A Systematic Review of
the Impacts of Clean and Improved Cooking interventions on
Adoption Outcomes and Health Impacts

An investigation of programme impacts on adoption of cleaner cooking practices, carbon monoxide, pneumonia, COPD, and blood pressure

7 AFFORDABLE AND CLEAN ENERGY

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Authors' contributions

The authors of this review include Lana Zaman, Faran Rana, and Olivia Baldy. L.Z. served as team leader and developed the methodology. All authors contributed to the search, screening, and selection of included studies. All authors contributed to extracting data from studies. L.Z. entered data into CMA, conducted analysis, and interpreted results. All authors drafted the final review.

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1 Abstract

Background: Indoor air pollution from cooking with traditional biomass presents a major health hazard in low- and middle-income countries. The 2030 Agenda for Sustainable Development, with Sustainable Development Goal (SDG) 7 dedicated to energy, sets the target to achieve universal access to clean [fuels and technologies for cooking by 2030. To date, countries have pursued a variety of policies and programmes in an effort to close the gap on clean cooking.

Objectives: In the context of SDG 7 on achieving universal access to affordable, reliable and modern energy services, the objective of this systematic review is to assess whether clean cooking interventions to date have been successful in (a) increasing users' adoption of clean cooking fuels and technologies (CFTs) and (b) improving a subset of long-term health impacts based on the use of CFTs. This review additionally examines the comparative effectiveness of various interventions and aims to identify specific challenges in the causal pathway.

Methods: This review includes studies that evaluate programme policy intervention aimed at increasing the use of CFTs in low- and middle-income countries. All the studies used a quantitative evaluation method such as a Randomized Control Trial (RCT) or a quasi-experimental approach. Based on a search for literature in three electronic databases – Scopus, Embase and Pubmed – and a search for gray literature using Google Scholar and other sources, the authors screened 1,090 papers, of which 86 studies met the inclusion criteria. The authors systematically extracted data from the qualifying studies, assessed the risk of bias, and conducted a meta-analysis on relevant outcomes to synthesize summative findings following the Campbell Collaboration Policies and Guidelines.

Results: This review finds that, on average, the clean cooking programmes and policies successfully increased adoption of CFTs; they significantly reduced fuelwood consumption, fuel collection time and cooking time. There was less evidence of the impact on health, although the review detected significant reductions in carbon monoxide levels and the odds of Chronic Obsessive Pulmonary Disorder (COPD) occurrence, based on three studies. In addition, the review found an evidence gap in that the majority of included evaluations examined improved biomass cooking stoves with few evaluations of other solutions such as liquid petroleum gas (LPG), biogas and electric cooking.

Authors' conclusions: This study found that, on average, interventions promoting improved biomass cooking stoves achieve preliminary adoption as well as intermediate benefits in terms of time use, but often do not achieve health benefits in the long term. The authors hypothesize that this may be due to (a) technologies that do not reduce air pollution enough to have a positive impact health or (b) the lack of sustained use of new technologies, often due to complex maintenance and repair requirements.

Key lessons and recommendations: With limited evidence of health benefits associated with improved biomass cooking stoves, a better solution may be to prioritize the cleanest and most stringent fuels and technologies in terms of lowering emissions; this includes LPG, gas and electric cooking solutions. Improved biomass cooking stoves do present some benefits, particularly in intermediate outcomes, and may therefore serve as a bridge technology; however, the provision of maintenance and repair facilities for these technologies is critical to retaining users.

Inclusive planning and programming have demonstrated effective results in terms of successful adoption. Small, flexible pilot programmes with evaluations and feedback loops can help implementers adapt programmes to local needs before bringing projects to scale. Monitoring and evaluation using precise methods and technologies, such as real-time sensors, could better inform about programme and policy implementation by tracking adoption behaviour and programme impacts.

2 Plain language summary

2.1 The review in brief

The global review suggests that, on average, clean cooking programmes and policies have successfully increased the adoption of clean cooking fuels and technologies (CFTs), and have significantly reduced fuelwood consumption, fuel collection time and cooking time. However, there is less evidence of the impacts on long-term health.

2.2 What is the review about?

Globally, cooking with open fires or simple stoves fuelled by kerosene, coal biomass such as wood, dung and agricultural residues leads to almost four million premature deaths per year.[1] In addition to po health, unclean cooking practices are linked to poverty, environmental degradation, air pollution, gender inequality and climate change. As of 2018, only 61% of the global population had access to clean cooking fuels and technologies (CFTs).[2] Filling this gap and attaining universal access by 2030, as stipulated under the 2030 Agenda for Sustainable Development, presents a challenge. Despite decades of effort, progress on this front has been slow. Implementation of effective policies and programmes could help accelerate the transition to clean cooking in line with Sustainable Development Goal (SDG) 7 on energy.

This systematic review examines the impacts of past policies and programmes aimed at increasing access to CFTs to assess whether they have successfully (a) increased adoption of CFTs (defined as both increased use of CFTs and decreased use of dirtier cooking practices measured through numerous indicators and proxies), and (b) improved long-term health impacts including acute respiratory infections (ARI), Chronic Obstructive Pulmonary Disease (COPD), pneumonia, hypertension and blood pressure.[3] In addition, this review examines heterogeneous findings between different evaluations in order to discuss what types of policies and programmes led to success or the lack thereof.

2.3 What types of studies are included?

This review includes quantitative studies using experimental or quasi-experimental designs to quantify the impacts of policies and programmes designed to increase access to CFTs in low- and middle-income countries. All the studies needed to have a valid counterfactual to allow for isolation of impacts. The included studies examined at least one of the following: (a) impacts on adoption outcomes (consumption of wood, charcoal LPG; ownership of an improved cooking stove);[4] (b) intermediate outcomes (fuel collection

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1   World Health Organization, "Household Air Pollution and Health Fact Sheet", 8 May 2018.
2   ESCAP, Asia-Pacific Energy Portal.
3   Although the terms 'blood pressure' and 'hypertension' overlap, the review treats 'hypertension' as a diagnosed medical condition while 'blood pressure' looks at changes in blood pressure levels over a certain period of time.
4   Any stove that was defined as 'improved' by individual study authors, because it was fuel efficient, reduced smoke and/or improved ventilation.

time, cooking time and carbon monoxide levels); and/or (c) long-term health impacts including pneumonia, ARI, COPD hypertension and blood pressure. All the studies needed to examine outcomes at least two weeks after the intervention.

The authors screened a total of 1,090 papers, from which 86 studies met the criteria of the systematic review. These consisted of 46,115 households globally.

2.4   What are the findings of this review?

This systematic review found that, on average, clean cooking interventions did indeed reduce fuelwood consumption,[5] **fuel collection time**[6] **and cooking time,**[7] **indicating that the programmes successfully increased the adoption of clean cooking fuels and technologies.** Adoption in this case is defined as both increased usage of CFTs and reduced usage of dirtier cooking practices, measured through various indicators. Although several studies noted reductions in the consumption of coal/charcoal and LPG, the summary statistic from the meta-analysis was not significant.

The review found evidence associating CFT interventions with a reduction in COPD; however, the review did not detect significant reductions in ARI, pneumonia, blood pressure or hypertension. The review also detected a significant reduction in carbon monoxide levels. Based on three long-term studies spanning 9-26 years of follow-

up,[8] the review found that CFT interventions reduced the odds of COPD by 77%. Impacts on pneumonia, blood pressure and hypertension were not statistically significant, although the number of the included studies examining each of these outcomes was quite low. Based on an examination of heterogeneous findings, there was some preliminary evidence of impact within specific subpopulations; some studies found that interventions had greater impact on the health of older populations, including the reduction and risk of hypertension. In addition, the review found a small but significant reduction in carbon monoxide levels, an intermediate outcome that could lead to a long-term positive health impact.

Based on qualitative analysis of the individual studies, many programmes struggled to achieve sustained use due to maintenance issues and lack of repair facilities. Although the results of this review suggest that the interventions indeed led to adoption, many of the studies' authors noted that users later abandoned new technologies due to malfunction, inconvenient maintenance requirement and/or lack of long-term repair facilities. They suggested that the need for maintenance and repair was likely a disincentive for sustained use.

Last, this review has found an evidence gap in which the majority of the evaluation literature focuses on improved biomass cooking stoves. This limits the ability of the current review to quantify the effectiveness

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5   Hedges's G = -0.52; CI: -0.83, -0.20.
6   Hedges's G = -0.35; CI: -0.63, -0.08.
7   Hedges's G = -0.25; CI: -0.48, -0.03.

8   Unlike Zhou (2014) and Chapman (2005) who followed study populations f a maximum of 9 and 26 years respectively, Peabody (2005) does not specify the exact years of follow-up. Instead, a one-time survey was conducted and inquired about the 'histy of COPD'. This review considers this to be a long-term study as it generates a hisical recall of the diagnosis and this could take any number of years depending on the age of the respondents and how recently they were diagnosed. Depending on the province, the average age of children ranged from 4.8-5.1 years and for adults, 39.7-43.7 years. No information is given on how recent the diagnosis was made.

of other solutions, such as LPG, gas and electric cooking stoves. Out of the 86 studies included in this review, 52 focused on improved biomass cooking stove solutions. With few studies examining the impacts of LPG, biogas and electricity for cooking, the conclusions of the current review primarily apply to improved biomass cooking stoves. Any intervention-specific findings are indicated.

Based on assessment of bias risk, using the Risk of Bias in Non-randomized Studies (ROBINS-I) tool,[9] the risk of bias in the included studies was relatively low. Studies with a high risk of bias were excluded.

2.5 What do the findings of this review mean?

The findings of this review indicate that while, on average, clean cooking policies and programmes have successfully led to short-term adoption, there is limited evidence of long-term health impacts. Stronger evidence on the long-term health impacts of interventions and pathways for change could help to provide information about effective policies and programming.

This review proposes two hypotheses for why the clean cooking interventions under examination might not have led to health benefits in terms of ARI, pneumonia or hypertension.

a. **The first hypothesis is that the included interventions might not have been clean enough to improve health.** As noted above, the majority of interventions focused on improved biomass cooking stoves. Many of these studies did not specify the quality of the device what tier of clean cooking access

it provided. The WHO Guidelines on Indo Air Quality suggests that although improved biomass cooking stoves effectively reduce air pollution when compared to traditional stoves, many of these technologies do not meet WHO standards.[10] For this reason, the air quality improvement may have been insufficient to lead to health gains.

b. **A second possibility is that a lack of sustained use of the clean technologies reduced health impacts.** The authors of many of the included studies noted that after initial adoption, users often abandoned new technologies, particularly improved biomass cooking stoves, in favour of their traditional cooking methods. The reasons most often cited were that the technologies broke or malfunctioned, and users were either unable or unwilling to invest in repairs and maintenance. This lack of sustained long-term use may have decreased the effectiveness of interventions.

An additional study is needed to determine whether these hypotheses are correct.

2.6 Key lessons and policy recommendations

Based on the summative findings of the meta-analysis as well as the qualitative information within the individual studies, and taking into account the WHO Guidelines for Indo Air Quality, the authors have identified the following policy recommendations:

♦ With limited evidence of health benefits associated with improved biomass cooking stoves, programmes and policies should

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9   Cochrane Methods. Robins-I Tool. Available at https://methods.cochrane.g/methods-cochrane/robins-i-tool

10   World Health Organization, 2014. WHO Guidelines f Indo Air Quality: Household Fuel Combustion. Available at https://www.who.int/airpollution/publications/household-fuel-combustion/en/

prioritize the cleanest and most stringent fuels and technologies in terms of lowering emissions. This includes LPG, gas and electric cooking solutions. Improved biomass cooking stoves present some intermediate benefits and are generally more affordable; therefore, they may serve well as a bridge technology;

◆ Many programmes fail to achieve sustained use due to maintenance issues and lack of repair facilities. To address this issue, implementers could prioritize solutions that require less maintenance, and/or make provisions for long-term repairs;

◆ Inclusive planning and programming have demonstrated effective results in terms of successful adoption. This requires intensive engagement with local communities and households to understand user-needs, and promote uptake of CFTs;

◆ Small, flexible pilot programmes with evaluations and feedback loops can help implementers adapt programmes to local needs before bringing projects to scale.

◆ Monitoring and evaluation, using precise methods and technologies such as real-time sensors, could provide better information about programme and policy implementation by tracking adoption behaviour and programme impacts over time.

2.7   How up-to-date is this review?

The team conducted the electronic search for papers in May 2020. The search for gray literature continued until June 2020. Accordingly, this systematic review covers papers published up to June 2020.

