for rural development in yogyakarta, Indonesia. Procedia Environ Sci 2014;20:20–9. https://doi.org/https://doi.org/10.1016/j.proenv.2014.03.005.
[85] Retired Professor Alois Sanga G, Jannuzzi M, Johansson T, Reddy KN, Goldemberg J, Williams R, et al. Impacts of efficient stoves and cooking fuel substitution in family expenditures of urban households in Dar es Salaam, Tanzania IEI Board of Directors. 2005.
[86] Kohler M, Rhodes B, Vermaak C. Developing an energy-based poverty line for South Africa. n.d.
[87] Jain G. Energy security issues at household level in India. https://doi.org/10.1016/j.enpol.2010.01.016; 2010. 38, 2835, 2845.
[88] van den Berg IC. Kenya's Strategy to Make LPG the Nation's primary fuel. 2018.
[89] Wang B, Li H-N, Yuan X-C, Sun Z-M. Energy poverty in China: a dynamic analysis based on a hybrid panel DataDecision model. ENERGIES 2017;10. https://doi.org/10.3390/en10121942.
[90] Viswanathan B, Kumar KSK. Cooking fuel use patterns in India: 1983-2000. Energy Pol 2005;33:1021–36. https://doi.org/10.1016/j.enpol.2003.11.002.
[91] Osano A, Maghanga J, Munyeza CF, Chaka B, Olal W, Forbes PBCC. Insights into household fuel use in Kenyan communities. Sustain Cities Soc 2020;55:102039.
[92] Benka-Coker ML, Tadele W, Milano A, Getaneh D, Stokes H. A case study of the ethanol Clean Cook stove intervention and potential scale-up in Ethiopia. Energy Sustain Dev 2018;46:53–64. https://doi.org/https://doi.org/10.1016/j.esd.2018.06.009.
[93] Dhingra C, Gandhi S, Chaurey A, Agarwal PK. Access to clean energy services for the urban and peri-urban poor: a case-study of Delhi, India. Energy Sustain Dev 2008;12:49–55. https://doi.org/https://doi.org/10.1016/S0973-0826(09)60007-7.
[94] Mudombi S, Nyambane A, von Maltitz GP, Gasparatos A, Johnson FX, Chenene Manuel L, Attanassov B, et al. User perceptions about the adoption and use of ethanol fuel and cookstoves in Maputo, Mozambique. ENERGY Sustain Dev 2018; 44:97–108. https://doi.org/10.1016/j.esd.2018.03.004.
[95] Dagnachew A, Lucas P, van Vuuren D, Hof A. Towards universal access to clean cooking solutions in sub-saharan Africa. 2018.
[96] Vaccari M, Vitali F, Tudor T. Multi-criteria assessment of the appropriateness of a cooking technology: a case study of the Logone Valley. Energy Pol 2017;109: 66–75. https://doi.org/https://doi.org/10.1016/j.enpol.2017.06.052.
[97] Lucon O, Coelho ST, Goldemberg J. LPG in Brazil: lessons and challenges. Energy Sustain Dev 2004;8:82–90. https://doi.org/https://doi.org/10.1016/S0973-0826(08)60470-6.
[98] Scott N, Candia H, Agbelie I, McCall B. Transitioning to modern energy for cooking. n.d.
[99] Bailis R, Ghosh E, O'Connor M, Kwamboka E, Ran Y, Lambe F. Enhancing clean cooking options in peri-urban Kenya: a pilot study of advanced gasifier stove adoption. Environ Res Lett 2020;15. https://doi.org/10.1088/1748-9326/ab865a.
[100] Smith KR, Sagar A. Making the clean available: Escaping India's chulha trap. Energy Pol 2014;75:410–4. https://doi.org/10.1016/j.enpol.2014.09.024.
[101] Ozuru H, Akahome J. Social Marketing: concept and energy poverty eradication: an evidence from Nigeria. Cape Town Int Conf Bus Manag Dyn 2016;2016:54–61. https://doi.org/https://doi.org/10.4102/aosis.2016.icbmd10.07.
[102] Mottaleb KA, Rahut DB. Biogas adoption and elucidating its impacts in India: implications for policy. Biomass Bioenergy 2019;123:166–74.
[103] Hakizimana J, de DK, Kim H-T. Peat briquette as an alternative to cooking fuel: a techno-economic viability assessment in Rwanda. Energy 2016;102:453–64. https://doi.org/https://doi.org/10.1016/j.energy.2016.02.073.
