Facilitators and barriers to the implementation of improved solid fuel cookstoves and clean fuels in low-income and middle-income countries: an umbrella review

Esther A Boudewijns, Maria Trucchi, Rianne M J J van der Kleij, Debbie Vermond, Charlotte M Hoffman, Niels H Chavannes, Onno C P van Schayck, Bruce Kirenga, Evelyn A Brakema

2·6 billion people rely on solid fuels for cooking or heating. Accelerating access to cleaner solutions is crucial to reduce the negative effects of solid fuel use. Despite abundant evidence on how to implement these solutions, previous attempts have been disappointing. An overview of the evidence is missing and the translation of the evidence into practice is poor. We conducted an umbrella review using eight databases to: consolidate evidence on the factors that influence the implementation of improved solid fuel cookstoves and clean fuels in low-income and middle-income countries; weigh the level of confidence in existing evidence; and develop two practical implementation strategy tools. We identified 31 relevant reviews (13 systematic reviews and 18 narrative reviews) that covered over 479 primary studies. We found 15 implementation factors supported by the highest level of evidence. Regarding improved solid fuel cookstoves, these factors included: cost; knowledge and beliefs about the innovation; and compatibility. For clean fuels these factors included: cost; knowledge and beliefs about the innovation; and external policy and incentives. The factors were synthesised into the Cleaner Cookstove Implementation Tool and the Clean Fuel Implementation Tool. These tools can be used to optimise the implementation of cleaner cooking solutions, thereby improving health, environmental, climate, and gender equity outcomes.

Introduction

Every day, 2·6 billion people use traditional solid, polluting fuels and rudimentary stoves to cook or to heat their homes, mainly in low-income and middle-income countries (LMICs).[1] These traditional technologies negatively affect health (by leading to chronic ailments, acute ailments, or premature mortality), the environment (by causing forest degradation and deforestation), and the climate crisis (by increasing emissions of greenhouse gases and black carbon).[2–4] Many women bear a disproportionate share of the negative health risks from household air pollution because they have primary responsibility for cooking tasks. Additionally, women and children often spend several hours a day on cooking-related tasks including fuel collection, food-processing activities, cooking, and cleaning, resulting in time poverty (ie, less time for education, rest, leisure, and income-generating activities).[2] Cleaner cooking interventions could offer a solution. In view of the negative effects of solid fuels on health, climate, and women, the opportunity costs of not transitioning to cleaner cooking solutions (including deaths, disability-adjusted life years, carbon prices, and women's time) are estimated at US$2·4 trillion per year.[2] Cleaner cooking solutions include improved solid fuel cookstoves (subsequently referred to as cleaner cookstoves) and clean fuels. Cleaner cookstoves are defined as any improvement from an open fire, traditional inefficient stove, or a kerosene stove. Cleaner cookstoves include improved wood stoves, pellet stoves, and briquette stoves. Clean fuels include electricity, liquefied petroleum gas (LPG), natural gas, biogas, solar cookers, and alcohol fuels, and their corresponding technologies.[5] Clean fuels are expected to have the largest effect on health, environment, climate, and gender equity and are

therefore crucial to achieving substantial gains.[6] Cleaner cookstoves, on the other hand, generally have a smaller effect on household air pollution than clean fuels, because the emissions often remain above those recommended by the WHO Air Quality Guideline.[5] Nevertheless, because clean fuels are unlikely to be widely available in the near future, cleaner cookstoves are needed in the interim.[2,7]

Successful implementation, defined as the sustained (more than 1 year of use after acquisition) and predominant

Key messages

- Expediting access to cleaner cooking is crucial to mitigate the effects of using solid fuels on health, the environment, climate, and gender equity
- Of the dozens of literature reviews (comprising hundreds of studies) conducted on how to implement cleaner cooking interventions, few have been translated into practice and the implementation success of cleaner cooking interventions is generally considered poor
- Our study identified and consolidated the facilitators and barriers that need to be addressed to improve the successful implementation of cleaner cooking solutions, weighed the level of confidence in the existing evidence, and developed two practical implementation strategy tools to bridge the gap between academic evidence and practice
- The Cleaner Cookstove Implementation Tool (CleanCIT) and the Clean Fuel Implementation Tool (CleanFIT) serve to improve the inclusion of important factors during implementation strategy development and hence avoid waste of scarce resources; which, in turn, could accelerate the large-scale implementation of cleaner cooking interventions

Department of Family Medicine, Care and Public Health Research Institute, Maastricht University, Maastricht, Netherlands
(E A Boudewijns MSc,
C M Hoffman MD,
Prof O C P van Schayck PhD);
Leiden University College The Hague, Leiden University, The Hague, Netherlands
(M Trucchi BSc); **Department of Public Health and Primary Care, Leiden University Medical Center, Leiden, Netherlands**
(R M J J van der Kleij PhD,
D Vermond MSc,
Prof N H Chavannes PhD,
E A Brakema MD); **Department of Medicine and Makerere Lung Institute, Makerere University, Kampala, Uganda**
(B Kirenga PhD)

Correspondence to:
Ms Esther A Boudewijns,
Department of Family Medicine,
Care and Public Health Research
Institute, Maastricht University,
6200 Maastricht, Netherlands
**esther.boudewijns@
maastrichtuniversity.nl**

use of cleaner cooking solutions, is crucial to achieving improvements in health, environment, climate, and gender equity.[3,7] Decades of experience have shown that the implementation of cleaner cooking interventions is both challenging and complex.[7] Even where transition is achieved, uptake is often only partial (also referred to as stacking).[8] A successful implementation process requires the involvement of multiple sectors, including, among others: social, environmental, political, health, and financial sectors. Furthermore, the involvement of multiple stakeholders is needed. These stakeholders should include: intended users and local groups; local and national governments; financial institutions; commercial enterprises; and non-governmental organisations. A successful implementation process requires careful attention to contextual factors on a micro scale (eg, household factors), meso scale (eg, wider context-specific conditions), and macro scale (eg, policies). Implementation science provides a multisectoral and systematic approach to this challenge.[7,9] Identifying and pragmatically structuring factors that enable or limit implementation can improve understanding of the implementation process, which, in turn, could lead to improved evidence-based implementation strategies that accelerate widespread access to cleaner cooking interventions.[7]

To date, hundreds of studies have assessed the implementation process of cleaner cooking interventions and dozens of literature reviews have been conducted. However, the implementation success of cleaner cooking interventions is generally considered to be poor.[10,11] Although a plethora of evidence exists, there is no up-to-date overview and there is little translation of academic evidence to help guide implementation into practice. Therefore, in this umbrella review, we consolidated all available evidence from existing literature reviews covering factors that influence the acquisition, initial adoption, and sustained use of cleaner cookstoves and clean fuels in LMICs. Furthermore, we weighed the level of confidence in the evidence for these factors and translated our findings into two practical tools for developing evidence-based implementation strategies for future cleaner cooking interventions. In our umbrella review we address the following questions: which factors enable or hamper the acquisition, initial adoption, and sustained use of cleaner cookstoves and clean fuels with corresponding technologies in LMICs, and what is the level of confidence in the evidence supporting these factors?

Methods

This umbrella review (ie, a review of systematic and narrative reviews) was part of a broader review conducted by Brakema and colleagues,[12] as part of the Horizon 2020 free respiratory evaluation and smoke exposure reduction by primary health care integrated groups (FRESH AIR) project.[13] The study was registered with PROSPERO (CRD42018088687) and a peer-reviewed study protocol is available.[14] Due to an absence of reporting standards for umbrella reviews (standards are currently under development[15]), we followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) reporting standard.[16]

Search strategy

Reviews were originally identified during a search conducted in a broader review by Brakema and colleagues.[12] The search was developed together with a certified librarian. The search was done on Oct 23, 2017, and it was updated on July 10, 2019. Two experts in the field of cleaner cooking (researchers and members of the
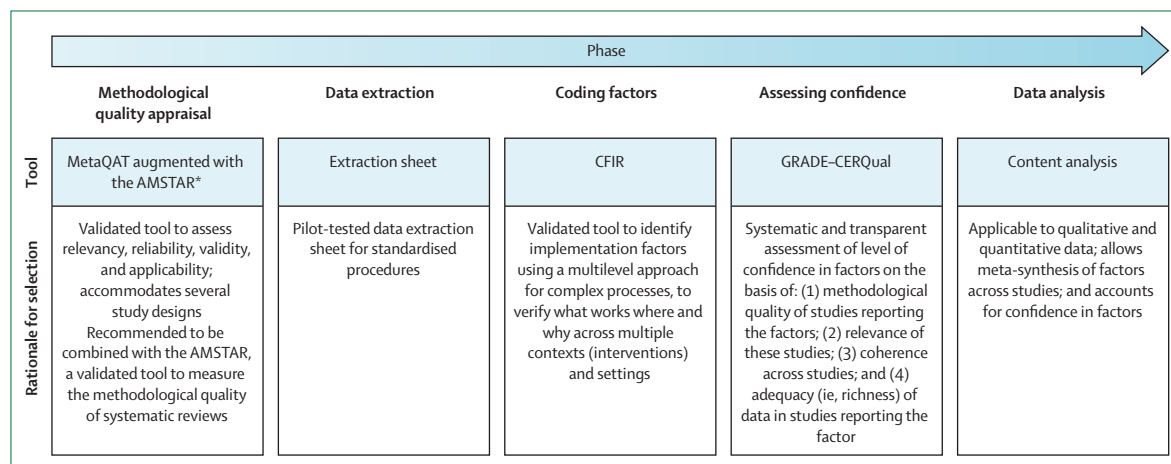