3 Background

3.1   Introduction

Globally, cooking with open fires or simple stoves fuelled by kerosene, coal, biomass such as wood, dung and agricultural residues leads to almost four million premature deaths per year. These inefficient cooking practices and the subsequent pollution have negative health impacts including pneumonia, stroke, ischaemic heart disease, chronic obstructive pulmonary disease and lung cancer. Women are at particularly high risk since in many countries they take primary responsibility for cooking. Children are also at high risk with indoor air pollution almost doubling their risk of pneumonia.[11]

Fuel gathering presents significant economic barriers. It consumes considerable time, particularly for women and girls who tend to be primary gatherers. This limits time that may have been spent on other productive activities such as income generation and education. Many women spend the majority of their productive hours gathering fuel and cooking, which drastically limits any other opportunities they may have had outside the home. Based on a study in Bangladesh, India and Nepal, the Clean Cooking Alliance estimates that women using traditional stoves spend an average of one hour per day gathering fuelwood and an additional four hours per day cooking every day.[12] Modern cooking stoves can drastically reduce this time. Furthermore, carrying heavy fuel such as wood can cause musculoskeletal damage. In less secure environments fuel gatherers may be vulnerable to gender-based violence. Last, as resources become depleted, women often need to travel further and further to gather wood; this travel exposes them to the risk of accident injury.

The 2030 Agenda for Sustainable Development prioritizes universal access to clean cooking under SDG 7 on energy. This goal includes three targets by 2030 to: (a) ensure universal access to affordable, reliable and modern energy services, including access the electricity and access to clean fuels and technologies; (b) increase substantially the share of renewable energy in the global energy mix; and (c) double the global rate of improvement in energy efficiency. Among the three targets, universal access to energy, particularly clean cooking, remains the most elusive. Approximately 35% of the global population is currently without access to clean cooking fuels and technologies. Among developing economies, the rate is closer to 45%.[13] Progress has been slow over the past 20 years as this issue is not often prioritized by Governments and policymakers. Initiatives are often undertaken at the project level with little coordination or long-term oversight. Clean cooking remains severely underfinanced. Sustainable Energy f All (SEfAll) estimates that during 2013-2017, only 1% of the annual investment required to attain universal access to clean cooking could be tracked in financial

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11   World Health Organization, "Household Air Pollution and Health Fact Sheet", 8 May 2018.
12   Clean Cooking Alliance, "Women spend 374 hours each year collecting firewood in India, study finds." Available at www.cleancookingalliance.g

13   https://www.iea.g/repts/sdg7-data-and-projections/access-to-clean-cookingInternational Energy Agency, SDG 7: Data and Projections, Access to clean cooking. Available at www.iea.org/reports/sdg7-data-and-projections/access-to-clean-cooking

commitments.[14] The prospects of achieving universal access by 2030 remain unlikely. There is a need for more comprehensive policies, strategies and targeted financing to address the clean cooking issue.

In collaboration with the Energy Foundation of China (EFC), the Energy Division of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) undertook the current study to quantify the impacts of clean cooking access on health outcomes of users with a view towards informing an evidence-based policy for attaining universal access. The review will help to understand better (a) whether clean cooking interventions are successfully leading to adoption of clean cooking solutions, and (b) what types of clean cooking interventions have been successful and which have not.

This study is the first of two systematic reviews that the Energy Division is undertaking on the subject of energy access. The current study focuses on the intermediate and long-term impacts of clean cooking interventions on clean cooking adoption and health; the second will examine the demonstrated impacts of electricity access programming on socioeconomic outcomes for target populations.

3.2   The issue

Cooking is a cultural experience, deeply rooted in tradition, and local norms and customs. Effecting change in cooking practices can be challenging; in order to be successful, policies and programmes should take into account local customs and preferences.[15] Experience has shown that effectively achieving a transition to the use of cleaner cooking fuels and technologies requires a great deal of behaviour change. In some cases, local communities are resistant to adopting clean cooking; in other cases, households may initially adopt cleaner cooking practices and then gradually go back to their original practices due to inappropriate technologies, lack of affordability, lack of awareness of the benefits lack of repair facilities.[16] In many cases, interventions do not adequately consider the specific needs and preferences of the local communities. In other cases, adoption rates are low due to a lack of understanding and misconceptions about the relative costs. For example, with electricity access rapidly increasing, cooking using electricity is in some cases cheaper than using LPG, but local communities still perceive electricity as expensive.[17]

In addition, while projections often assume that users will adopt new fuels technologies in full, the much more common trend is fuel stacking. Users tend to use a portfolio of different kinds of fuels and technologies, which they alternate based on prices and cooking preferences for specific dishes. For example, studies in India have shown that while many rural users enjoy using LPG to prepare tea and snacks, they still use unsustainable biomass and traditional stoves to cook regular meals.[18] Similarly, numerous studies have found that the comparative cost of different cooking fuels is a key determinant of fuel usage. For

14   SEforAll, Energizing Finance: Understanding the Landscape, 2019. Available at www.seforall.org/publications/energizing-finance-understanding-the-landscape-2019

15   United Nations Department of Economic and Social Affairs, 2018, "Achieving Universal Access to Clean and Modern Cooking Fuels, Technologies and Service".

16   Rosenthal et al, 2017, "Implementation science to accelerate clean cooking for public health", *Environmental Health Perspective*, vol. 125, No. 1. Available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5226685/

17   LEADERS Nepal, University of Houston, 2019, "Electricity Use and Cost for Cooking".

18   Carlos F. Gould and Johannes Urpelainen, November 2018, "LPG as a clean cooking fuel: Adoption, use, and impact in rural India", *Energy Policy*, vol. 122, pp. 395-408.

example, if the kerosene price falls, households are comparatively more likely to use it.[19]

From 2010 to 2018, the global rate of clean cooking [access] rose from approximately 52% to 62%.[20] While this reflects steady progress, the pace of improvement is insufficient to attain universal access by 2030 in keeping with the SDGs. Clean cooking initiatives are often undertaken at the project level with funding by donor agencies the private sect, but without coordination with larger national plans.[21] Addressing the issue comprehensively, and in cooperation with national Governments, will be critical to eliminating the associated premature deaths as well as the advancement of sustainable and inclusive development. In this regard, systematic assessment of clean cooking interventions helps to shed light on what types of programmes and policies are likely to effect change.

/3.3 Why carrying out this review is important

The current study serves to quantify the uptake of clean cooking solutions as well as their impacts on long-term health, based on econometric studies from around the globe. Furthermore, this study examines the specific challenges along the theory of change based on study findings.

While much of the existing literature discusses the detrimental health impacts of cooking with traditional biomass, there is limited systematic evidence on how clean cooking interventions

have an impact on health in the field. In addition, existing literature sheds light on some of the contextual characteristics that influence adoption, but there remains little quantitative evidence of what types of interventions (e.g., type of fuel/technology type training/programme monitoring) lead to adoption. The current study aims to help fill these research gaps and inform about evidence-based policy. Compared with existing evidence, the current study has three unique features: (a) the focus on clean cooking policies and programmes; (b) examination of fuel-stacking practices; and (c) the focus on field-based evidence. These three features are considered in greater detail below:

a. **Clean cooking interventions.** Because the purpose of this report is to inform programmes and policies, this systematic review focuses exclusively on evaluations in which there is a distinct policy programme intervention designed to boost clean cooking practices; the study examines what worked and what didn't among these interventions to help inform future interventions, particularly with regard to how to boost adoption. While existing literature on the drivers and barriers to adoption can help inform of the pre-existing conditions that motivate adoption, this study focuses on how targeted interventions, including small-scale projects, policies and programmes, can have greater impact;

b. **Fuel stacking practices.** There remains little evidence on the specific nature of fuel stacking. In order to capture fuel stacking trends, this review defined adoption broadly as both adoption of clean fuels and technologies (such as LPG, biogas, electric cooking or improved biomass cooking stoves) as well as reduced use of dirtier fuels and technologies (such as wood or dung using traditional cooking stoves or

19 Arjun S. Bedi, Robert Sparrow and Luca Tasciotti, 2017, "The impact of a household biogas programme on energy use and expenditure in East Java", *Energy Economics*, vol. 68.

20 United Nations Economic and Social Commission for Asia and the Pacific. Asia-Pacific Energy Portal. Available at https://asiapacificenergy.g/

21 United Nations Economic and Social Commission for Asia and the Pacific, 2018, *Energy Transition Pathways f the 2030 Agenda in Asia and the Pacific*.

open fires). The study accordingly examined the impact of various clean cooking interventions on the usage of different fuels;

c. **Field-based evidence.** Last, the current study focuses exclusively on field-based evidence. Some studies only examine outcomes in the very short-term under settings that me closely resemble a laboratory experiment than typical field usage. For example, field-based researchers work directly with participants throughout the cooking process in order to ensure correct usage of equipment, and then to test indoor air pollution levels immediately afterwards. In an effort to capture the impacts of interventions under typical field usage, this review has excluded such studies and focused on evaluations examining impacts a minimum of two weeks after the start of the programme.

3.4 How the intervention might work: Theory of change of outcomes

Within the development literature, there is a widely accepted they that clean cooking interventions lead to intermediate outcomes of lower pollution and less time spent gathering fuel, which in turn leads to health improvements, reduced deforestation, increased productivity and women's empowerment. In practice, however, achieving long-term even intermediate change through clean cooking interventions is often challenging, possibly due to low adoption rates of clean fuels and technologies discontinuation of use.[22] Cooking is a habitual practice, deeply rooted in local customs and practices;

motivating change in the ways that people cook and enjoy food is extremely challenging, and not very well-researched. Furthermore, even if beneficiaries adopt clean cooking practices initially, attaining long-term benefits requires continued correct use of the fuel technology as well as regular repair repurchase as needed.

For these reasons, the current study elaborates on some of the implicit assumptions of the clean cooking they of change. Based on a review of several theories, the study adopts a modified version of Burwen's complex they of change, which demonstrates how clean cooking interventions may lead to intermediate and long-term benefits in a complex environment; this they of change further elaborates some of the underlying assumptions f interventions to be successful.[23] As shown in figure 1, the adoption and continued use are two of the key underlying assumptions regarding the success and long-term impact of clean cooking interventions.
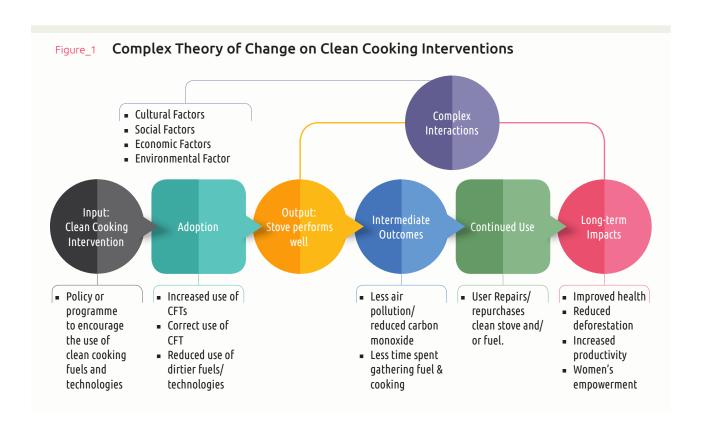
Because household cooking is often characterized by fuel stacking – the practice of using multiple types of fuels and technologies in the same household – "adoption of clean cooking practices" in this case is defined as the increased use of clean fuels/technologies, and/ the decreased use of dirty fuels/technologies, and/ the correct use of clean fuels and technologies. While research projections often assume perfect compliance in the transition from dirtier to cleaner cooking practices, this assumption is not always realistic in the field. For this reason, this study examines the specific changes in the usage of different types of fuels and technologies resulting from clean cooking interventions. In addition, cooking technologies are not always aligned to

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22 Hanna Rema, 2012, "Up in Smoke: The influence of household behaviour on the long-run impact of improved cooking stove". Available at https://www.nber.g/system/files/wking_papers/w18033/w18033.pdf

23 Jason Burwen, 2011, "From Technology to impact: Understanding and measuring behavior change with improved biomass cookstoves". Available at https://www.cleancookingalliance.g/binary-data/CMP_CATALOG/file/000/000/124-1.pdf

Figure_1 Complex Theory of Change on Clean Cooking Interventions

Complex Interactions

- Cultural Factors
- Social Factors
- Economic Factors
- Environmental Factor

Input: Clean Cooking Intervention → **Adoption** → **Output: Stove performs well** → **Intermediate Outcomes** → **Continued Use** → **Long-term Impacts**

- Policy or programme to encourage the use of clean cooking fuels and technologies

- Increased use of CFTs
- Correct use of CFT
- Reduced use of dirtier fuels/ technologies

- Less air pollution/ reduced carbon monoxide
- Less time spent gathering fuel & cooking

- User Repairs/ repurchases clean stove and/ or fuel.