[104] Hamid RG, Blanchard RE. An assessment of biogas as a domestic energy source in rural Kenya: developing a sustainable business model. Renew Energy 2018;121: 368–76. https://doi.org/https://doi.org/10.1016/j.renene.2018.01.032.
[105] Demierre J, Bazilian M, Carbajal J, Sherpa S, Modi V. Potential for regional use of East Africa's natural gas. Appl Energy 2015;143:414–36. https://doi.org/10.1016/J.APENERGY.2015.01.012.
[106] Van Leeuwen R, Evans A, Hyseni B. Increasing the use of liquefied petroleum gas in cooking in developing countries. 2017. Washington, DC.
[107] Grové J. Energy transitions in developing countries and the role of alternative liquid fuels in reducing energy poverty: exploring the use of domestically produced dimethyl ether (DME) to augment the use of imported liquefied petroleum gas (LPG) as a clean cooking fuel in India. The University of Queensland; 2017.
[108] Mensah JT, Adu G. An empirical analysis of household energy choice in Ghana. Renew Sustain Energy Rev 2015;51:1402–11. https://doi.org/https://doi.org/10.1016/j.rser.2015.07.050.
[109] Kar A. A behavioral perspective on transition pathways to clean cooking fuels: the case of LPG usage in India. University of British Columbia; 2019.
[110] Gizachew B, Tolera M. Adoption and kitchen performance test of improved cook stove in the Bale Eco-Region of Ethiopia. Energy Sustain Dev 2018;45:186–9. https://doi.org/https://doi.org/10.1016/j.esd.2018.07.002.
[111] Paudel U, Khatri U, Pant KP. Understanding the determinants of household cooking fuel choice in Afghanistan: a multinomial logit estimation. Energy 2018; 156:55–62. https://doi.org/https://doi.org/10.1016/j.energy.2018.05.085.
[112] Riley PH. Affordability for sustainable energy development products 2014;132: 308–16.
[113] Manirafasha E, Maniragaba D, Karemera S. Socioeconomic factors associated with the use of clean energy for cooking in informal settlements of Kigali City 2020;6. Rwanda.
[114] Jan I, Akram W. Willingness of rural communities to adopt biogas systems in Pakistan: critical factors and policy implications. Renew Sustain Energy Rev 2018;81:3178–85. https://doi.org/https://doi.org/10.1016/j.rser.2017.03.141.
[115] Kojima M. The role of liquefied petroleum gas in reducing energy poverty. 2011.
[116] Mani S, Jain A, Tripathi S, Gould CF. The drivers of sustained use of liquified petroleum gas in India. Nat Energy 2020;5:450–7. https://doi.org/10.1038/s41560-020-0596-7.
[117] Fields BC. Environmental economics: an introduction. Boston: Irwin/McGraw-HIll; 1997.
[118] Manyo-Plange NC. The changing climate of household energy: determinants of cooking fuel choice in domestic settings in Axim. 2011. Ghana.
[119] Schlag N, Zuzarte F. Market barriers to clean cooking fuels in sub-saharan Africa: a review of literature. 2008.
[120] MacCarty NA, Bryden KM. Costs and impacts of potential energy strategies for rural households in developing communities. Energy 2017;138:1157–74. https://doi.org/https://doi.org/10.1016/j.energy.2017.07.051.
[121] Darko Osei R. Toyola charcoal stove: improving the environment and health of the poor in Ghana. 2010.
[122] Landi M, Sovacool BK, Eidsness J. Cooking with gas: policy lessons from Rwanda's national domestic biogas program (NDBP). Energy Sustain Dev 2013; 17:347–56. https://doi.org/https://doi.org/10.1016/j.esd.2013.03.007.
[123] Kumar P, Dhand A, Tabak RG, Brownson RC, Yadama GN. Adoption and sustained use of cleaner cooking fuels in rural India: a case control study protocol to understand household, network, and organizational drivers. Arch Publ Health 2017;75. https://doi.org/10.1186/s13690-017-0244-2.
[124] Practical Action. Poor people's energy outlook. 2018 [Achieving Energy Access at Scale. n.d].
[125] Hall P, Adamson G, Gibbs MR, Arnold M. Institute of electrical and electronics engineers. The implications of clean and renewable energy development for gender equality in poor communities in South Asia. IEEE; 2012.
[126] Narula K, Sudhakara Reddy B, Pachauri S. Sustainable Energy Security for India: an assessment of energy demand sub-system. Appl Energy 2017;186:126–39. https://doi.org/https://doi.org/10.1016/j.apenergy.2016.02.142.