Figure 1: **Tools applied in each phase of the umbrella review**
Each phase used a different tool or methodology.[20–27] Figure adapted from Brakema and colleagues[12] and reproduced from Boudewijns and colleagues[14] with permission from BMJ Publishing Group. AMSTAR=Assessment of Multiple Systematic Reviews. CFIR=Consolidated Framework for Implementation Research. GRADE–CERQual=Grading of Recommendations Assessment Development and Evaluation–Confidence in the Evidence from Reviews of Qualitative Research. MetaQat=Meta Quality Appraisal Tool. *Tools to assess the quality of narrative reviews are not in the list of recommended design-specific companion tools to augment the MetaQAT tool;[20] therefore, it was decided to use the AMSTAR tool for systematic and narrative reviews.

clean cooking implementation science network) were consulted to identify relevant reviews published from July 10, 2019, to Jan 13, 2022. Full details, including the search strategy, are available in the protocol and appendix (pp 2–3).[14]

Selection criteria

The selection criteria we used are provided in the panel.[17,18] Because we anticipated little evidence in the literature concerning implementation factors that influence the sustained use of cleaner cooking solutions, we also included acquisition (purchase or installation) and initial adoption (use for less than 1 year from acquisition) in this umbrella review.[19] A distinction was made between cleaner cookstoves and clean fuels, because we expected that the factors determining the implementation success of cleaner cookstoves and the factors determining the implementation success of clean fuels would differ. The protocol stated that articles would be excluded if they focused on legislation at a national governmental scale.[14] Nevertheless, we decided to include these articles as we felt we could not neglect the central role that governments play in implementing national policies and strategies that prioritise cleaner cooking; in developing and enforcing regulations and standards; and in enlarging and investing in infrastructure.[2] Review selection, including title and abstract screening (EABr and DV) and full-text screening (EABo and MT or CH), was done using independent verification by two or more authors.

Quality appraisal and data extraction

Reviews were appraised and data were extracted and analysed in five steps using validated tools (figure 1).[20–27] Two researchers conducted all five steps independently (EABo and MT or CH) and a third researcher (EABr) was consulted to resolve any disagreements. During the first step, the methodological quality of the reviews was appraised using the Meta Quality Appraisal Tool (MetaQAT).[20] This tool is validated to assess the relevancy, reliability, validity, and applicability of studies, and accommodates several study designs. The tool was augmented with the Assessment of Multiple Systematic Reviews (AMSTAR) tool (appendix pp 4–10).[21] The combined MetaQAT and AMSTAR tool contains descriptive appraisals instead of numeric appraisals and is designed to document relevant information to enhance transparency. The results of the quality appraisal provided the basis for assessing confidence in the evidence during step four. This approach accounted for the risk of biased recommendations from narrative reviews during the meta-synthesis. During the second step, data on descriptive review characteristics and factors influencing the implementation of cleaner cooking interventions were extracted using standardised data extraction forms and were summarised in tables (appendix pp 11–21).[22] We did not distinguish between facilitators and barriers, because reversed facilitators can often be interpreted as barriers and vice versa.[12,28] Both modifiable factors (eg, fuel accessibility) and non-modifiable factors (eg, age) were extracted.

Evidence synthesis

The third step involved the coding of factors that influence the implementation of cleaner cooking interventions using the Consolidated Framework for Implementation Research (CFIR).[23] The CFIR is a validated tool to identify implementation factors for complex processes from a multilevel perspective to verify what works where and why, and how they work across multiple contexts and settings (appendix pp 22–70).[23–25] The CFIR is recommended for research and practice in environmental health.[29,30] The CFIR includes five domains, with each domain including several constructs. The five CFIR domains are: (1) intervention characteristics; (2) outer setting; (3) inner setting; (4) characteristics of the individuals involved; and (5) the implementation process.[23] During the fourth step, confidence in the evidence of the extracted factors was calculated using the Grading of Recommendations

See **Online** for appendix
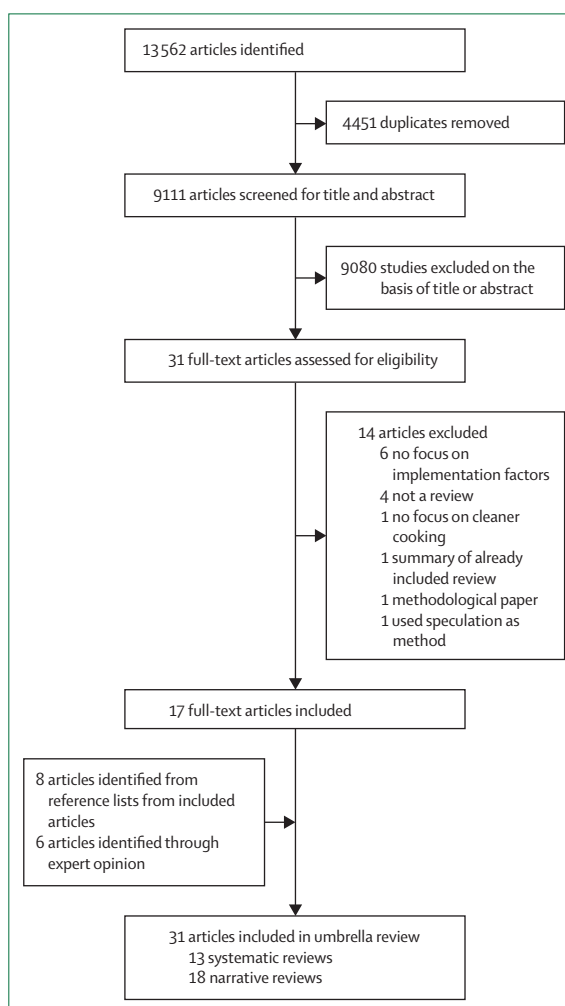
For the **CFIR** see https://cfirguide.org/