- Improved health
- Reduced deforestation
- Increased productivity
- Women's empowerment

cooking practices in the field. For this reason, technologies sometimes perform much better in laboratory testing than they do in the field. Using the technology differently from what it was designed for will lower the total reduction in pollution, rendering the intervention less helpful. However, few evaluations report on this phenomenon.

Last, household energy requirements and the specific expectations/need from cooking technologies vary widely, based on context. This is represented by the "complex interactions" in figure 1, encompassing cultural, social, economic and environmental facts that influence both adoption and long-term impacts of the clean cooking interventions.

/3.5 Review of related literature

The systematic review methodology, particularly when including meta-analysis, is a very powerful tool for cumulating and summarizing the research across a field of knowledge.[24] Systematic reviews bring together and make comparable studies from different settings that would otherwise be difficult to compare. This makes it possible to overcome some of the limitations of a single individual study; for example, a single evaluation may be highly accurate for one particular programme population, while meta-analysis can draw conclusions about the efficacy of a type of programme implemented across multiple settings. Because it consolidates quantitative impacts into one combined effect size, meta-analysis

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24 Estaban Walker, Adrian Hernandez and Michael Katta, 2008, "Meta-analysis: It's strengths and limitations," *Cleveland Clinic Journal of Medicine*, vol. 75, No. 6.

is one of the most comprehensive and least biased approaches to examining an issue. Because clean cooking has been a challenging issue to address in many countries, attaining high-quality quantitative evidence on what programme elements effectively lead to adoption will be a critical input to future programming

While there are several systematic reviews on the topic of clean cooking, this study is the first to use meta-analysis to comprehensively analyse adoption of clean cooking fuels and technologies based on programmes as a pathway for long-term impact. Relevant systematic reviews are summarized briefly in table 1 and the subsequent text.

3.5.1 Impacts of clean cooking on health

Several of the systematic reviews listed in table 1 found that cooking with dirty fuels is associated with negative health impacts. Amegah (2014) found that household combustion of fuel leads to adverse pregnancy outcomes, including a 35% increase in the risk of low birth weight and 29% increase in the risk of stillbirth. Bruce (2013) found similar impacts as well as evidence linking household air pollution (HAP) with a higher likelihood of respiratory infection, stunting and all-cause mortality among children aged under five years. Dherani (2008) found that HAP increased children's pneumonia risk by a factor of 1.8. Pope (2017), Quansah (2017) and Thomas (2015) demonstrate that clean cooking interventions help lower PM 2.5 and carbon monoxide levels, but not enough to meet levels recommended by WHO. Thomas (2015) also notes that for programmes to effectively reduce HAP, good design, strong implementation and continual monitoring are critical. Thakur (2018) examined the impacts of improved biomass cooking stoves on intermediate health outcomes, fand found

that they can reduce coughing by 28%, phlegm by 35%, wheezing by 59% and conjunctivitis by 42%. These intermediate symptoms can be indicators of long-term health issues such as COPD, suggesting that improved cooking stoves might benefit long-term health.

25 Adeladza K. Amegah, Reginald Quansah and Jouni Jaakkola, 2914, "Household air pollution from solid fuel use and risk of adverse pregnancy outcomes: A systematic review and meta-analysis of the empirical evidence", *Plos One*, vol. 12, No .9.

26 95% Confidence Interval: -117.37, -55.49.

27 95% Confidence Interval: 1.23, 1.48

28 95% Confidence Interval: 1.18, 1.41

29 Bruce, N. G. et al., 2013, "Control of household air pollution f child survival: estimates f intervention impacts", *BMC Public Health*, vol.13, No. S8.

30 Lewis, J. J. and S. K. Pattanayak, 2012', "Who adopts improved fuels and cookstoves? A systematic review", *Environmental Health perspectives*, vol. 120, No. 5 .

31 Patelarou, E. and F. J. Kelly, 2014, "Indo exposure and adverse birth outcomes related to fetal growth, miscarriage and prematurity – A systematic review", *International Journal of Environmental Research and Public Health*, vol. 11,

32 Dherani, M. et al., and others, 2008, "Indo air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis", *Bulletin of the World Health Organization*.

33 Daniel Pope and others, 2017, "Real-life effectiveness of 'improved' stoves and clean fuels in reducing: PM2.5 and CO: Systematic review and meta-analysis", *Environment International*, vol. 101, pp. 7-18.

34 Reginald Quansah and others, "Effectiveness of interventions to reduce household air pollution and/ improve health in homes using solid fuel in low-and-middle income countries: A systematic review and meta-analysis", *Environment International*, vol. 103, pg. 73-90 (March 2017).

35 Eva A. Rehfuess and others, "Enablers and Barriers to Large-Scale Uptake of Improved Solid Fuel Stoves: A Systematic Review", Environmental Health Perspectives, vol. 122, No. 122 (February 2014).

36 Fuel and technology characteristics; Household and setting characteristics, knowledge and perceptions; financial, tax and subsidy aspects; market development; regulation, legislation and standards; programmatic and policy mechanisms – including issues that impacted equity

Table_1   **Systematic reviews examining cooking practices, adoption of clean cooking and health impacts**

Author and year	Topic	Key findings
Amegah, 2014[25]	The impacts of household air pollution (HAP) on adverse pregnancy outcomes.	This systematic review with meta-analysis found that household combustion of solid fuels resulted in adverse pregnancy outcomes, including: 86.43 g reduction in birth weight (LBW);[26] 35% increase in risk of low birth weight;[27] 29% increase in risk of stillbirth.[28]
Bruce, 2013[29]	The impacts of HAP exposure on child pneumonia, adverse pregnancy outcomes, stunting and all-cause mortality for children aged 0-59 months.	This systematic review with meta-analysis found evidence linking HAP exposure with child acute lower respiratory infection (ALRI), LBW, stillbirth, pre-term birth, stunting and all-cause mortality.
Dherani, 2008[30]	The impact of air pollution from the use of unprocessed solid fuel on pneumonia risk for children under 5.	This systematic review with meta-analysis found that exposure of young children to unprocessed solid fuels increases the risk of pneumonia by a fact of 1.8.
Lewis, 2012[31]	Summary of existing evidence of facts associated with household adoption in developing countries of (a) improved cooking stoves, and (b) cleaner fuels.	This systematic review with a simple vote-counting meta-analysis found that income, education and urban location were positively associated with adoption. The influence of fuel availability and prices, household size and composition, and sex is unclear. The study further highlights the fact that literature on clean cooking adoption is scarce, scattered and of differential quality.
Patelarou, 2014[32]	Summary of existing epidemiological evidence of the association between air pollution and adverse birth outcomes.	This systematic review assessed the impacts of indoor air pollution on fetal growth, prematurity and miscarriage based on quantitative estimates. The study concluded that there is insufficient research on potential association between indoor air pollution and early life effects. Further research is needed.
Pope, 2017[33]	The impact of clean cooking interventions on PM2.5 and carbon monoxide in low- and middle-income countries with respect to WHO guidelines.	This systematic review with meta-analysis found that while clean cooking interventions led to reduced PM2.5 and carbon monoxide levels, they did not achieve results close to World Health Organization (WHO) recommended levels. This may be due to neighbourhood contamination, which suggests that household energy policy should prioritize community wide use of clean fuel.
Quansah, 2017[34]	The impact of household air pollution interventions on improved indoor air quality in low- and middle-income countries. A secondary objective was to evaluate improvements in health.	This systematic review with meta-analysis found that the interventions improved PM2.5 and carbon monoxide concentrations at the micro-environment and personal level. Significant improvement was observed in personal PM among children. Post-intervention levels of pollutants were generally still greatly in excess of the relevant WHO guideline. Findings on health were inconclusive mainly due to limited evidence.
Rehfuess, 2014[35]	Summary of existing evidence on facts that influence large-scale uptake of improved solid fuel stoves in low- and middle-income countries.	The study identifies 31 facts across seven domains[36] that jointly influence adoption and sustained use of improved solid fuel stoves. While all domains matter, the relative importance of these facts is context specific and requires further research, Thus, achieving large-scale adoption and sustained use requires that all facts be assessed and supported by policy.

Author and year	Topic	Key findings
Saleh, 2020[37]	Summary of existing RCT's focusing on clean cooking interventions to reduce particulate matter and improve respiratory health in low- and middle- income countries.	The systematic review found that clean cooking interventions, mainly improved cooking stoves (ICS) using biomass, produced limited benefits for respiratory health.
Simkovich, 2019[38]	The impact of clean cooking Technologies on time use in low- and middle-income countries.	The systematic review with meta-analysis indicates that clean fuel interventions (not including improved biomass cooking stoves) can lead to significant time savings.[39]
Thakur, 2018[40]	The impact of improved biomass cooking stoves interventions on women's and child morbidity and mortality in low- and middle-income countries.	The systematic review with meta-analysis indicates that improved biomass cooking stoves can reduce airway symptoms and conjunctivitis, and potentially also COPD incidence among women: 28% reduction in cough[41] 35% reduction in phlegm[42] 59% reduction in wheezing[43] 42% reduction in conjunctivitis[44] No demonstrable child health impact was observed.
Thomas, 2015[45]	Summary of existing evidence on improved stove interventions aimed at reducing household air pollution in low- and middle-income countries.	The study finds that stove interventions can have positive effects when well-designed, implemented and monitored. However, the impacts are unlikely to reduce pollutants to levels recommended by WHO. Future studies require greater process evaluation to improve knowledge of implementation barriers and facilitators.
Vigolo, 2018[46]	Systematic literature review comprising of 81 studies to (i) identify drivers and barriers that influence consumers' adoption of ICS, and (ii) differences in consumer perception of ICS in comparison with traditional cooking stoves.	The study finds that determinants of adoption include economic standing, socio-demographic characteristics, fuel availability, consumer perceptions, and other social and cultural influences.

37 Saleh et. al.., 2020, "Air pollution interventions and respiratory health: A systematic review", *International Journal of Tuberculosis and Lung Disease*, vol. 24.

38 Suzzane M. Simkovich and others, 2019, "A systematic review to evaluate the association between clean cooking technologies and time use in low- and middle-income countries", *International Journal of Environmental Research and Public Health*.

39 The review included only two studies based in India

40 Megha Thakur and others, 2018, "Impact of improved cookstoves on women's and child health in low- and middle-income countries: a systematic review and meta-analysis", *Thorax*, vol. 73.

41 Risk Ratio=0.72, 95% Confidence Interval: 0.60 to 0.87.

42 Risk Ratio =0.65, 95% Confidence Interval: 0.52 to 0.80.

43 Risk Ratio =0.41, 95% Confidence Interval: 0.29 to 0.59.

44 Risk Ratio =0.58, 95% Confidence Interval: 0.43 to 0.78.

45 Emma Thomas and others, 2015, "Improved stove interventions to reduce household air pollution in low- and middle-income countries: A descriptive systematic review", BMC Public Health, vol. 15, No. 650.

46 Vania Vigolo et al., 2018, "Drivers and barriers to clean cooking: A systematic literature review from a consumer behaviour perspective", *Sustainability*, vol. 10, No. 11.

3.5.2 Adoption of clean cooking practices

While there are several systematic reviews of the health impacts of clean cooking, few examine clean cooking adoption. To date the research team has encountered three systematic reviews and one systematic evaluation of evidence on adoption. Rehfuess (2014) and Vigolo (2018) focus on the household characteristics and contexts that determine adoption. Rehfuess (2014) identifies 31 facts across seven main domains that have an impact on the adoption of improved biomass stoves:

a. Fuel and technology characteristics;

b. Household and community characteristics;

c. Local perceptions and knowledge;

d. Costs and financing;

e. Market development;

f. Regulation, legislation and standards;

g. Programmatic and policy mechanisms.

While all of these domains matter, their relative importance is context-specific; therefore decision-makers would benefit from considering all domains and their relative importance in pursuing large-scale adoption.

The study by Vigolo (2018), "Drivers and Barriers to Clean Cooking: A Systematic Literature Review from a Consumer Behavior Perspective", found that determinants of adoption of ICS include economic standing, socio-demographic characteristics, fuel availability, consumer perceptions, and other social and cultural influences. In this regard, households that were wealthier, more educated, or more accepting of technology were more likely to adopt ICS. In terms of family, female-headed households were also more likely to adopt, suggesting that where women had the autonomy to do so, they were more likely to value clean cooking. Large families were less likely to use ICS, in part because they found these stoves too small to accommodate their needs.