[127] Dave R, Keller S, Koo BB, Fleurantin G, Portale E, Rysankova D. Beyond connections Cambodia energy access diagnostic report based on the multi-tier framework. 2018. Washington D.C.
[128] Jian L. Socioeconomic barriers to biogas development in rural southwest China: an Ethnographic case study. Hum Organ 2009;68:415–30. https://doi.org/10.17730/humo.68.4.y21mu5lt8075t881.
[129] Karanja A, Mburu F, Gasparatos A. A multi-stakeholder perception analysis about the adoption, impacts and priority areas in the Kenyan clean cooking sector. Sustain Sci 2020;15:333–51. https://doi.org/10.1007/s11625-019-00742-4.
[130] Shankar AV, Quinn AK, Dickinson KL, Williams KN, Masera O, Charron D, et al. Everybody stacks: lessons from household energy case studies to inform design

principles for clean energy transitions. Energy Pol 2020;141:111468. https://doi.org/10.1016/J.ENPOL.2020.111468.
[131] Christiaensen L, Heltberg R. Greening China's rural energy new insights on the potential of smallholder biogas. 2012. Washington D.C.
[132] Moore Delate E, Calvel A, Munos O, Biney S. Clean Cooking Energy in Cote D'Ivoire: Situation and Outlooks. 2015.
[133] Hollada J, Williams KN, Miele CH, Danz D, Harvey SA, Checkley W. Perceptions of improved biomass and liquefied petroleum gas stoves in Puno, Peru: implications for promoting sustained and exclusive adoption of clean cooking technologies. Int J Environ Res Publ Health 2017;182:14. https://doi.org/10.3390/ijerph14020182.
[134] Sharma A, Parikh J, Singh C. Transition to LPG for cooking: a case study from two states of India. Energy Sustain Dev 2019;51:63–72. https://doi.org/10.1016/j.esd.2019.06.001.
[135] Gunther M. These cheap, clean stoves were supposed to save millions of lives. What happened? Washington Post 2015. https://www.washingtonpost.com/opinions/these-cheap-clean-stoves-were-supposed-to-save-millions-of-lives-what-happened/2015/10/29/c0b98f38-77fa-11e5-a958-d889faf561dc_story.html. [Accessed 30 July 2020].
[136] Troncoso K, Soares da Silva A. LPG fuel subsidies in Latin America and the use of solid fuels to cook. Energy Pol 2017;107:188–96.
[137] Taylor MJ, Moran-Taylor MJ, Castellanos EJ, Elías S. Burning for sustainability: biomass energy, international migration, and the move to cleaner fuels and cookstoves in Guatemala. Ann Assoc Am Geogr 2011;101:918–28. https://doi.org/10.1080/00045608.2011.568881.
[138] Ekouevi K, Tuntivate V. Household energy access for cooking and heating: lessons learned and the way forward. 2011. Washington D.C.
[139] Dalaba M, Alirigia R, Mesenbring E, Coffey E, Brown Z, Hannigan M, et al. LPG supply and demand for cooking in northern Ghana. https://doi.org/10.1007/s10393-018-1351-4; 2018. 15, 716, 728.
[140] Lambe F, Jürisoo M, Wanjiru H, Senyagwa J. Bringing clean, safe, affordable cooking energy to households across Africa: an agenda for action. 2015.
[141] Elgarah W. Microfinance for liquefied petroleum gas. 2011.
[142] Clean Cooking Alliance. 2018 annual report. Washington D.C. 2018.
[143] WHO. Opportunities for transition to clean household energy: application of the household energy assessment Rapid tool (HEART): India. 2018.
[144] Collins D, Morduch J, Rutherford S, Ruthven O. Portfolios of the poor. Princeton University Press; 2010.
[145] Mullainathan S, Shafir E. Scarcity: why having too little means so much. first ed. New York: Times Books; 2013.
[146] Clasen T, Smith KR. Let the "A" in WASH stand for air: integrating research and interventions to improve household air pollution (HAP) and water, sanitation and hygiene (waSH) in low-income settings. Environ Health Perspect 2019;127. https://doi.org/10.1289/EHP4752.
[147] Abdulai MA, Afari-Asiedu S, Carrion D, Ayuurebobi K, Gyaase S, Mohammed M, et al. Experiences with the mass distribution of LPG stoves in rural communities of Ghana. EcoHealth 2018;15:757–67.