Figure 2: Study selection

	Study design	Intervention used
Barnes et al (1993)[45]	Narrative review	Improved cooking stoves (different types)*
Bonan et al (2017)[46]	Narrative review	Improved cookstoves (all kinds of innovation);* electricity connection (on-grid, off-grid, micro-photovoltaic, home solar system, and improvements in the quality of the electricity supply)†
Clemens et al (2018)[47]	Narrative review	Biodigester implementation through market development (Africa Biogas Partnership Program)†
Energy Sector Management Assistance Program (2021)[34]	Systematic review	Modern Energy Cooking Services Programme (transition is treated as any upward movement from a baseline cooking system to an improved one, as defined by the studies and programs evaluated)‡
Furszyfer Del Rio et al (2020)[43]	Systematic review	Improved cookstoves*
Gall et al (2013)[48]	Narrative review	Improved cookstoves*
Gill-Wiehl et al (2021)[49]	Narrative review	Improved biomass stoves, biogas, liquid petroleum gas, electricity, ethanol, natural gas, and solar ovens‡
Goodwin et al (2015)[35]	Systematic review	Cleaner cooking interventions‡
Guta et al (2022)[44]	Systematic review	Improved biomass stove;* electric stove, liquid petroleum gas, biogas, solar cooker, solar heater, and ethanol†
Karanja and Gasparatos (2019)[50]	Narrative review	Clean bioenergy cookstoves (eg, improved biomass stoves, biomass gasifier stoves, biogas stoves, and ethanol stoves)‡
Khandelwal et al (2017)[51]	Narrative review	Improved cookstoves*
Kowsari and Zerriffi (2011)[52]	Narrative review	Modern energy systems‡
Leach (1992)[53]	Narrative review	Modern energy sources (eg, liquid petroleum gas, bottled gas, kerosene, and electricity)†
Lewis and Pattanayak (2012)[36]	Systematic review	Improved cookstoves*; clean fuels (eg, kerosene, liquid petroleum gas, electricity, or solar)†
Lindgren (2021)[54]	Narrative review	Biomass improved cookstoves (eg, rocket, forced air, gasifier stoves, top lift updraft stoves, or addition of a chimney);* solar cookers†
Martinot et al (2002)[55]	Narrative review	More efficient biomass stoves;* renewable energy (eg, biogas stoves and solar cookers)†
Mittal (2018)[37]	Systematic review	Small-scale biogas plants†
Puzzolo et al (2016)[6]	Systematic review	Clean fuels (eg, liquid petroleum gas, biogas, solar cooking, and alcohol fuels)†
Puzzolo et al (2019)[56]	Narrative review	Clean fuels: electricity (grid and photovoltaic), liquid petroleum gas, alcohol fuels (ethanol or methanol), biogas, and compressed biomass pellets‡
Quinn et al (2018)[57]	Narrative review	Liquid petroleum gas, biogas digesters, biogas stoves, ethanol, and compressed biomass fuels (pellets and briquettes), which all meet the ISO tier 4 standard for emissions‡
Rehfuess et al (2014)[28]	Systematic review	Improved solid fuel stoves*
Ruiz-Mercado et al (2011)[3]	Narrative review	Clean fuels and cookstoves‡
Shankar et al (2014)[58]	Narrative review	Improved cookstoves*
Shankar et al (2020)[8]	Narrative review	Biomass pellets;* liquid petroleum gas, electric cooking, induction cooking, ethanol, and biogas†
Sharma and Dasappa (2017)[59]	Narrative review	Improved cookstoves (ie, forced draft gasification and natural draft combustion)*
Shen et al (2015)[38]	Systematic review	Clean cookstoves;* clean fuels†
Stanistreet et al (2014)[39]	Systematic review	Improved solid fuel stoves*
Thomas et al (2015)[40]	Systematic review	Improved stove interventions*
Thurber et al (2013)[41]	Systematic review	Improved biomass cookstoves*
Van der Kroon et al (2013)[60]	Narrative review	Modern forms of energy (eg, electricity and liquid petroleum gas)†
Vigolo et al (2018)[42]	Systematic review	Improved cooking stoves*

ISO=International Organization for Standardization. *Paper included in analysis of cleaner cookstoves. †Paper included in analysis of clean fuels. ‡Paper included in both the analysis of cleaner cookstoves and the analysis of clean fuels.

Table: **Characteristics of the included reviews**

Assessment, Development, and Evaluation (GRADE) and Confidence in the Evidence from Reviews of Qualitative research (CERQual) tool.[26] The GRADE–CERQual tool can be applied to several fields, including environmental research and international development.[31] This tool consists of four domains: methodological limitations, relevance, coherence, and adequacy. For each of these domains, we assigned a score per included review, ranging from one point (substantial concerns) to four points (no concerns to very minor concerns).[26] A score for coherence was not assigned, because the fit between the data was considered during the content analysis (step five). The

score for the methodological limitations was assigned on the basis of the reliability and validity category of the combined Meta-QAT and AMSTAR tool; the score for relevance was assigned on the basis of the relevance category of the combined Meta-QAT and AMSTAR tool; and the score for adequacy was assigned on the basis of the data sources (appendix p 71). The content analysis allowed for meta-synthesis of factors across reviews while accounting for confidence in factors.[27,32] This step was conducted separately for factors influencing the implementation of cleaner cookstoves and clean fuels. Reviews that did not distinguish between factors for

cleaner cookstoves and clean fuels were included in both analyses. For each factor (categorised by the CFIR), we determined a score by multiplying the score for the quality of the review in which the factor was mentioned (step four) by the number of reviews in which the factor was mentioned (appendix pp 72–81). To account for varying levels of reporting detail across reviews, each CFIR construct was considered only once for each review, even though various implementation factors were coded to the same CFIR construct (eg, age and household composition are different implementation factors, but we used the same CFIR construct [ie, other personal attributes] for both). Furthermore, we calculated the overall level of confidence in the implementation factors by totalling the scores of the three domains. Therefore, a higher score indicated higher adequacy of the review, higher relevance of the review, higher quality of the review, or higher frequency of the factor, or all of these factors combined. The implementation factors supported by evidence with the highest level of confidence, their corresponding level of evidence, and practical examples of each factor were consolidated in a comprehensive overview.

Different systematic reviews sometimes included the same primary studies, resulting in some evidence being counted twice. Therefore, a matrix of primary studies included in systematic reviews was prepared to gain insight into double counting of primary studies.[33] Because narrative reviews often do not present the studies included, narrative reviews were not included in the matrix (appendix pp 82–112).

Results

From a screening of 9111 unique articles, 31 reviews were included. Of these 31 reviews, 13 (42%) were systematic reviews[6,28,34–44] and 18 (58%) were narrative reviews (figure 2).[3,8,45–60] The systematic reviews included 479 unique primary papers. The included reviews were published between 1992 and 2022 and were conducted in a variety of geographical settings. 12 (39%) reviews reported factors that affected the implementation of clean fuels, including electricity, liquid petroleum gas, bottled gas, biogas, solar cookers, and alcohol fuels (ie, ethanol and methanol). Two (6%) reviews included kerosene as a clean fuel.[36,53] 18 (58%) reviews described implementation factors that concerned a wide variety of cleaner cookstoves, seven (23%) reviews reported separate factors for cleaner cookstoves and clean fuels, and eight (26%) reviews did not differentiate between cleaner cookstoves or clean fuels. Details of the included reviews are provided in the table and the appendix (pp 7–20). The results of the quality appraisal, data extraction, and CFIR coding are documented on more than 310 pages. These results are available from the corresponding author upon reasonable request.

Quality appraisal

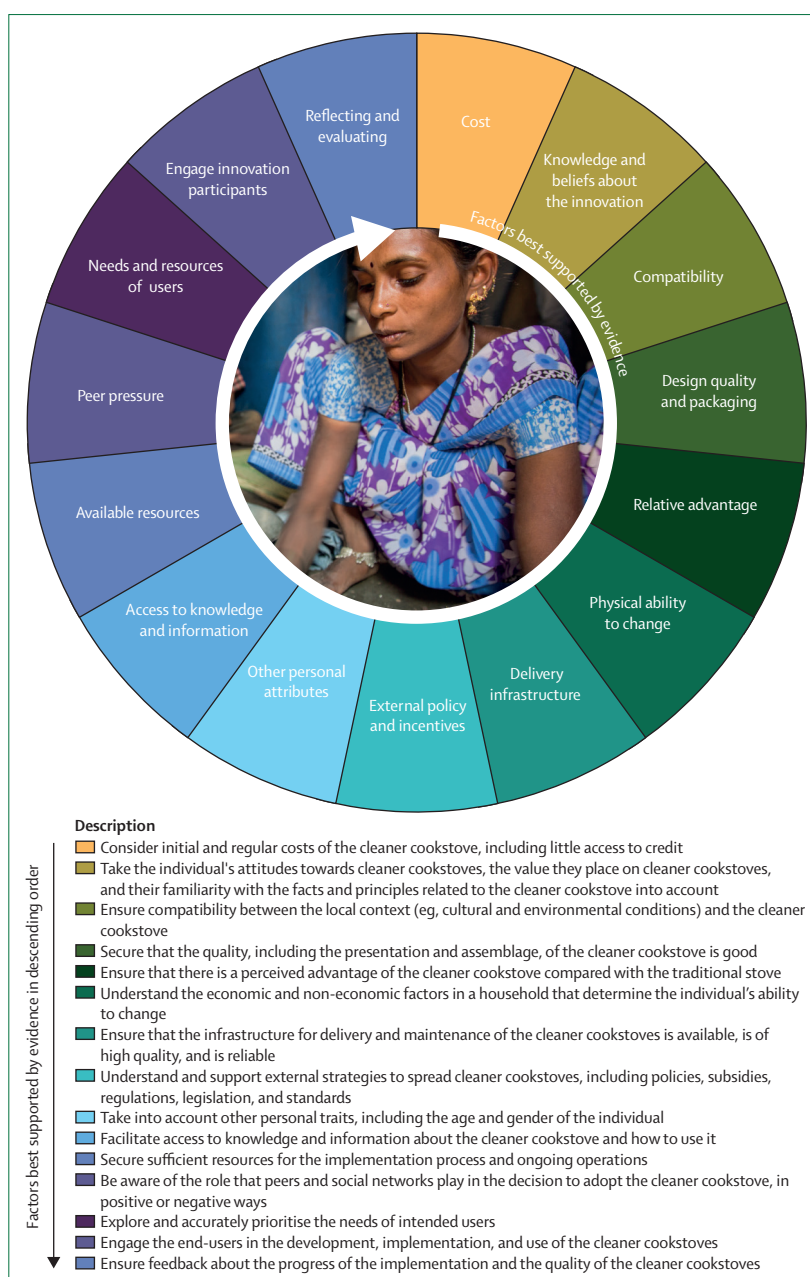The relevance, reliability, validity, and applicability of the