Social influence and consumer perceptions were also important facts. The opinions of respected community members and leaders were highly influential in the adoption of clean cooking practices, suggesting that social influence could be a critical area in programming. Furthermore, establishing ICS as a status symbol luxury item further improved its adoption, suggesting that branding may be an important fact. Convenience of use and awareness of the health and environmental impacts were also critical to uptake. However, Vigolo (2018) focused exclusively on ICS and did not examine other clean cooking fuels and technologies such as LPG.

Simkovich (2019)[47] examined various clean cooking interventions, not including biomass cooking stoves. Based on two studies in India, Simkovich found that biogas interventions led to significant time savings in terms of less time spent cooking and gathering fuel.

An upcoming systematic evaluation of evidence by Modern Energy Cooking Services (MECS) on "Analysis of the Drivers and Barriers for Transition to Modern Energy Cooking Services (MECS)" notes that the literature on clean cooking adoption is hardly conclusive, owing to the fragmented nature of the evidence and the variation across studies in terms of data collection, reporting and methodology. The

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47 Suzzane M. Simkovich et al., 2019, "A systematic review to evaluate the association between clean cooking technologies and time use in low- and middle-income countries", *International Journal of Environmental Research and Public Health*.

study highlights the need for more rigorous evaluation of clean cooking programmes that statistically account for confounding and contextual variables, given that clean cooking interventions are implemented in a complex environment affected, both by observable channels (demographics, climate, fuelwood availability) and by unobservable channels (deep-rooted cultures and traditions).

In that context, the current study attempts to collect and analyse the most up-to-date, high quality quantitative evidence on the clean cooking adoption and its impact.

4 Objectives

The objective of this systematic review is to assess whether clean cooking interventions to-date have been successful in (a) increasing users' adoption of clean cooking fuels and technologies, and (b) improving long-term health impacts.

A secondary objective of this review is to examine the comparative effectiveness of various interventions and identify specific challenges in the causal pathway. In pursuing this objective, the authors analysed the quantitative evidence (effect sizes) of included studies, and examined some heterogeneous findings based on the qualitative evidence provided by individual authors of studies.

4.1 Research questions

The guiding research questions aim to identify the causal link from an intervention to adoption of clean cooking fuels and technologies and ultimately to health benefits. The research team additionally investigated the current cooking behaviour and trends, as well as differential impacts based on intervention characteristics and context.

4.1.1 Main questions

a. Do clean cooking interventions successfully have an impact on the adoption of clean cooking fuels and technologies?

b. What is the impact of clean cooking interventions on health?

4.1.2 Supplemental questions

a. How do impacts vary, based on the type of fuel/technology in the intervention?

b. How do results vary by geographic region?

c. What specific programme components lead to impact the lack thereof?

5 Methodology

In conducting this systematic review, the research team followed the guidelines advocated by the Campbell Collaboration for systematic reviews, as described in this section. The Campbell Collaboration is an international network with a mission to "promote positive social change by contributing to better-informed decisions and greater effectiveness for public and private services around the world". The group supports the development and dissemination of high-quality systematic reviews on the effectiveness of social programmes, policies and practices.[48] The current systematic review is not registered with the Campbell Collaboration, but follows many of the organization's guidelines and guiding principles for conducting a systematic review.

In keeping with the Campbell Collaboration's recommendation to use a theory-based approach, the theory of change (ToC) described in figure 1 was the primary guide for the research framework. It covered the inclusion criteria, outcomes examined, and data coded. ESCAP also conducted a descriptive qualitative analysis of papers in order to identify causal linkages as well as breakdowns in the ToC. The team examined both the long-term impacts (health) and the intermediate outcomes (adoption). The focus on intermediate outcomes helps to fill a research gap on a key challenge in this field and determine the success of programmes and policies. This study uses meta-analysis to quantify impacts as well as qualitative analysis to provide insights and details of pathways for achieving impacts. This section provides a brief summary. The overall methodology covering the selection criteria, search strategy and data collection and analysis is laid out in Annexes 3 to 5.

5.1 Search strategy and process

5.1.1 Inclusion criteria

The inclusion criteria employ the PICOS framework outlined in table 2 which stands for population, intervention, comparator, outcomes and study designs. In sum, this study undertakes a global review of CFT interventions in low- and middle-income countries. It only includes studies in which there was an explicit programme policy intervention focused on CFTs and a valid counterfactual using a control group, before-after design or quasi-experimental methods. Studies were included if the outcomes on adoption and health (listed in table 2) were assessed at least two weeks after the initial intervention. Study designs included randomized control trials and/or quasi-experimental designs (natural experiments, before-after studies, cross-sectional studies)

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48 Campbell Collaboration. "Campbell systematic reviews: policies and guidelines". November 2019. Available at https://onlinelibrary.wiley.com/pb-assets/assets/18911803/Campbell%20Policies%20and%20Guidelines%20v4-1559660867160.pdf

49 World Bank. "World Bank Country and Lending Groups – World Bank Data Help Desk" 2020. Available at https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups#:~:text=For%20the%20current%202021%20fiscal,those%20with%20a%20GNI%20per

50 Although the terms 'blood pressure' and 'hypertension' overlap, the review treats 'hypertension' as a diagnosed medical condition while 'blood pressure' looks at changes in blood pressure levels over a certain period of time.

Table_2   PICOS Framework summary

Population	Low- and middle-income countries based on World Bank classifications.[49] Communities receiving clean cooking interventions
Intervention	Improved biomass cooking stoves (ICS), biogas biofuel, liquid petroleum gas (LPG), natural gas, ethanol, electric cooking/induction stoves, solar cookers, and any subsidy programmes focused on these fuels and/or technologies.
Comparator	Valid counterfactual using a control group, before-after design, or quasi-experimental methods.
Outcome(s)	Adoption: (i) consumption of fuelwood, coal and LPG; (ii) usage/maintenance of clean cooking technologies. Intermediate outcomes: (i) time allocation; (ii) fuel collection time, cooking time; and (ii) carbon monoxide – ambient and personal exposure. Long-term health impacts: (i) pneumonia; (ii) chronic obstructive pulmonary disease (COPD); (iii) acute respiratory infections (ARI); (iv) hypertension; and (v) blood pressure (systolic and diastolic[50]).
Study design	Randomized control trials (RCTs), quasi-experimental designs (natural experiments, before-after studies, cross-sectional)

that sufficiently accounted for confounding facts and enabled determination of the causal impact of the clean cooking component in the intervention.

In addition, criteria include studies that examine outcomes at a minimum of two weeks after the initial intervention. Due to resource constraints, this systematic review was conducted exclusively in English. Therefore, it only includes studies published in, or translated into English.

The team also initially attempted to identify which improved biomass cooking stoves met WHO requirements for air quality; however, many studies do not provide this data. In addition, many technologies that meet WHO standards, by assuming perfect usage and regular maintenance, are not as efficient under typical field conditions. For this reason, this review includes all improved biomass cooking stoves designed to reduce pollution and fuel usage.

5.2   Search process

The team developed a comprehensive list of keywords (Annex 1) and conducted the PICOS search on 4 May 2020 in electronic databases including Scopus, Embase and PubMed. To minimize the possibility of publication bias, the research team also made efforts to search for both published and unpublished literature. Additional hand searches were conducted in Google, Google Scholar and various donor websites listed in Annex 2 in order to capture some of the gray literature that might not have been published in traditional journals. The team also reached out to the author of each eligible paper and inquired whether the author had written or knew of any published or unpublished studies that met the criteria for inclusion in the systematic review. All the results were systematically compiled into databases, cleaned of duplicates, and then screened. More information on the search process is provided in Annex 4.

5.3   Screening process

To facilitate the screening and selection of studies, the team uploaded the titles, abstracts and metadata from the electronic search into Abstrackr,[51] a free open-source software, recommended in the Campbell Search Strategy Guidelines, to facilitate review and screening for systematic reviews. When uploaded in Abstrackr, a team of three analysts double-screened all titles and abstracts. In the pilot stage, the first 100 titles and abstracts were screened by all three screeners in order to ensure agreement across the team on what types of papers qualified.

After that, two analysts independently screened each title and abstract for inclusion, and recorded reasons for exclusion where relevant. In cases of disagreement, the full team reviewed the title and abstract to come to consensus. In this stage, studies were screened on the inclusion criteria outlined based on the subject matter and the PICOS framework outlined in table 2. However, because study design and comparison are not always explicit in the title and abstract of a study, wherever analysts were uncertain of these characteristics, studies were included for further review at the full-text screening stage. For the papers attained through hand search, an initial analyst first identified qualifying studies, after which a second analyst reviewed the selections to verify.

All studies that met the inclusion criteria based on title and abstract screening then underwent a full text screening. In this stage, analysts reviewed the full document based on the inclusion criteria with particular emphasis on methodology and statistical design. Studies that met the inclusion criteria based on the full text screening went into the data collection.

5.4   Data collection and statistical analysis

In analysing each of the qualifying studies, the analysts collected detailed data on population, intervention, comparison group, outcomes of interest and study design. In addition, they extracted the effect sizes for the included outcomes and related statistical data needed to calculate standardized mean differences (SMDs), following the guidance of the Cochrane Handbook for Systematic Reviews of Interventions.[52] This included summary statistics such as averages, standard deviations, standard errors and confidence intervals. The team additionally analysed each paper to assess its risk of bias, based on a modified version of the Risk of Bias in Non-randomized Studies (ROBINS) tool, which was designed to assess the comparative effectiveness of interventions from studies that did not randomize assignment to treatment and control groups. [53, 54]

To provide a quantitative assessment of the summative findings, across studies, the authors conducted a meta-analysis. In order to be included in the meta-analysis a study had to meet the following additional criteria:

1. Include an effect size for one of the above-listed outcomes;

51   Byron C. Wallace, Kevin Small, Carla E. Brodley, Joseph Lau and Thomas A. Trikalinos. Deploying an interactive machine learning system in an evidence-based practice centre: Abstrackr. In Proc. of the ACM International Health Informatics Symposium (IHI), p.819--824. 2012.

52   Cochrane Training, 2019, Cochrane Handbook for Systematic Reviews of Interventions (Version 6). Available at https://training.cochrane.g/handbook/current

53   Cochrane Methods, Robins-I Tool. Available at https://methods.cochrane.g/methods-cochrane/robins-i-tool

54   Sterne, Jonathan AC, 2016, ROBINS-I: A tool for assessing risk of bias in non-randomized studies of interventions. BMJ 2011;343:d5928. Available at https://www.bmj.com/content/343/bmj.d5928#:~:text=The%20risk%20of%20bias%20tool%20covers%20six%20domains%20of%20bias,the%20domain%2C%20%20different%20outcomes

2. Include sufficient data about this effect size to enable calculation of a standardized mean difference;

3. Effect sizes included in meta-analysis must be independent (Annex 5).

For studies that did not provide sufficient data for inclusion in the meta-analysis, per the Cochrane Collaboration Guidance, analysts contacted authors to request the additional data needed.[55] After two weeks, analysts reached out a second time to any authors who did not respond. If an author did not respond a second time and analysts could not find sufficient data, the study was excluded from the meta-analysis. Authors undertook additional analysis to ensure independence of findings of all results included in the meta-analysis. Further details on data collected and the full list of outcomes are presented in Annex 5). The authors conducted the meta-analysis, using Comprehensive Meta-Analysis (CMA) software.[56]

5.4.1 Measurement of treatment effects

Using the effect sizes and summary statistics indicated in, each study, the authors compiled and standardized treatment effects. The specific type of effect size used depended on the outcome measured. For continuous variables, including fuel consumption, time allocation, carbon monoxide levels, and systolic and diastolic blood pressure, the effect size is expressed in Hedges's g.

Hedges's g statistic is a standardized difference between means. A Hedges's g equal to ±1 indicates that the treatment and control group differ by one standard deviation, while ±2 -2 indicates they differ by two standard deviations, and so forth. The general interpretation is that Hedges's g<0.2 indicates a small effect size, while Hedges's g>0.8 indicates a large effect.[57] The equations of Hedges's g are further detailed in annex 7.