[148] Pollard SL, Williams KN, O'Brien CJ, Winiker A, Puzzolo E, Kephart JL, et al. An evaluation of the Fondo de Inclusión Social Energético program to promote access to liquefied petroleum gas in Peru. Energy Sustain Dev 2018;46:82–93. https://doi.org/10.1016/J.ESD.2018.06.001.
[149] Hanna R, Duflo E, Greenstone M. Up in smoke: the influence of household behavior on the long-run impact of improved cooking stoves. Am Econ J Econ Pol 2016;8:80–114. https://doi.org/10.1257/pol.20140008.
[150] Gitau JK, Mutune J, Sundberg C, Mendum R, Njenga M. Implications on livelihoods and the environment of uptake of gasifier cook stoves among Kenya's Rural Households. Appl Sci 2019;9. https://doi.org/10.3390/app9061205.
[151] Jan I, Ullah S, Akram W, Khan NP, Asim SM, Mahmood Z, et al. Adoption of improved cookstoves in Pakistan: a logit analysis. Biomass Bioenergy 2017;103:55–62. https://doi.org/https://doi.org/10.1016/j.biombioe.2017.05.014.
[152] Indian Ministry of Petroleum and Natural Gas. Ujjwala saga: unending happiness and health. 2019. New Delhi.
[153] Asante KP, Afari-Asiedu S, Abdulai MA, Dalaba MA, Carrión D, Dickinson KL, et al. Ghana's rural liquefied petroleum gas program scale up: a case study. Energy Sustain Dev 2018;46:94–102. https://doi.org/https://doi.org/10.1016/j.esd.2018.06.010.
[154] Matthews WG, Zeissig HR. Residential market for LPG: a review of experience of 20 developing countries. 2011.
[155] Banerjee AV, Duflo E. Poor economics. New York: Public Affairs; 2011.
[156] Rousseau N, Leach M, Scott N, Bricknell M, Leary J, Abagi N, et al. Overcoming the "Affordability Challenge" associated with the transition to electric cooking. MECS Prog Rep 2021:1–32.
[157] World Bank. Modern energy cooking services (MECS). Cooking with electricity: a cost perspective. 2020. Washington D.C.
[158] Malhotra P, Neudoerffer RC, Dutta S. A participatory process for designing cooking energy programmes with women. Biomass Bioenergy 2004;26:147–69. https://doi.org/https://doi.org/10.1016/S0961-9534(03)00083-7.
[159] Women Energy and Economic Empowerment. Boil point. 2015.
[160] Rosenberg M, Armanios DE, Aklin M, Jaramillo P. Evidence of gender inequality in energy use from a mixed-methods study in India. Nat Sustain 2020;3:110–8. https://doi.org/10.1038/s41893-019-0447-3.
[161] Alderman H, Chiappori P-A, Haddad L, Hoddinott J, Kanbur R. Unitary versus collective models of the household: is it time to shift the burden of proof? World Bank Res Obs 1995;10:1–19.
[162] World Survey on the Role of Women in Development Report of the Secretary-General: why addressing women's income and time poverty matters for sustainable development Summary. 2019.
[163] Bhojvaid V, Jeuland M, Kar A, Lewis JJ, Pattanayak SK, Ramanathan N, et al. How do people in rural India perceive improved stoves and clean fuel? Evidence from Uttar Pradesh and Uttarakhand. Int J Environ Res Publ Health 2014;11:1341–58. https://doi.org/10.3390/ijerph110201341.
[164] Ezzati M, Bailis R, Kammen DM, Holloway T, Price L, Cifuentes LA, et al. Energy management and global health. Annu Rev Environ Resour 2004;29:383–419. https://doi.org/10.1146/annurev.energy.29.062103.121246.
[165] Batchelor S, Brown E. Cooking health energy environment and gender (CHEEG) - guiding covid recovery plans. 2020.
[166] Goddard JJ, Ray I, Balazs C. Water affordability and human right to water implications in California. PloS One 2021;16:3–5. https://doi.org/10.1371/journal.pone.0245237.
[167] Kessides I, Miniaci R, Scarpa C, Valbonesi P. Toward defining and measuring the affordability of public utility services. World Bank Policy Res Work Pap 2009;4915:38.
[168] Millward-Hopkins J, Steinberger JK, Rao ND, Oswald Y. Providing decent living with minimum energy: a global scenario. Global Environ Change 2020;102168:65. https://doi.org/10.1016/j.gloenvcha.2020.102168.