Figure 3: **The CleanCIT, an evidence-based implementation strategy tool for cleaner cookstoves.**
The order in which the factors are listed reflects the level of evidence for each factor, not its importance. Practical examples of each factor are provided in the appendix (pp 113–14). Photo used with permission of copyright owner and from the individuals pictured. CleanCIT=Cleaner Cookstove Implementation Tool.

reviews was appraised using the combined MetaQAT and AMSTAR tool. 22 (71%) articles had a high score for relevance in the combined MetaQAT and AMSTAR tool, nine (29%) articles had a medium relevance score, and no articles had a low score (appendix pp 7–10). The reliability of the included articles varied: 11 (35%) articles had a high score, ten (32%) had a medium score, and ten (32%) had a low score. The main reasons for low or medium reliability scores were unclear reporting methods and
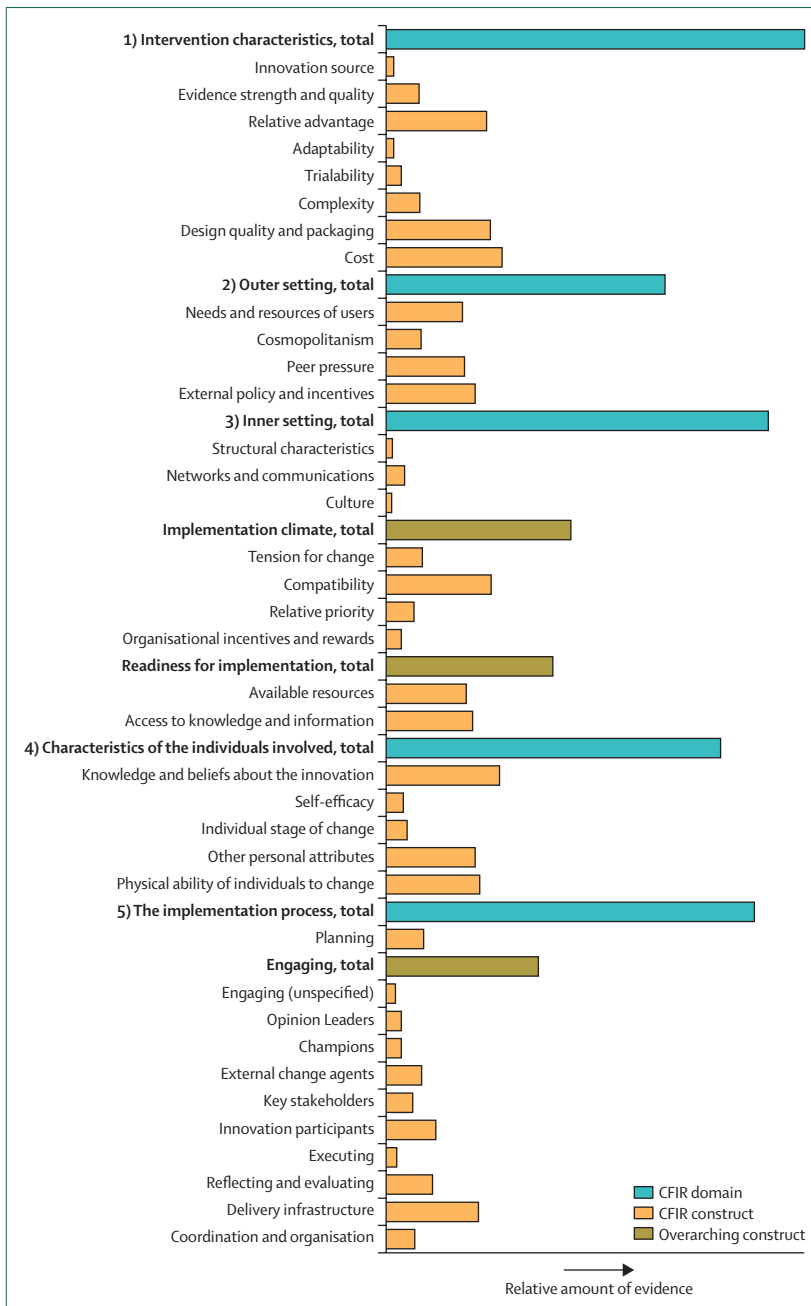
Figure 4: Overview of implementation factors per domain and relative levels of evidence for factors for cleaner cookstoves
Bar sizes indicate the relative certainty as to whether the factor influences implementation. CFIR (overarching) constructs are described in the appendix (pp 22–27). CFIR=Consolidating Framework for Implementation Research.

14 (45%) articles. The kappa with linear weighting was 0·56, which indicated moderate reviewer agreement. The systematic reviews had little overlap in the primary studies that they included (appendix pp 82–112).

Implementation factors and the Cleaner Cookstove Implementation Tool

We found that the influence of factors on successful implementation of cleaner cooking solutions varied markedly depending on the technology being introduced and the specific context. On the basis of our content analysis, the 15 factors (CFIR constructs) for which the level of confidence in supporting evidence was highest were summarised in the Cleaner Cookstove Implementation Tool (CleanCIT; figure 3). Examples of each factor are included in the appendix (pp 113–14). A full list of factors for each CFIR construct is also included in the appendix (pp 29–49). We describe the three factors with the best supporting evidence for an influence on implementation, which accounted for 19% of the sum scores of the content analysis.

The best supported factor (ie, associated with the highest level of evidence regarding implementation) was cost. High initial costs, little access to credit, and ongoing costs for maintenance were reported as key barriers to the acquisition and sustained use of cleaner cookstoves in several reviews (appendix pp 32–33). Reviews recommended considering ways to facilitate the purchase of cleaner cookstoves, because the price of a cleaner cookstove is high relative to the purchasing power of a lower-income household and compared with traditional stoves that are produced at no cost (appendix pp 32–33). Addressing affordability constraints (eg, by community lending schemes, price incentives, or free repairs) could, to some extent, address the high upfront costs of cleaner cookstoves. Evidence supporting a role for subsidies was inconsistent: some reviews reported that subsidies facilitated adoption, whereas other reviews reported that adoption rates for cleaner cookstoves did not increase (appendix pp 32–33).

The second best supported factor was knowledge and beliefs concerning the innovation. Reviews showed that a higher level of education was, in general, positively associated with the adoption of cleaner cookstoves (appendix pp 42–43). Little previous knowledge about available cookstoves or the consequences of cooking with traditional and inefficient stoves inhibited the transition to cleaner cookstoves. Programmes that used behaviour change techniques (eg, shaping knowledge and social support) reported higher adoption rates than programmes that did not use these techniques. Public cooking demonstrations, training sessions, and campaigns are useful tools for communicating the advantages of cleaner cookstoves to a community. It is recommended that all implementation efforts anticipate the value that end users place on cleaner cookstoves, including safety, cleanliness, home improvement, and

insufficient information on data sources. In terms of validity, seven (23%) articles had a high score, 15 (48%) articles had a medium score, and nine (29%) articles had a low score. Articles had lower scores due to risk of bias, methodological flaws (eg, no duplicate data extraction and no assessment of the quality of included studies), or unclear reporting of analytical methods. The applicability score was high for 17 (55%) articles and medium for

short-term health benefits.

The third best supported factor influencing implementation was compatibility. Many programmes did not account for the fact that the specifics of cooking vary by culture, geography, season, fuel type, local practices, and cooking needs. Several reviews reported that cleaner cookstoves suitable for the preparation of local dishes were preferred (appendix pp 37–40). Examples of facilitators of implementation included: the suitability of the stove to meet the household's cooking demands; the ability to accommodate multiple fuels, fuel sizes, and pot types; the fit of the stove in the typical kitchen space; technologies that did not affect the taste of food; and compatibility with current cooking schedules. A few reviews indicated that the additional energy services obtained from traditional stoves, such as heating and lighting, were a factor that hindered the adoption of cleaner cookstoves (appendix pp 37–40). Furthermore, a cleaner cookstove needs to be compatible with cultural practices, traditions, and beliefs.

Other factors associated with high confidence in the level of evidence included: design quality and packaging; relative advantage; physical ability to change; delivery infrastructure; external policy and incentives; other personal attributes; access to knowledge and information; available resources; peer pressure; needs and resources of users; engaging innovation participants; and reflecting and evaluating. In total, 44 factors (constructs) were included in the CFIR, of which 37 (84%) were reported to influence the implementation of cleaner cookstoves (figure 4).