Long-term health outcomes, including chronic obstructive pulmonary disease, respiratory infection and hypertension, were primarily measured on odds ratio (OR), and were combined accordingly. Several studies included effect sizes in risk ratio (RR). In those cases, the review team used supplemental data on the numbers of participants in each intervention group which did and did not experience the event to derive OR and combine studies accordingly. The pneumonia effect sizes were primarily stated in rate ratio and were combined accordingly. In cases where data were insufficient to transform an effect size into the common standard for a meta-analysis, the outcome was excluded. After deriving the necessary statistics, the team input the data into Comprehensive Meta-Analysis (CMA) software to calculate the standardized mean differences (SMDs) and their confidence intervals. [58]

In cases where data were missing, and the team was unable to procure the necessary data from the author, the team made several assumptions, including:

a. Where it was not specified how much of the sample was in the control group and how much was in the treatment group, the reviewers assumed that the total sample was divided equally between both groups;

55 Cochrane, 2011, Methods for obtaining unpublished data. Available at https://www.cochrane.g/MR000027/METHOD_methods-f-obtaining-unpublished-data

56 Comprehensive Meta-Analysis (Version 3) [Computer software], 2020, Englewood, NJ: Biostat. Available at https://www.meta-analysis.com/

57 Cohen. "Statistical power analysis for the behavioral sciences. 1977. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc. Available at: https://www.sciencedirect.com/book/9780121790608/statistical-power-analysis-for-the-behavioral-sciences

58 Ibid.

b. Where standard deviation was only provided either before or after an intervention, the team assumed that standard deviation was similar at both points in time.

5.4.2 Data synthesis

After obtaining the SMDs, the team used CMA to calculate pooled effect sizes for each outcome. CMA calculates the pooled effect sizes as weighted averages of the SMDs, weighted based on inverse variance. Because there is a great deal of heterogeneity in the contexts, geographical locations, interventions and populations, the team used a random effects model to account for random differences between studies. The team then used CMA to produce forest plots with summative statistics, visually demonstrating the individual findings from different studies as well as conclusions about the pooled effect sizes. The team also presented these results by using moderators (subgroup analysis by region and intervention).

5.4.3 Additional analysis

The team also examined publication bias, heterogeneity and subgroup analysis based on moderators, the methodological details of which are presented in Annex 5.

Publication bias occurs when the published literature on a topic is systematically different from the complete population of literature.[59] For example, studies demonstrating statistically significant findings may be more likely to get published than those that find null results, resulting in a bias in which the readily available publications suggest stronger findings than the complete body of research. Authors used various statistical techniques to investigate and minimize publication bias.

To further investigate trends in findings, the authors used two moderators for analysis: (1) the type of intervention; and (2) the geographic subregion. These moderators help to identify potential trends based on interventions and population subgroups.

5.4.4 Treatment of qualitative research

While the systematic review did not include studies that were purely qualitative, the team made efforts to incorporate and analyse some of the qualitative information in order to validate and further elaborate on quantitative findings. Campbell guidelines suggest that qualitative information can be valuable in terms of defining interventions in detail, providing insight into heterogeneous findings, and identifying some of the characteristics that led to success or the lack thereof.[60] In particular, qualitative analysis was used to inform heterogeneous findings as well as policy recommendations.

59 Publication Bias in Meta-Analysis – Prevention, Assessment and Adjustments, edited by H.R. Rothstein, A.J. Sutton and M. Borenstein, © 2005, John Wiley & Sons, Ltd. Available at https://www.meta-analysis.com/downloads/PBPreface.pdf

60 Campbell Collaboration, 2019, "Campbell systematic reviews: policies and guidelines". Available at https://training.cochrane.org/handbook

6 Results

6.1 Results of the search

6.1.1 Search and screening results

A total of 1,076 records were identified through electronic search in databases including Scopus, Pubmed and Embase. The hand searches identified an additional 350 records. Many of the relevant studies came from reference searches, particularly those among other systematic reviews. Other helpful resources were found by using Google Scholar. Although the team made efforts to search various donor websites for evaluations that might not have been published in journals, they found very few studies on those sites. In combining these search lists, the team identified 336 duplicate entries, leaving 1,090 records for the title and abstract screening stage.

6.1.1.1 Title and abstract screening results

A total of 1,090 titles and abstracts were double screened between two out of the three analysts using Abstrackr.[61] In the pilot stage, the first 100 titles and abstracts were screened by all three screeners in order to ensure agreement across the team on what types of papers qualified. During this pilot stage, screeners attained an overall agreement rate of 89.3% and a marginal free kappa of 0.79 (0.69, 0.88). The team calculated the Kappa rate using the free online software tool, Online Kappa
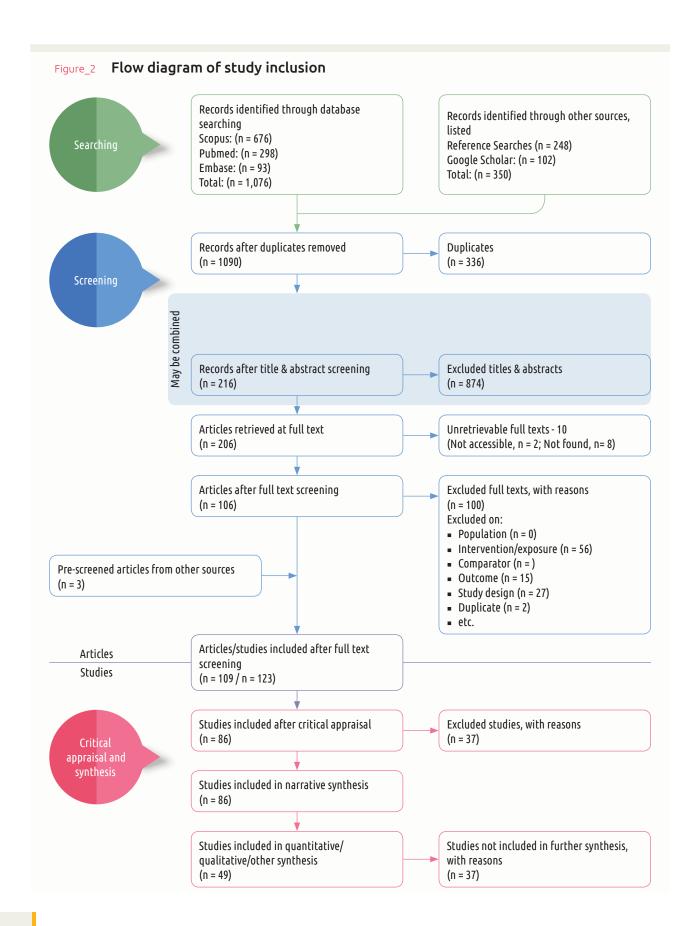
Calculator.[62] With this high level of agreement, screeners continued with double screening. Any conflicts were resolved by all three coders. The screening process identified 216 titles and abstracts, which were short-listed for a full text screening. About 874 papers were excluded; the reasons for exclusion are indicated in figure 3.
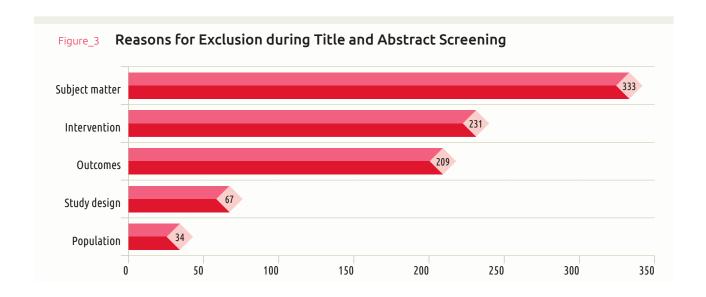
A total of 333 papers were screened out due to wrong subject matter, i.e., unrelated to the topic of clean cooking. An additional 231 papers were excluded because the study did not include a qualifying intervention. Many of these studies did not have an intervention at all. For example, several studies investigated the factors influencing household adoption of clean fuels and technology, e.g., income or education in regions where there had been no explicit programme or policy intervention. These studies were excluded. Other papers focused on the impact of traditional biomass use on health. Because this review focused on the impacts of clean cooking interventions, these studies were also excluded.

A total of 209 papers were excluded because the outcomes were not of interest. For example, some papers conducted a cost-benefit analysis or computed the willingness to pay for clean cooking technology. An additional 67 papers were excluded based on study design. These included studies for which the titles and abstracts indicated beyond reasonable doubt that the paper did not have a valid counter-factual quantitative methodology. Because

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61   Byron C. Wallace, Kevin Small, Carla E. Brodley, Joseph Lau and Thomas A. Trikalinos, 2012, Deploying an interactive machine learning system in an evidence-based practice centre: Abstrackr. In Proc. of the ACM International Health Informatics Symposium (IHI), p.819--824.

62   J. J. Randolph, 2008, Online Kappa Calculator [Computer software]. Available at http://justus.randolph.name/kappa

Figure_2 **Flow diagram of study inclusion**

Searching

Records identified through database searching
Scopus: (n = 676)
Pubmed: (n = 298)
Embase: (n = 93)
Total: (n = 1,076)

Records identified through other sources, listed
Reference Searches (n = 248)
Google Scholar: (n = 102)
Total: (n = 350)

Screening

Records after duplicates removed
(n = 1090)

Duplicates
(n = 336)

May be combined

Records after title & abstract screening
(n = 216)

Excluded titles & abstracts
(n = 874)

Articles retrieved at full text
(n = 206)

Unretrievable full texts - 10
(Not accessible, n = 2; Not found, n= 8)

Articles after full text screening
(n = 106)

Excluded full texts, with reasons
(n = 100)
Excluded on:
- Population (n = 0)
- Intervention/exposure (n = 56)
- Comparator (n =)
- Outcome (n = 15)
- Study design (n = 27)
- Duplicate (n = 2)
- etc.

Pre-screened articles from other sources
(n = 3)

Articles

Studies

Articles/studies included after full text screening
(n = 109 / n = 123)

Critical appraisal and synthesis

Studies included after critical appraisal
(n = 86)

Excluded studies, with reasons
(n = 37)

Studies included in narrative synthesis
(n = 86)

Studies included in quantitative/qualitative/other synthesis
(n = 49)

Studies not included in further synthesis, with reasons
(n = 37)

Figure_3 **Reasons for Exclusion during Title and Abstract Screening**

Reason	Value
Subject matter	333
Intervention	231
Outcomes	209
Study design	67
Population	34

some studies did not explicitly state the study design in the abstract, if the team was unsure of the study design the paper was included at this stage and further examined in the full text screening. An additional 34 papers were excluded because they did not focus on low- to middle-income countries.
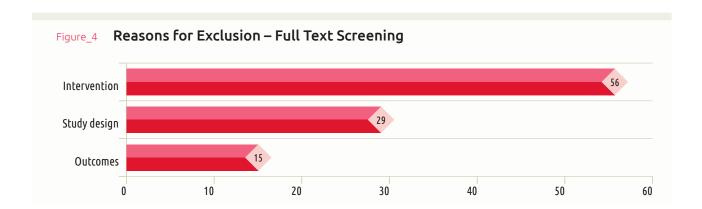
6.1.1.2 Full text screening results
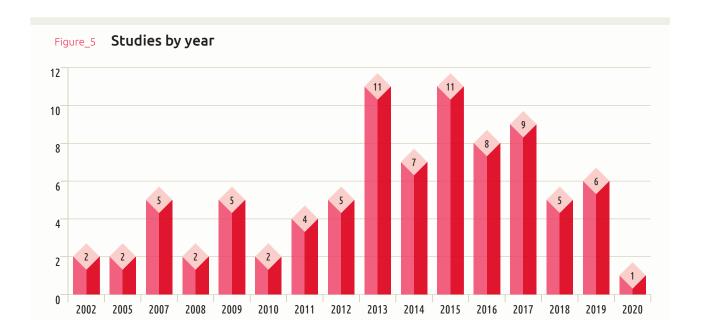
Of the 216 remaining papers, 10 were irretrievable, leaving 206 for full text screening. During this stage, 100 articles were excluded due to the reasons indicated in figure 4. As shown, 56 were excluded due to interventions that did not qualify. The majority of these studies did not include any explicit programme

or policy to boost clean cooking. An additional 29 studies were excluded due to non-qualifying study designs, and 15 due to non-qualifying outcomes.

6.1.1.3 Coding results

After the full-text screening, 109 papers were fully coded; they included 123 studies, as some of the papers included more than one study. Of these studies, 37 were excluded at the coding stage due to the following reasons: (a) violation of independent findings (due to overlapping study populations); (b) non-qualifying interventions; (c) non-qualifying study design (e.g., if only summary statistics were given without a hypotheses test); or (d)

Figure_4 **Reasons for Exclusion – Full Text Screening**

Reason	Value
Intervention	56
Study design	29
Outcomes	15

Figure_5 **Studies by year**

Figure_5 Studies by year

insufficient methodology. This left 86 studies that were included in the narrative synthesis of the systematic review. This included over 46,115 households globally.[63] Of these, 49 studies qualified for the meta-analysis. Studies were excluded from the meta-analysis if the data provided were insufficient to synthesize findings, or if the outcome was reported in a measurement inconsistent with the effect size used. For example, one study was excluded from the meta-analysis of pneumonia because the effect was measured in hazard ratio, whereas other studies measured pneumonia in rate ratio. That study was excluded because the effect sizes could not be combined.