Implementation factors and the Clean Fuel Implementation Tool

The 15 constructs supported by evidence with the highest level of confidence are summarised in the Clean Fuel Implementation Tool (CleanFIT; figure 5). Practical examples of each factor are included in the appendix (pp 115–16), and a full list of factors for each CFIR construct is also included in the appendix (pp 50–70). We describe the three factors with the best evidence for influencing the implementation of clean fuels and corresponding technologies, which covered 21% of the total sum scores of the content analysis.

Similar to the analysis of cleaner cookstoves, the best supported factor (ie, associated with the highest level of evidence regarding implementation) was cost. Affordability constraints concerning the upfront capital costs of the clean fuel technology, ongoing fuel costs, and cost of maintenance were all reported as barriers to successful implementation of clean fuels and corresponding technologies. Monetary incentives (eg, subsidies) were often reported to increase adoption, although they could also reduce adoption upon withdrawal. Several reviews recommended ensuring access to credit and avoiding lump sum payments. The main role of fuel prices was to cause a shift between fuels among those households who
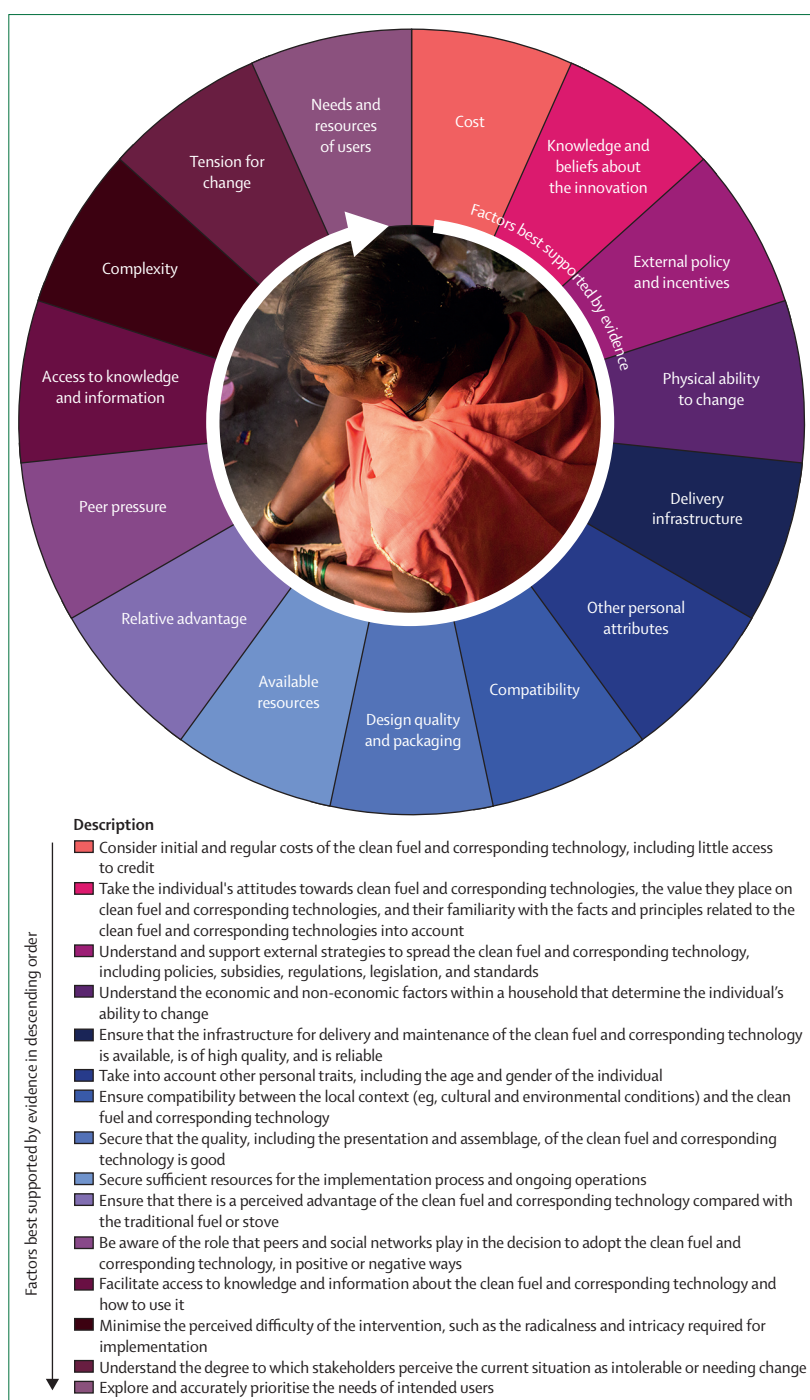

Description

- Consider initial and regular costs of the clean fuel and corresponding technology, including little access to credit
- Take the individual's attitudes towards clean fuel and corresponding technologies, the value they place on clean fuel and corresponding technologies, and their familiarity with the facts and principles related to the clean fuel and corresponding technologies into account
- Understand and support external strategies to spread the clean fuel and corresponding technology, including policies, subsidies, regulations, legislation, and standards
- Understand the economic and non-economic factors within a household that determine the individual's ability to change
- Ensure that the infrastructure for delivery and maintenance of the clean fuel and corresponding technology is available, is of high quality, and is reliable
- Take into account other personal traits, including the age and gender of the individual
- Ensure compatibility between the local context (eg, cultural and environmental conditions) and the clean fuel and corresponding technology
- Secure that the quality, including the presentation and assemblage, of the clean fuel and corresponding technology is good
- Secure sufficient resources for the implementation process and ongoing operations
- Ensure that there is a perceived advantage of the clean fuel and corresponding technology compared with the traditional fuel or stove
- Be aware of the role that peers and social networks play in the decision to adopt the clean fuel and corresponding technology, in positive or negative ways
- Facilitate access to knowledge and information about the clean fuel and corresponding technology and how to use it
- Minimise the perceived difficulty of the intervention, such as the radicalness and intricacy required for implementation
- Understand the degree to which stakeholders perceive the current situation as intolerable or needing change
- Explore and accurately prioritise the needs of intended users

Figure 5: The CleanFIT, an evidence-based implementation strategy tool for clean fuels
The order in which the factors are listed reflects the level of evidence for each factor, not its importance. Examples of each factor are provided in the appendix (pp 115–16). Photo used with permission from copyright owner and from the individual pictured. CleanFIT=Clean Fuel Implementation Tool.

use several fuels, with fuel price differentials having a higher likelihood of resulting in a so-called backward substitution than a so-called upward transition.

The second best supported factor was knowledge and beliefs regarding the innovation. Similar to the analysis of
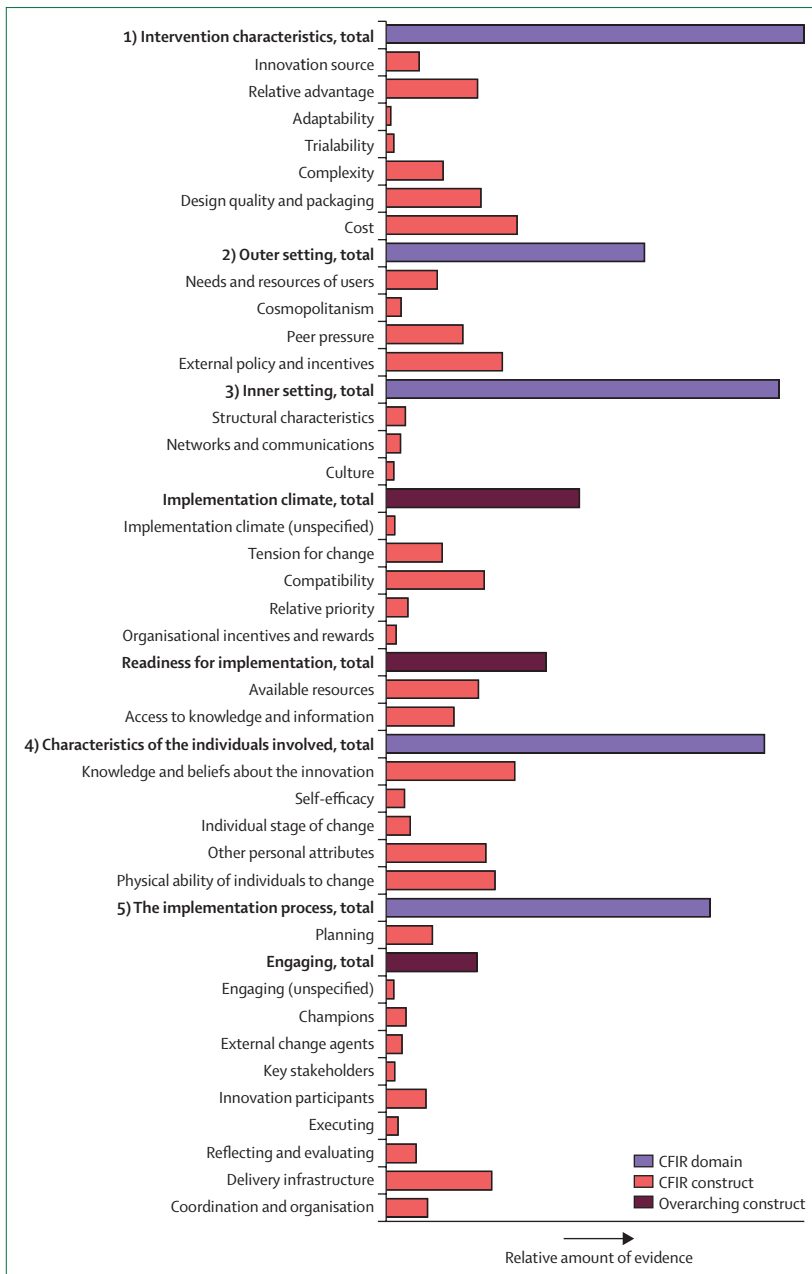
Figure 6: Overview of implementation factors per domain and relative levels of evidence for factors for clean fuels