The complete list of studies included in this systematic review is detailed in annex 6.

6.1.1.4   Studies by year

As shown in figure 5, the clean cooking evaluation literature has been increasing

since 2002. Most of the studies that met the inclusion criteria were published after 2010, with a peak from 2013 to 2017.
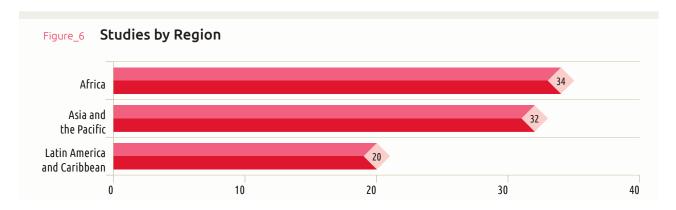
6.1.1.5   Studies by region and country
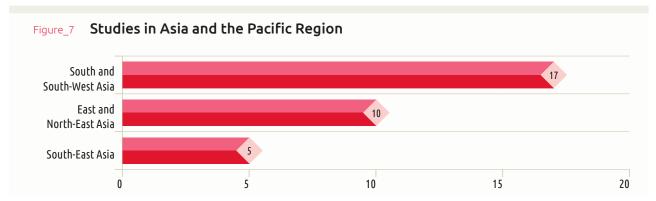
Figures 6 and 7 display the breakdown of papers by region. A total of 34 studies took place in Africa, 32 in Asia and 21 in Latin America and the Caribbean. No studies that met the inclusion criteria were found in other regions; this is consistent with the fact that the majority of the remaining clean cooking gap is in those regions.[64]

The evaluation literature seems to cluster in a few specific countries. In Africa, most evaluations took place in Kenya, followed by Rwanda, Senegal and Nigeria. In Asia, this included mainly China and India, with Nepal and Pakistan also receiving some coverage. The review also included a small number of studies each from the following countries: Malawi and Mozambique in Africa; Indonesia and Bangladesh in Asia; and Haiti and Nicaragua

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63   A few studies measured the sample size in individuals instead of households. These are indicated in Annex 6. Due to the difference in measurements, the authors could not include these in the total number of households in the study.

64   SE4All. Clean Cooking heat map. Available at https://www.seforall.org/data-stories/clean-cooking

Figure_6 **Studies by Region**

Figure_7 **Studies in Asia and the Pacific Region**

in Latin America and the Caribbean. In Latin America, more than half of the papers focused on Guatemala, all linked to one large-scale randomized control trial distributing improved cooking stoves.

6.1.1.6 Studies by intervention
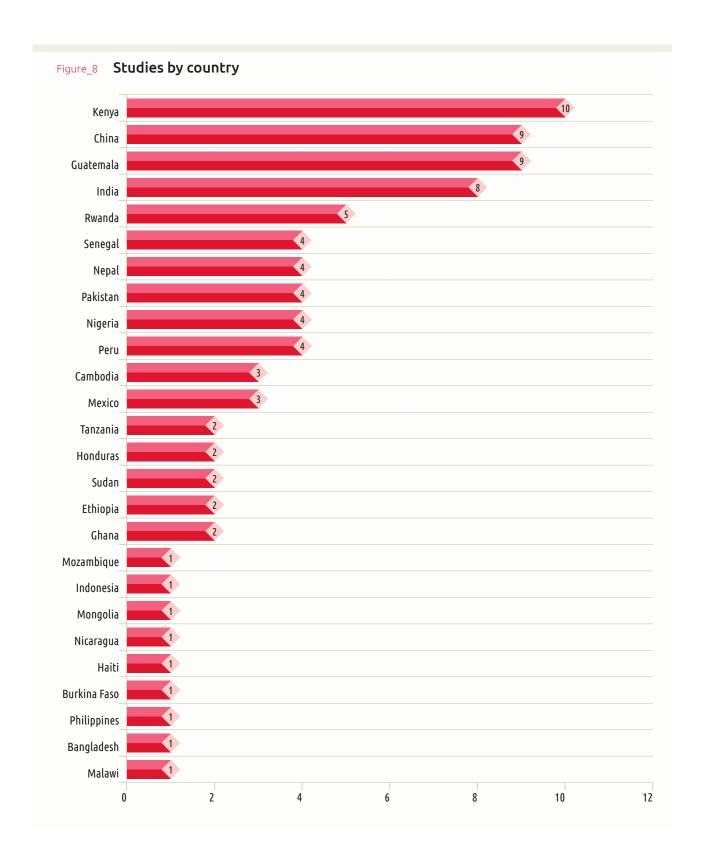
The literature mainly centred around improved traditional biomass cooking stoves, followed by studies on biogas and LPG (mainly under multipronged interventions including other components such as subsidies and awareness campaigns). Only one study focused on solar oven/cookers and electric cooking stoves, respectively.

/6.2 Risk of bias in included studies

The authors assessed the risk of bias within the individual studies, using a modified version

of the Risk of Bias in Non-randomized Studies (ROBINS) tool.[65] This tool is specifically designed to assess the comparative effectiveness of interventions from studies that did not used randomized assignment for treatment and control groups.[66] As demonstrated in figure 10, all studies included in the systematic review were assessed across six domains of potential bias. Overall, the majority of studies included in this systematic review were assessed to be ranking in either the low or medium risk of bias categories, with some ranked at high risk. Any studies that raised critical concerns about bias were excluded from the systematic review.

65 Cochrane Methods. Robins-I Tool. Accessed at: https://methods.cochrane.org/methods-cochrane/robins-i-tool

66 Sterne, Jonathan AC (2016). ROBINS-I: a tool for assessing risk of bias in non-randomized studies of interventions. BMJ 2011;343:d5928. Available at https://www.bmj.com/content/343/bmj.d5928#:~:text=The%20risk%20of%20bias%20tool%20covers%20six%20domains%20of%20bias,the%20domain%2C%20or%20different%20outcomes

Figure_8   **Studies by country**

Country	Studies
Kenya	10
China	9
Guatemala	9
India	8
Rwanda	5
Senegal	4
Nepal	4
Pakistan	4
Nigeria	4
Peru	4
Cambodia	3
Mexico	3
Tanzania	2
Honduras	2
Sudan	2
Ethiopia	2
Ghana	2
Mozambique	1
Indonesia	1
Mongolia	1
Nicaragua	1
Haiti	1
Burkina Faso	1
Philippines	1
Bangladesh	1
Malawi	1

Figure_9   **Studies by intervention type**

Intervention type	Value
ICS (traditional biomass)	52
Biogas digesters	13
ICS-multipronged intervention	9
Combined clean fuels	4
ICS and LPG-multipronged intervention	3
LPG-multipronged intervention	2
LPG/subsidy	1
ICS and electric stove-multipronged intervention	1
Solar oven/cooker	1

Figure 10 shows that the domains with highest instances of bias are participant selection, baseline confounding, and measurement of outcomes. Bias in participant selection most often stemmed from non-randomized assignment and/or sampling which may give rise to differences in observable and non-observable characteristics. Bias from baseline confounding was recorded if these differences persisted as a result of insufficient methodology. With regard to bias in the measurement of outcomes, many studies relied on self-reported measurement of outcomes which can be subject to recall bias. For example, self-reported health symptoms are more prone to bias than official hospital records. The most common cause of bias due to missing data was attrition. In many cases, it was not possible to follow up with all participants, often because they were unavailable for the follow-study. Few studies displayed bias due to departure from intended interventions or reported results.

6.3   Synthesis of results

Because some of the studies in the systematic review could not be included in the meta-

Figure_10 **Assessment of bias**

Figure_10 Assessment of bias

analysis, table 3 demonstrates the overall findings of the narrative synthesis. This consists of a simple count of how many studies found positive, negative or null results on each of the respective outcomes. This is based purely on the conclusions of the authors of the individual studies. As shown, six out 10 studies found a significant decrease in wood consumption, three out of five found a significant decrease in coal consumption, and one out of two papers found a significant reduction in LPG consumption. Overall, these findings suggest that CFT interventions successfully reduce consumption of dirtier fuels. In addition, there appears to be a trend of time savings, with nine out of 17 studies finding a significant reduction in collection time and six out of 12 finding a reduction in cooking time. With 11 out of 19 papers finding a significant reduction in carbon monoxide levels, there appear to be some preliminary health benefits.

For health outcomes, a handful of evaluations looked at pneumonia and hypertension; the majority did not find a significant impact. Of the

10 studies evaluated for the impact on systolic and diastolic blood pressure, only one found significant impact. Finally, the three papers that examined COPD all found a significant reduction associated with interventions. While more health impact research is needed, the authors explore these findings more rigorously in the subsequent meta-analyses.

To examine adoption outcomes, the authors reviewed a combination of factors indicative of adoption and usage of CFTs as well as a tendency to stop using dirty fuels and technologies. Given the high prevalence of fuel stacking, no single indicator can fully reflect adoption; the studies most often examined consumption of various fuels.

6.3.1 Effects of interventions on adoption outcomes

This section presents the results of the meta-analysis for each outcome of interest. A moderator analysis (analysis by different population subgroups) was conducted only

Table_3 **Overall findings from the narrative synthesis**

Outcome	General trend	Number of studies with significant increase	Number of studies with significant decrease	Number of studies with null findings	Total number of studies examining outcome
Wood consumption	↓	0	15	9	24
Coal consumption	?	0	3	5	8
LPG consumption	?	0	1	1	2
Clean stove ownership	↑	2	0	1	3
Time spent collecting wood	↓	1	9	7	17
Cooking time	↓	1	6	5	12
Carbon monoxide	↓	0	11	8	19
Pneumonia	?	0	1	3	4
Hypertension	?	0	0	2	2
COPD	↓	0	3	0	3
Systolic blood pressure	?	0	1	9	10
Diastolic blood pressure	?	0	1	9	10
ARI	?	0	2	2	4

↑ More than half of the relevant studies showed a decrease   ↓ More than half of the relevant studies showed a decrease   ? No clear trend

for those outcomes where sufficient data were available. This is discussed below and the results of the moderator analysis results are presented in Annex 9.

6.3.1.1   Fuelwood consumption

As shown in figure 11, there were 16 studies that analyzed wood consumption, including several subgroups of the population. The meta-analysis of these findings demonstrated a statistically significant decrease in wood consumption as a result of clean cooking interventions. With a Hedges's g of -0.53 (CI: -0.83, -0.20) the impact was moderately large. While there was some heterogeneity of findings, all studies except for one demonstrated either a negative impact or a null effect, suggesting overall consistency.

Examining the impact by moderators, the impact on fuelwood consumption varied based on both intervention type and region. Annex 9 shows that improved biomass cooking stoves led to a large, significant reduction in wood consumption (Hedges's g= -1.14; CI: -1.72, -.55). While the reduction associated with biogas interventions was large (Hedges's g = -1.27; CI: -2.57, 0.04), this result had a wide margin of error and was not statistically significant. This suggests that biogas may lower wood consumption, but additional research is needed to confirm this fact. Only one study examined solar cookers (Beltramo, 2013). This study examined impacts based on three different subpopulations and found no detectable programme impact on wood consumption. The impacts of biogas digesters and solar cookers should, however, be interpreted with caution, as each of these categories contained few

Figure_11 **Wood Consumption Meta-analysis**

Study name	Subgroup within study	Statistics for each study			Hedges' g and 95% CI
		Hedges' g	Lower limit	Upper limit	
Adrianzen 2010		-0.50	-0.88	-0.12	
Beltramo 2013	HH 3 13+ persons	-0.02	-0.28	0.25	
Beltramo 2013	HH w 6 persons or less	0.04	-0.22	0.31	
Beltramo 2013	HH w 7-12 person	-0.30	-0.57	-0.04	
Bensch 2013		-0.41	-0.56	-0.26	
Bensch 2015		-0.80	-1.08	-0.53	
Burwen 2012		-0.17	-0.35	-0.00	
Dohoo 2013		0.13	-0.36	0.62	
Dutch Ministry of Foreign Affairs 2014		-0.32	-0.48	-0.15	
Gizachew 2018		-1.25	-1.83	-0.68	
Jeuland 2020		0.10	-0.06	0.26	
Johnson 2013		-0.70	-1.27	-0.12	
Ludwwinski 2011		-0.86	-1.36	-0.37	
Muriuki 2015		-1.98	-2.23	-1.72	
Ochieng 2013		-0.48	-0.82	-0.15	
Pattanayak 2019		-0.09	-0.29	0.11	
Putra 2017		-2.89	-3.22	-2.56	
Yu 2011	Behavioral intervention only	0.05	-0.29	0.40	
Yu 2011	Stove and behavioral intervention	0.48	0.23	0.74	
		-0.52	-0.83	-0.20	

-4.0   -2.0   0.0   2.0   4.0

Favours A   Favours B

$I^2 = 24.86$

studies. Additional studies would help confirm results.