Bar sizes indicate the relative certainty as to whether the factor influences implementation. CFIR (overarching) constructs are described in the appendix (pp 22–27). CFIR=Consolidating Framework for Implementation Research.

the implementation of cleaner cookstoves, several reviews identified a positive relationship between level of education and a switch to clean fuels and corresponding technologies. Knowledge and awareness of the benefits of using clean fuels enabled adoption. Perceptions of cleanliness (eg, no soot or ash), home improvement, and safety were often mentioned as highly valued by end users.

The third best supported factor was external policy and incentives. This factor included external strategies to promote the adoption and use of clean fuels and corresponding technologies, including policies, subsidies, regulations, legislation, and standards. These strategies included policy changes that led to higher income levels, financial support targeted to poor individuals, government commitment to the provision of infrastructure, and market and trade policies (eg, supportive and effective instruments for regulation, certification, and standard-isation). Furthermore, the need for collaborative action to promote behavioural change and to create a conducive policy environment was highlighted.

Other factors that were well supported by evidence included: physical ability to change; delivery infrastructure; other personal attributes; compatibility; design quality and packaging; available resources; relative advantage; peer pressure; access to knowledge and information; complexity; tension for change; and needs and resources of users. In total, we identified 36 factors (CFIR constructs) in the reviews that influence the implementation of clean fuels and corresponding technologies (figure 6).

Similarities and differences between the implementation of cleaner cookstoves and clean fuels

Most of the factors that were supported by a high level of evidence were found to influence the implementation of both cleaner cookstoves and clean fuels, although we found some differences in the level of supporting evidence for factors between the two approaches. For example, external policy and incentives was supported by a higher level of evidence for clean fuels than for cleaner cookstoves. This difference could be due to the influence of policy tools on upfront costs and recurrent fuel costs, which are often relatively high, and due to the regulations and standards needed to promote a safe and sustainable supply of clean fuels. Conversely, compatibility was supported by a higher level of evidence for cleaner cookstoves than for clean fuels. An explanation for this difference could be learning from mistakes made during implementation efforts of cleaner cookstoves, which have a longer history than clean fuels, and consequently compatibility is more carefully considered during the implementation of clean fuels and corresponding technologies. We do not mean to imply that compatibility is an unimportant factor for implementing clean fuels, but rather that it has been better considered in implementation strategies of clean fuels compared to cleaner cookstoves.

Discussion
Summary of findings
In this umbrella review, we aggregated and weighed the level of confidence in evidence found in 31 systematic and narrative reviews that covered 479 primary studies on factors that are crucial to the implementation success of cleaner cooking interventions in LMICs. Our results show that a range of factors synergistically influence the acquisition, initial adoption, and sustained use of cleaner cooking solutions, indicating that a comprehensive

approach to cleaner cookstove and clean fuel implementation is needed. The 15 factors supported by the highest level of evidence, and examples of their influence in practice, were consolidated in the CleanCIT and the CleanFIT.

Interpretation of results

The level of confidence in evidence supporting a particular factor should not be interpreted as a prioritisation of the relative importance of that factor and neither should it be considered an indication of an order in the steps of implementation. Rather, the level of confidence in the evidence supporting implementation factors simply represents the relative certainty as to whether a factor influences implementation. We would argue that all factors included in the tools should be properly addressed or at least considered. Conversely, the absence of a factor does not necessarily imply that the factor is not important, but might simply indicate a scarcity of available evidence. Potential missing factors in our tool will be obtained in future studies if they appear to be important. Notably, the presentation of evidence in reviews is dependent on the methodologies used and on the perspective of the researcher, implementer, and end user.

Considerations

The factors identified in this umbrella review should be clearly addressed, or at least considered, during the development of evidence-based implementation strategies for cleaner cooking interventions. The tools developed during this study will help programmes avoid neglecting important factors, such as local needs, financing options, or after-sales support, when designing implementation strategies. These factors being neglected was a shortcoming encountered in earlier programmes.[34] These tools will help accelerate the large-scale implementation of cleaner cooking interventions but should not be interpreted as a guarantee of successful implementation. Facilitators and barriers for implementation are highly dependent on contextual factors, but due to the nature of the study we were not able to distinguish between the facilitators and barriers in different regions or countries. Tools and reports to assess the current state of household energy in specific regions or countries, such as the Clean Household Energy Solutions Toolkit, are readily available.[61] Some of the factors mentioned can be tackled by small, local organisations, whereas other factors require the involvement of national and international institutions or governments. For example, shaping knowledge through marketing messages, word of mouth, or practical demonstrations can be done by a local implementer.[43] Meanwhile, energy policy and regulations regarding the production and distribution of energy carriers and energy appliances are the responsibility of local or national institutions or governments.[52] We decided to include all factors in the tools, regardless of which organisation could tackle these factors, to urge implementers to at least consider how these factors could influence their implementation strategy. Our approach underlines the importance of a multilevel stakeholder approach and a system-wide perspective regarding cleaner cooking interventions. Factors influencing acquisition, initial adoption, and sustained use were not distinguished in this umbrella review, but it should be noted that the extent to which the factors influence these stages of implementation might differ. The same applies to large and small-scale implementation. Furthermore, in line with the pledge to "leave no one behind" in the UN Agenda for Sustainable Development 2030, we recommend considering equity in relation to gender, socioeconomic status, and the urban–rural divide. These issues are discussed in a study by Puzzolo and colleagues.[6]

Strengths and limitations

Commitment to implementation research is a prerequisite for enhancing health in the face of increasingly harmful environmental trends.[9,62] To the best of our knowledge, this is the first umbrella review to have consolidated and weighed evidence on factors that are crucial to the successful implementation of cleaner cooking interventions. However, bridging the gap between research and practice requires more than evidence alone.[62] Therefore, we developed two new evidence-based implementation strategy tools. These tools provide a practical overview of the factors that influence the implementation of cleaner cookstoves and clean fuels and show the level of supporting evidence for these factors, together with examples of how these factors affect implementation. By adhering to the PRISMA reporting standard, our study was rigorous in design and execution,[16] and reproducibility and transparency were ensured throughout the entire process through the use of validated tools applied by two independent researchers. The study included an extensive literature search, with no date or language restrictions, and although the search was originally conducted in July 2019, a consultation of experts allowed us to identify relevant publications up to January, 2022. We decided to include both systematic and narrative reviews in this umbrella review, because only a fraction of all literature is captured by systematic reviews. Double inclusion was addressed in systematic reviews but was not possible in the case of narrative reviews. Unfortunately, grey literature sources (such as policy reports) were not included, although we acknowledge that these sources contain important data. Previous literature has highlighted the challenge of identifying data in non-academic literature.[34] In addition, although specific names of fuels (eg, biogas or ethanol) were not included as search terms, we do not expect that this has led to a review being missed in our analysis. Furthermore, kerosene, a relatively efficient fuel but with substantial health risks, was considered to be a clean fuel by two reviews.

Recommendations for implementation initiatives

To organisations contemplating the challenge of implementation, we would stress that hundreds of papers have been dedicated to this complex subject. Therefore, we strongly advocate for the design of a comprehensive strategy regarding the implementation of cleaner cookstoves and clean fuels. This strategy should consist of a multilevel stakeholder approach and a system-wide perspective. The CleanCIT and CleanFIT (figures 3 and 5), which were developed in this study, suit this purpose. In collaboration with stakeholders, we now plan to further develop these tools as an inclusive online interactive platform and recommend pilot-testing the tools and, if this pilot-testing is successful, promoting them to regional and global initiatives. Lastly, we advise continuous monitoring of the effectiveness of any implementation strategy, together with the adoption of necessary improvements. The Reach, Effectiveness, Adaption, Implementation, and Maintenance framework is a suitable tool for assessing the effectiveness of a particular strategy.[7]

Recommendations for implementation research

By collating data from numerous fragmented studies, we have distilled clear recommendations that can be used to improve current practice, and we are therefore confident that this umbrella review will boost the implementation of cleaner cooking. For future research, we recommend the use of standardised methods and structured reporting (eg, the Standards for Reporting Implementation Studies Statement).[63] Echoing a common recommendation, we urge for a clarification of the definitions of adoption and sustained use, as these terms are used interchangeably in many reports.[64] For example, the Adoption Index, which was developed by the Clean Cooking Alliance, can be used

to quantify rates of adoption.[65] Furthermore, several reviews have indicated that exclusive use of cleaner cooking solutions is unusual and that fuel stacking (ie, the use of multiple stoves or fuels, or both) is common practice.[8,57] As stacking reduces the potential benefits of cleaner cooking interventions, we advise offering a range of cleaner cooking solutions to meet the diverse cooking demands of a household.[66] Furthermore, in addition to paying attention to the uptake and sustained use of clean cooking solutions, we also recommend focusing on the suspension of solid fuels and traditional stoves. A systematic review published in 2022 highlighted the differences between factors that influence household uptake and sustained use of less polluting fuels and stoves and factors that influence use and suspension of solid fuels.[44] We recommend future studies to assess the role of stacking in their research. Objective measurements regarding the use of fuels and technologies (eg, stove use monitors) could help to better understand the adoption process and the effect of the use of one or multiple cleaner cooking solutions.[3] In this umbrella review, we merged data on a variety of clean fuels (ie, electricity, LPG, natural gas, biogas, solar cookers, and alcohol fuels). However, we would recommend separately reviewing the role of implementation factors associated with these specific fuels when more evidence becomes available. More studies are needed to better understand the implementation factors that influence the sustained use of cleaner cooking methods, because existing reviews often have short follow-up periods and therefore only cover the acquisition and initial adoption of cleaner cookstoves or clean fuels. Furthermore, the reliability of the strategy tools deserves further research, with special attention required for the prioritisation of the importance of known factors.

Conclusion

With 2·6 billion people using traditional fuels and stoves daily, and the climate crisis being the greatest threat to public health in the 21st century,[67] there is an urgent need to accelerate the implementation of cleaner cooking interventions. The evidence presented in this umbrella review supports a comprehensive approach to the development of evidence-based implementation strategies, including the 15 factors identified here, and argues for a multilevel stakeholder approach and a system-wide perspective. This umbrella review, and the CleanCIT and CleanFIT, will serve as a useful basis for the planning and delivery of cleaner cooking interventions. Improved implementation of cleaner cooking interventions could facilitate substantial health gains, lead to less forest degradation and deforestation, mitigate negative effects on our climate, and contribute to gender equity.

Contributors

EABo conceptualised the study. EABo and EABr elaborated the concept and design. Title and abstract screening was done by EABr and DV. EABo and MT or CMH conducted the full-text screening. Methodological quality appraisal, data extraction, coding of factors,

assessing of confidence, and data analysis were conducted by EABo and MT or CMH, supervised by EABr. DV made the matrix for double counting. EABo wrote the first version of the manuscript and developed the figures. EABr supervised the various stages of the writing of the manuscript. DV, RMJJvdK, NHC, BK, and OCPvS critically reviewed the paper. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

References

1 International Energy Agency. Financing clean energy transitions in emerging and developing economies. Paris: International Energy Agency, 2021. https://www.iea.org/reports/financing-clean-energy-transitions-in-emerging-and-developing-economies (accessed May 10, 2022).

2 Energy Sector Management Assistance Program. The state of access to modern energy cooking services. Washington, DC: World Bank, 2020. https://www.worldbank.org/en/topic/energy/publication/the-state-of-access-to-modern-energy-cooking-services?msclkid=78ca749 (accessed May 10, 2022).

3 Ruiz-Mercado I, Masera O, Zamora H, Smith KR. Adoption and sustained use of improved cookstoves. *Energy Policy* 2011; **39:** 7557–66.

4 Shupler M, Hystad P, Birch A, et al. Household and personal air pollution exposure measurements from 120 communities in eight countries: results from the PURE-AIR study. *Lancet Planet Health* 2020; **4:** e451–62.

5 WHO. WHO guidelines for indoor air quality: household fuel combustion. Geneva, Switzerland: World Health Organization, 2014. https://apps.who.int/iris/handle/10665/141496 (accessed May 10, 2022).

6 Puzzolo E, Pope D, Stanistreet D, Rehfuess EA, Bruce NG. Clean fuels for resource-poor settings: a systematic review of barriers and enablers to adoption and sustained use. *Environ Res* 2016; **146:** 218–34.

7 Rosenthal J, Balakrishnan K, Bruce N, et al. Implementation science to accelerate clean cooking for public health. *Environ Health Perspect* 2017; **125:** A3–7.

8 Shankar AV, Quinn A, Dickinson KL, et al. Everybody stacks: lessons from household energy case studies to inform design principles for clean energy transitions. *Energy Policy* 2020; **141:** 111468.

9 Pattanayak SK, Haines A. Implementation of policies to protect planetary health. *Lancet Planet Health* 2017; **1:** e255–56.

10 Bailis R, Cowan A, Berrueta V, Masera O. Arresting the killer in the kitchen: the promises and pitfalls of commercializing improved cookstoves. *World Dev* 2009; **37:** 1694–705.

11 Thomas E, Wickramasinghe K, Mendis S, Roberts N, Foster C. Improved stove interventions to reduce household air pollution in low and middle income countries: a descriptive systematic review. *BMC Public Health* 2015; **15:** 650.

12 Brakema EA, Vermond D, Pinnock H, et al. Implementing lung health interventions in low- and middle-income countries: a FRESH AIR systematic review and meta-synthesis. *Eur Respir J* 2020; **56:** 2000127.

13 Cragg L, Williams S, Chavannes NH. FRESH AIR: an implementation research project funded through Horizon 2020 exploring the prevention, diagnosis and treatment of chronic respiratory diseases in low-resource settings. *NPJ Prim Care Respir Med* 2016; **26:** 16035.

14 Boudewijns EA, Vermond D, van der Kleij RMJJ, et al. Factors critical to implementation success of cleaner cooking interventions in low-income and middle-income countries: protocol for an umbrella review. *BMJ Open* 2020; **10:** e041821.

15 Pollock M, Fernandes RM, Pieper D, et al. Preferred Reporting Items for Overviews of Reviews (PRIOR): a protocol for development of a reporting guideline for overviews of reviews of healthcare interventions. *Syst Rev* 2019; **8:** 335.

16 Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Int J Surg* 2010; **8:** 336–41.

17 Peters DH, Adam T, Alonge O, Agyepong IA, Tran N. Implementation research: what it is and how to do it. *BMJ* 2013; **347:** f6753.

18 World Bank. World Bank country and lending groups. 2017. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519 (accessed May 10, 2022).

19 Puzzolo E, Stanistreet D, Pope D, Bruce N, Rehfuess E. Factors influencing the large-scale uptake by households of cleaner and more efficient household energy technologies. 2013. https://eppi.ioe.ac.uk/cms/Default.aspx?tabid=3426 (accessed May 10, 2022).

20 Rosella L, Bowman C, Pach B, Morgan S, Fitzpatrick T, Goel V. The development and validation of a meta-tool for quality appraisal of public health evidence: Meta Quality Appraisal Tool (MetaQAT). *Public Health* 2016; **136:** 57–65.

21 Shea BJ, Grimshaw JM, Wells GA, et al. Development of AMSTAR: a measurement tool to assess the methodological quality of systematic reviews. *BMC Med Res Methodol* 2007; **7:** 10.

22 Higgins JP, Thomas J, Chandler J, et al. Cochrane handbook for systematic reviews of interventions, 2nd edition. Chichester: John Wiley & Sons, 2019.

23 Damschroder LJ, Aron DC, Keith RE, Kirsh SR, Alexander JA, Lowery JC. Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. *Implement Sci* 2009; **4:** 50.