Examining differential impacts by region, the majority of these studies took place in Africa, and the largest impact was seen there. With an SMD of -0.5 (CI: -0.82, -0.17), the impact in Africa was moderate and statistically significant. The reductions in wood consumption in Asia and the Pacific, as well as Latin America and the Caribbean (LAC) were moderate (-0.56 and -0.65, respectively); however, while the summary statistic for LAC is statistically significant, the finding for the Asia-Pacific region was not. Within the Asia-Pacific region, there was greater heterogeneity among studies, with one study demonstrating much greater benefit than any of the others. Given that there were less than 10 studies each from Asia and the Pacific and LAC, these results should also be interpreted with caution, as impacts in the wider population may vary.

Additional studies would help to confirm the results.
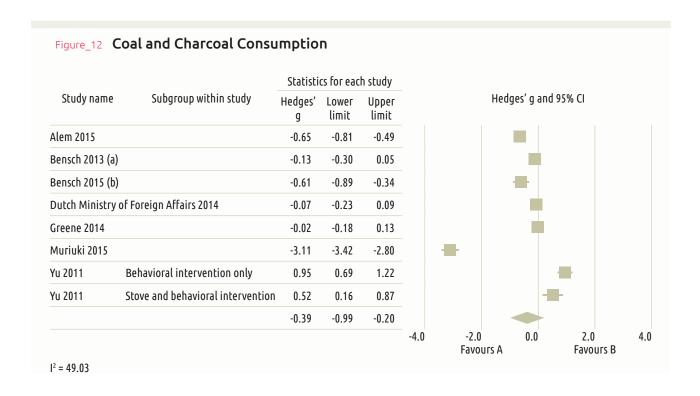
6.3.1.2 Coal consumption

A meta-analysis of seven studies suggests that clean cooking interventions led to a moderate reduction in the consumption of coal and charcoal, but the results were not statistically significant (SMD = -0.39; CI: -0.99, 0.21). As demonstrated in figure 12, there was moderate heterogeneity among studies (I^2 = 49.03), but the heterogeneity remained below the critical threshold of 50. As demonstrated, two studies found results that were positive and significant, while all other results were negative, with several that were statistically significant. This suggests that the overall trend among clean cooking interventions was to decrease the consumption of coal and charcoal; however, additional studies are needed to confirm these results.

Unfortunately, there were too few studies to examine differential impacts based on moderators.
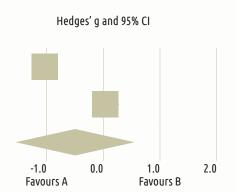
6.3.1.3 LPG consumption

Only two studies examined intervention impacts on LPG consumption; one took place in Kenya and the other in Indonesia. Both studies focused on biogas clean cooking interventions, and therefore treated LPG as a less clean form of cooking fuel (although in comparison to traditional biomass, LPG would be considered cleaner). The meta-analysis displayed in figure 13 demonstrates a moderate but not statistically significant reduction in LPG use as a result of the biogas programme. Given that there were only two studies, additional research would be needed to establish whether there is a consistent trend. In this case, the Muriuki (2015) found a statistically significant decrease in the use of LPG in Kenya, while Putra (2017) found no detectable impact in Indonesia.

Figure_12 **Coal and Charcoal Consumption**

Study name	Subgroup within study	Statistics for each study			Hedges' g and 95% CI
		Hedges' g	Lower limit	Upper limit	
Alem 2015		-0.65	-0.81	-0.49	
Bensch 2013 (a)		-0.13	-0.30	0.05	
Bensch 2015 (b)		-0.61	-0.89	-0.34	
Dutch Ministry of Foreign Affairs 2014		-0.07	-0.23	0.09	
Greene 2014		-0.02	-0.18	0.13	
Muriuki 2015		-3.11	-3.42	-2.80	
Yu 2011	Behavioral intervention only	0.95	0.69	1.22	
Yu 2011	Stove and behavioral intervention	0.52	0.16	0.87	
		-0.39	-0.99	-0.20	

I^2 = 49.03

Figure_13 LPG consumption meta-analysis

Study name	Subgroup within study	Statistics for each study			Hedges' g and 95% CI
		Hedges' g	Lower limit	Upper limit	
Muriuki 2015		-1.03	-1.25	-0.81	
Putra 2017		0.04	-0.19	0.27	
		-0.50	-1.54	0.55	

-2.0   -1.0   0.0   1.0   2.0

Favours A   Favours B

6.3.1.4 Clean technology uptake/usage

Few studies examined outcomes pertaining to the uptake and usage of clean cooking fuels and technologies, using a robust statistical design that could be included in the meta-analysis. Among those that did, there was little consistency in the specific metrics measured. The most consistent outcome, however, was to establish whether the household still owned a cleaner cooking technology after the intervention. Clean cooking stove ownership may include the technology distributed through the intervention or any other clean cooking stove that the household may have purchased or otherwise procured. Three studies examined this outcome. While the results were not combined due to differences in the metrics used, the findings are listed in table 4. As shown, only two out of three studies found that households that received an intervention were significantly more likely to own an improved cooking stove at the time of follow-up.

6.3.2 Effects of interventions on intermediate outcomes

To validate the theory of change, the authors examined intermediate outcomes including fuel collection time, cooking time, and ambient and personal carbon monoxide levels. Collection time and cooking time may provide some indication of whether the intervention is functioning well as well as whether users are using the technologies optimally to reduce the time needed for fuel collection and cooking. Carbon monoxide provides an indication

Table_4 Impacts of Interventions on clean cooking stove ownership

Study	Outcome
Hanna, 2016	Households that received the intervention were 47% more likely to own any low polluting stove at the time of follow-up (p = 0.<0.01)
Bensch, 2019	Households that received the intervention were 1% more likely to own a fuelwood ICS at the time of follow-up (p = 0.77)
Jeuland, 2020	Intervention households were 119 times more likely to own an ICS compared with households that did not receive the intervention (p <0.01)
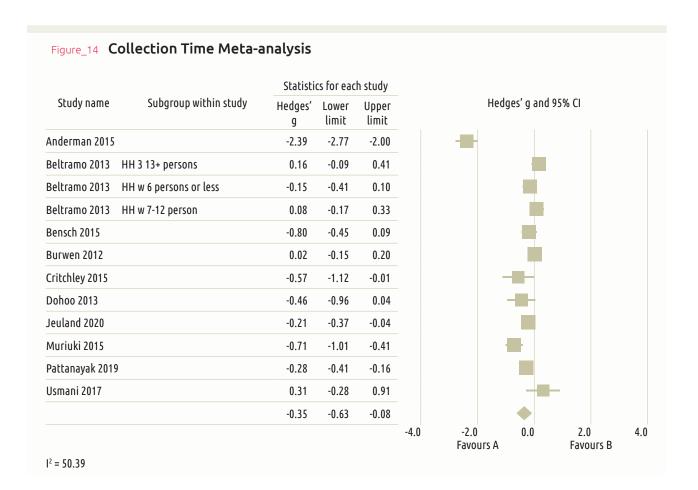
of whether the intervention is successfully providing some preliminary health benefits.

6.3.2.1 Collection time

As shown in figure 14, the meta-analysis found that clean cooking interventions were associated with a moderate and statistically significant reduction in time spent collecting fuelwood (SMD = -0.35; CI: -0.63, -0.08). With moderate heterogeneity (I^2 = 50.39), approximately half of observed variance between studies may be due to actual differences in effect sizes. This suggests that impacts may vary widely among different populations.

Based on the moderator analysis presented in Annex 9, there appears to be some correlation between intervention type and size of impact on collection time. Biogas digesters appear to have the largest impact on reducing collection time for fuelwood (SMD = -1.19; CI: -2.36, -0.01). Improved traditional biomass cooking stoves appeared to reduce collection time slightly, although the summary statistic was not statistically significant. While the impact of electric cooking stoves is also significant, this is based on only one study. Last, the impact of solar cooker intervention, based on only one study, was indistinguishable from zero. The reductions in time spent gathering fuelwood indicate that interventions were successfully adopted and functioned well in order to reduce wood collection. However, it does not account for time spent on other tasks such as gathering dung in the case of biogas digesters.

Figure_14 Collection Time Meta-analysis

Study name	Subgroup within study	Statistics for each study			Hedges' g and 95% CI
		Hedges' g	Lower limit	Upper limit	
Anderman 2015		-2.39	-2.77	-2.00	
Beltramo 2013	HH 3 13+ persons	0.16	-0.09	0.41	
Beltramo 2013	HH w 6 persons or less	-0.15	-0.41	0.10	
Beltramo 2013	HH w 7-12 person	0.08	-0.17	0.33	
Bensch 2015		-0.80	-0.45	0.09	
Burwen 2012		0.02	-0.15	0.20	
Critchley 2015		-0.57	-1.12	-0.01	
Dohoo 2013		-0.46	-0.96	0.04	
Jeuland 2020		-0.21	-0.37	-0.04	
Muriuki 2015		-0.71	-1.01	-0.41	
Pattanayak 2019		-0.28	-0.41	-0.16	
Usmani 2017		0.31	-0.28	0.91	
		-0.35	-0.63	-0.08	

I^2 = 50.39

With limited studies in each category, these results must be interpreted with caution. It is notable that no studies evaluating LPG made it to this analysis. Additional research could help confirm the impacts of various CFTs.

Studies in Africa suggest that interventions led to a small decrease in collection time (SMD = -0.18; CI: -0.45, 0.09), while studies in Asia Pacific suggest a moderate decrease in collection time (SMD = -0.65; CI: -1.35, 0.05); however, results were not statistically significant in either case.
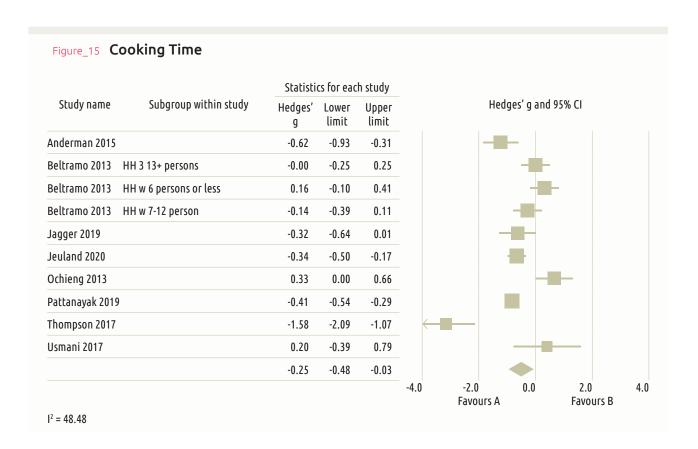
6.3.2.2 Cooking time

As shown in figure 15, the meta-analysis suggests that clean cooking interventions were associated with a small but significant reduction in time spent cooking (SMD = -0.25; CI: -0.48, -0.03). This may be an indication of successful adoption and use of clean cooking fuels and

technologies that, when used correctly, can decrease the time needed to cook. With an I^2 of 48.48, there was moderate heterogeneity among the studies. As shown, four of the eight studies demonstrated significant reductions in cooking time, with one study demonstrating a particularly large reduction.

Among those studies examining cooking time, interventions included biogas digesters, electric cooking interventions, improved cooking stoves, solar cookers and LPG subsidies. Because many of these categories included only one study, it was not possible to deduce trends by intervention category. The authors did, however, group the analysis by region.

As shown in Annex 9, while clean cooking interventions led to a significant decrease in time spent cooking in the Asia-Pacific region

Figure_15 Cooking Time

Study name	Subgroup within study	Statistics for each study			Hedges' g and 95% CI
		Hedges' g	Lower limit	Upper limit	
Anderman 2015		-0.62	-0.93	-0.31	
Beltramo 2013	HH 3 13+ persons	-0.00	-0.25	0.25	
Beltramo 2013	HH w 6 persons or less	0.16	-0.10	0.41	
Beltramo 2013	HH w 7-12 person	-0.14	-0.39	0.11	
Jagger 2019		-0.32	-0.64	0.01	
Jeuland 2020		-0.34	-0.50	-0.17	
Ochieng 2013		0.33	0.00	0.66	
Pattanayak 2019		-0.41	-0.54	-0.29	
Thompson 2017		-1.58	-2.09	-1.07	
Usmani 2017		0.20	-0.39	0.79	
		-0.25	-0.48	-0.03	

$I^2 = 48.48$

and LAC, the effect appeared more ambiguous in Africa. With few studies in each respective category, however, additional research is needed to verify these findings. Furthermore, with an I^2 of 79.30, this analysis likely contains substantial heterogeneity.