24 Damschroder LJ, Lowery JC. Evaluation of a large-scale weight management program using the consolidated framework for implementation research (CFIR). *Implement Sci* 2013; **8:** 51.

25 Moullin JC, Sabater-Hernández D, Fernandez-Llimos F, Benrimoj SI. A systematic review of implementation frameworks of innovations in healthcare and resulting generic implementation framework. *Health Res Policy Syst* 2015; **13:** 16.

26 Lewin S, Glenton C, Munthe-Kaas H, et al. Using qualitative evidence in decision making for health and social interventions: an approach to assess confidence in findings from qualitative evidence syntheses (GRADE-CERQual). *PLoS Med* 2015; **12:** e1001895.

27 Dixon-Woods M, Agarwal S, Young B, Jones D, Sutton A. Integrative approaches to qualitative and quantitative evidence. London: Health Development Agency, 2004.

28 Rehfuess EA, Puzzolo E, Stanistreet D, Pope D, Bruce NG. Enablers and barriers to large-scale uptake of improved solid fuel stoves: a systematic review. *Environ Health Perspect* 2014; **122:** 120–30.

29 Haque SS, Freeman MC. The applications of implementation science in water, sanitation, and hygiene (WASH) research and practice. *Environ Health Perspect* 2021; **129:** 065002.

30 Tinc PJ, Gadomski A, Sorensen JA, Weinehall L, Jenkins P, Lindvall K. Applying the consolidated framework for implementation research to agricultural safety and health: barriers, facilitators, and evaluation opportunities. *Saf Sci* 2018; **107:** 99–108.

31 Lewin S, Booth A, Glenton C, et al. Applying GRADE-CERQual to qualitative evidence synthesis findings: introduction to the series. *Implement Sci* 2018; **13** (suppl 1): 2.

32 Krippendorff K. Content analysis: an introduction to its methodology. London: Sage Publications, 2018.

33 Lunny C, Brennan SE, Reid J, McDonald S, McKenzie JE. Overviews of reviews incompletely report methods for handling overlapping, discordant, and problematic data. *J Clin Epidemiol* 2020; **118:** 69–85.

34 Energy Sector Management Assistance Program. What drives the transition to modern energy cooking services? A systematic review of the evidence. Washington, DC: World Bank, 2021. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/518251613714281312/pdf (accessed May 10, 2022).

35 Goodwin NJ, O'Farrell SE, Jagoe K, et al. Use of behavior change techniques in clean cooking interventions: a review of the evidence and scorecard of effectiveness. *J Health Commun* 2015; **20** (suppl 1): 43–54.

36 Lewis JJ, Pattanayak SK. Who adopts improved fuels and cookstoves? A systematic review. *Environ Health Perspect* 2012; **120**: 637–45.

37 Mittal S, Ahlgren EO, Shukla P. Barriers to biogas dissemination in India: a review. *Energy Policy* 2018; **112**: 361–70.

38 Shen G, Lin W, Chen Y, Yue D, Liu Z, Yang C. Factors influencing the adoption and sustainable use of clean fuels and cookstoves in China—a Chinese literature review. *Renew Sustain Energy Rev* 2015; **51**: 741–50.

39 Stanistreet D, Puzzolo E, Bruce N, Pope D, Rehfuess E. Factors influencing household uptake of improved solid fuel stoves in low- and middle-income countries: a qualitative systematic review. *Int J Environ Res Public Health* 2014; **11**: 8228–50.

40 Thomas E, Wickramasinghe K, Mendis S, Roberts N, Foster C. Improved stove interventions to reduce household air pollution in low and middle income countries: a descriptive systematic review. *BMC Public Health* 2015; **15**: 650.

41 Thurber MC, Warner C, Platt L, Slaski A, Gupta R, Miller G. To promote adoption of household health technologies, think beyond health. *Am J Public Health* 2013; **103**: 1736–40.

42 Vigolo V, Sallaku R, Testa F. Drivers and barriers to clean cooking: a systematic literature review from a consumer behavior perspective. *Sustainability (Basel)* 2018; **10**: 4322.

43 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; **70**: 101788.

44 Guta D, Baumgartner J, Jack D, et al. A systematic review of household energy transition in low and middle income countries. *Energy Res Soc Sci* 2022; **86**: 102463.

45 Barnes DF, Openshaw K, Smith KR, Plas Rvd. The design and diffusion of improved cooking stoves. *World Bank Res Obs* 1993; **8**: 119–41.

46 Bonan J, Pareglio S, Tavoni M. Access to modern energy: a review of barriers, drivers and impacts. *Environ Dev Econ* 2017; **22**: 491–516.

47 Clemens H, Bailis R, Nyambane A, Ndung'u V. Africa Biogas Partnership Program: a review of clean cooking implementation through market development in east Africa. *Energy Sustain Dev* 2018; **46**: 23–31.

48 Gall ET, Carter EM, Earnest CM, Stephens B. Indoor air pollution in developing countries: research and implementation needs for improvements in global public health. *Am J Public Health* 2013; **103**: e67–72.

49 Gill-Wiehl A, Price T, Kammen DM. What's in a stove? A review of the user preferences in improved stove designs. *Energy Res Soc Sci* 2021; **81**: 102281.

50 Karanja A, Gasparatos A. Adoption and impacts of clean bioenergy cookstoves in Kenya. *Renew Sustain Energy Rev* 2019; **102**: 285–306.

51 Khandelwal M, Hill ME Jr, Greenough P, et al. Why have improved cook-stove initiatives in India failed? *World Dev* 2017; **92**: 13–27.

52 Kowsari R, Zerriffi H. Three dimensional energy profile: a conceptual framework for assessing household energy use. *Energy Policy* 2011; **39**: 7505–17.

53 Leach G. The energy transition. *Energy Policy* 1992; **20**: 116–23.

54 Lindgren S. Cookstove implementation and education for sustainable development: a review of the field and proposed research agenda. *Renew Sustain Energy Rev* 2021; **146**: 111184.

55 Martinot E, Chaurey A, Lew D, Moreira JR, Wamukonya N. Renewable energy markets in developing countries. *Annu Rev Environ Resour* 2002; **27**: 309–48.

56 Puzzolo E, Zerriffi H, Carter E, et al. Supply considerations for scaling up clean cooking fuels for household energy in low- and middle-income countries. *Geohealth* 2019; **3**: 370–90.

57 Quinn A, Bruce N, Puzzolo E, et al. An analysis of efforts to scale up clean household energy for cooking around the world. *Energy Sustain Dev* 2018; **46**: 1–10.

58 Shankar A, Johnson M, Kay E, et al. Maximizing the benefits of improved cookstoves: moving from acquisition to correct and consistent use. *Glob Health Sci Pract* 2014; **2**: 268–74.

59 Sharma M, Dasappa S. Emission reduction potentials of improved cookstoves and their issues in adoption: an Indian outlook. *J Environ Manage* 2017; **204**: 442–53.

60 Van der Kroon B, Brouwer R, Van Beukering PJ. The energy ladder: theoretical myth or empirical truth? Results from a meta-analysis. *Renew Sustain Energy Rev* 2013; **20**: 504–13.

61 WHO. Clean Household Energy Solutions Toolkit (CHEST). https://www.who.int/tools/clean-household-energy-solutions-toolkit?msclkid=b4c31c72c6cf11ec8f2230d9bbf94fc0 (accessed May 10, 2022).

62 Whitmee S, Haines A, Beyrer C, et al. Safeguarding human health in the Anthropocene epoch: report of the Rockefeller Foundation—*Lancet* Commission on planetary health. *Lancet* 2015; **386**: 1973–2028.

63 Pinnock H, Barwick M, Carpenter CR, et al. Standards for reporting implementation studies (StaRI) statement. *BMJ* 2017; **356**: i6795.

64 Lindgren SA. Clean cooking for all? A critical review of behavior, stakeholder engagement, and adoption for the global diffusion of improved cookstoves. *Energy Res Soc Sci* 2020; **68**: 101539.

65 Troncoso K. A recipe for developing adoption & impact indices. Washington, DC: Global Alliance for Clean Cookstoves, 2014. https://cleancooking.org/reports-and-tools/a-recipe-for-developing-adoption-impact-indices-3/ (accessed May 10, 2022).

66 Ochieng CA, Zhang Y, Nyabwa JK, Otieno DI, Spillane C. Household perspectives on cookstove and fuel stacking: a qualitative study in urban and rural Kenya. *Energy Sustain Dev* 2020; **59**: 151–59.

67 Watts N, Amann M, Arnell N, et al. The 2018 report of the *Lancet* Countdown on health and climate change: shaping the health of nations for centuries to come. *Lancet* 2018; **392**: 2479–514.