6.3.2.3   Carbon monoxide

As shown in figure 16, a total of 15 studies analysed carbon monoxide exposure, including several subgroups of the population. Overall, the meta-analysis found that clean cooking interventions were associated with a small but significant reduction in exposure, with a summative statistic of -0.15 (CI: -0.24, -0.06). With an I^2 of 71.17, there may be substantial heterogeneity among studies. Approximately half of the studies demonstrated non-significant effects; five studies demonstrated moderate and significant reductions in exposure, while Oluwole (2013) found a very large and significant decrease in exposure. To conduct a sensitivity analysis, the team additionally ran the meta-analysis without this outlier, but found the results to be similar (SMD = -0.13; CI: -0.22, -0.05,). Surprisingly, within the subpopulation of households with six persons or less, Beltramo (2013) found a moderate but significant increase in carbon monoxide exposure.

The moderator analysis shown in Annex 9 demonstrates impacts based on intervention type and region respectively. Overall, improved traditional biomass cooking stoves led to a small but significant decrease in carbon monoxide exposure (SMD = -0.20; CI: -0.29, -0.11). Results were not significant for either solar oven/cooker or LPG subsidies; however, with few studies in each of these two categories, additional research is needed to attain conclusive evidence. Unfortunately, none of the qualifying studies included biogas,

electric stove or any other CFT within the scope of this study

In examining impacts by geographic region, studies in Africa demonstrated a small overall impact, but this result was not statistically significant. Studies in Asia demonstrated a small but statistically significant impact (SMD = -0.11; CI: -0.2, -0.03), while studies in Latin America and the Caribbean suggested a large, and statistically significant impact (SMD = -0.73; CI: -1.47, -0.008). Heterogeneity was moderate in this analysis (I^2 = 55.83), with few studies from each region, results should be interpreted with caution.

6.3.3 Effects of Interventions on long-term health impacts

6.3.3.1   Acute respiratory infections

Among the three studies included in the meta-analysis examining acute respiratory infections (ARI) in children, all reviewed improved cooking stove interventions. The summative statistic was not significant at the 95% confidence level as shown in figure 17; however, a significant decrease was recorded in one study of households that use improved cooking stoves exclusively.

6.3.3.2   Pneumonia

Among the three studies that examined childhood pneumonia, all reviewed improved biomass cooking stove interventions. While two of these studies saw small non-significant decreases in both pneumonia and severe pneumonia as a result of the interventions, the summative statistic was not distinguishable from zero in either case. The results are shown in figures 18 and 19. Unfortunately, there were too few studies to examine the moderator analysis.

Figure_16 Carbon Monoxide

Study name	Subgroup within study	Statistics for each study			Hedges' g and 95% CI
		Hedges' g	Lower limit	Upper limit	
Beltramo 2013	HH 3 13+ persons	0.02	-0.23	0.26	
Beltramo 2013	HH w 6 persons or less	0.53	0.28	0.77	
Beltramo 2013	HH w 7-12 person	0.03	-0.21	0.27	
Bruce 2007a		-0.95	-1.49	-0.42	
Bruce 2007b		-0.64	-1.00	-0.28	
Bruce 2007c		0.15	-0.25	0.55	
Cheng 2015		-0.23	-1.44	0.98	
Clark 2009		-0.94	-1.50	-0.39	
Clark 2012		-1.30	-2.06	-0.53	
Greene 2014		-1.30	-2.06	-0.53	
Hannah 2016	Children	-0.02	-0.08	0.04	
Hannah 2016	Primary cooks	-0.04	-0.10	0.02	
Khushk 2015		-0.27	-0.54	0.00	
Oluwole 2015		-3.55	-5.46	-1.63	
Onyeneke 2017		-0.15	-0.27	-0.04	
Peabody 2010		-0.06	-0.10	-0.01	
Singh 2012		-0.79	-1.47	-0.10	
Smith 2009		-0.17	-0.26	-0.08	
		-0.15	-0.24	-0.06	

-4.0   -2.0   0.0   2.0   4.0
Favours A   Favours B

I^2 = 71.17

Figure_17 Acute Respiratory Infections

Study name	Subgroup within study	Statistics for each study					Hedges' g and 95% CI
		Rate ratio	Lower limit	Upper limit	Z-value	p-value	
Schilmann 2014	Children <5*	0.411	0.212	0.796	-2.634	0.008	
Schilmann 2014	Children <5**	0.682	0.349	1.333	-1.119	0.263	
Tielsch 2016	Children <3	0.870	0.670	1.130	-1.044	0.296	
		0.676	0.435	1.051	-1.739	0.082	

0.1   0.2   0.5   1   2   5   10
Favours A   Favours B

*Exclusive ICS Use in household.
**Non-exclusive use in household

A Systematic Review of **the Impacts of Clean and Improved Cooking Interventions on** Adoption Outcomes and Health Impacts
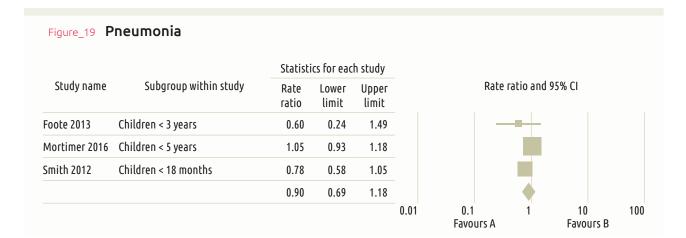
6.3.3.3   Chronic obstructive pulmonary disease
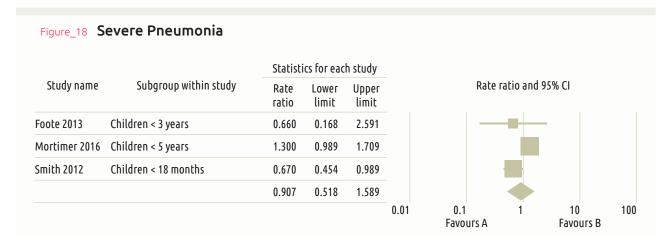
Among the three studies that examined chronic obstructive pulmonary disease (COPD), all three took place in China, with one examining impacts within subpopulations of men and women (figure 20). The summative statistic suggests that there was a significant reduction in COPD as a result of large-scale policies to promote clean cooking. With an odds ratio of 0.23 and a confidence interval that does not encompass '1', it is possible to reject the null hypothesis that no change took place. All three studies independently found significant reductions. Chapman (2005), who examined impacts by gender, found large and significant reductions among both men and women.

6.3.3.4   Blood pressure

Blood pressure measures included three indicators – hypertension, systolic blood pressure and diastolic blood pressure.

As shown in figure 21, only two studies examined hypertension, with one examining the impacts in different age groups. Although the summary statistic suggests a small reduction in hypertension, this finding was not statistically significant. Among the results, Neupane (2014) found a significant reduction in hypertension among the subgroup of primary cooks over the age of 50. Additional research could help inform as to whether there

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Figure_19   **Pneumonia**

| Study name | Subgroup within study | Statistics for each study | | | Rate ratio and 95% CI |
		Rate ratio	Lower limit	Upper limit	
Foote 2013	Children < 3 years	0.60	0.24	1.49	
Mortimer 2016	Children < 5 years	1.05	0.93	1.18	
Smith 2012	Children < 18 months	0.78	0.58	1.05	
		0.90	0.69	1.18	

Figure_18   **Severe Pneumonia**

| Study name | Subgroup within study | Statistics for each study | | | Rate ratio and 95% CI |
		Rate ratio	Lower limit	Upper limit	
Foote 2013	Children < 3 years	0.660	0.168	2.591	
Mortimer 2016	Children < 5 years	1.300	0.989	1.709	
Smith 2012	Children < 18 months	0.670	0.454	0.989	
		0.907	0.518	1.589	

Figure_20 COPD meta-analysis

Study name	Subgroup within study	Statistics for each study			Odds ratio and 95% CI
		Odds ratio	Lower limit	Upper limit	
Chapman 2005	Men	0.17	0.15	0.20	
Chapman 2005	Women	0.22	0.19	0.26	
Peabody 2010		0.41	0.24	0.70	
Zhou 2014		0.28	0.11	0.72	
		0.23	0.17	0.31	

$I^2 = 26.98$

are similar findings in other settings among this age group.
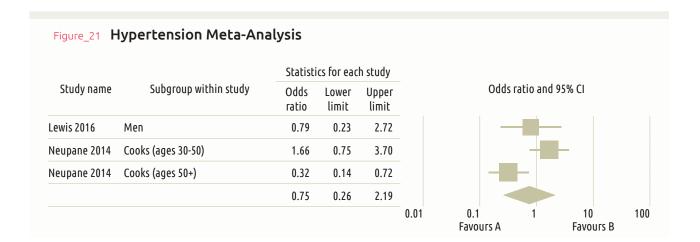
Eight studies examined systolic and diastolic blood pressure (figure 22), with two also examining age-based subgroups. The summary statistic showed no significant reduction in systolic blood pressure. Among the individual results, Clark (2012) found a significant reduction among primary female cooks aged 40 and older. This is consistent with Neupane's finding that clean cooking interventions reduced hypertension among women over 50. Additional study could help to shed light on whether clean cooking might
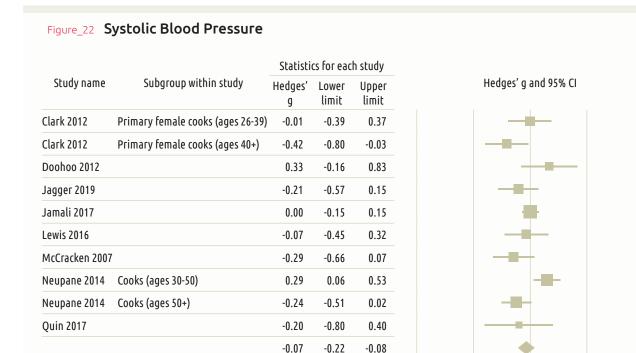
result in consistent health benefits among older women.

Similarly, clean cooking interventions had no detectable impact on diastolic blood pressure. As shown in figure 23, a couple of the individual studies detected significant reductions in diastolic blood pressure, but the overall summary statistic detected a null result.

6.3.4 Heterogeneous findings

This section discusses some of the heterogeneity among studies in order to qualitatively explore differences in

Figure_21 Hypertension Meta-Analysis

Study name	Subgroup within study	Statistics for each study			Odds ratio and 95% CI
		Odds ratio	Lower limit	Upper limit	
Lewis 2016	Men	0.79	0.23	2.72	
Neupane 2014	Cooks (ages 30-50)	1.66	0.75	3.70	
Neupane 2014	Cooks (ages 50+)	0.32	0.14	0.72	
		0.75	0.26	2.19	

Figure_22 **Systolic Blood Pressure**

Study name	Subgroup within study	Statistics for each study			Hedges' g and 95% CI
		Hedges' g	Lower limit	Upper limit	
Clark 2012	Primary female cooks (ages 26-39)	-0.01	-0.39	0.37	
Clark 2012	Primary female cooks (ages 40+)	-0.42	-0.80	-0.03	
Doohoo 2012		0.33	-0.16	0.83	
Jagger 2019		-0.21	-0.57	0.15	
Jamali 2017		0.00	-0.15	0.15	
Lewis 2016		-0.07	-0.45	0.32	
McCracken 2007		-0.29	-0.66	0.07	
Neupane 2014	Cooks (ages 30-50)	0.29	0.06	0.53	
Neupane 2014	Cooks (ages 50+)	-0.24	-0.51	0.02	
Quin 2017		-0.20	-0.80	0.40	
		-0.07	-0.22	-0.08	

Hedges' g and 95% CI — axis: -2.0, -1.0, 0.0, 1.0, 2.0 — Favours A / Favours B

$I^2 = 0.00$

Figure_23 **Diastolic Blood Pressure**

Study name	Subgroup within study	Statistics for each study			Hedges' g and 95% CI
		Hedges' g	Lower limit	Upper limit	
Clark 2012	Primary female cooks (ages 26-39)	-0.19	-0.56	0.18	
Clark 2012	Primary female cooks (ages 40+)	0.00	-0.23	0.23	
Doohoo 2012		0.12	-0.38	0.61	
Jagger 2019		-0.34	-0.70	0.01	
Jamali 2017		0.04	-0.10	0.19	
Lewis 2016		-0.30	-0.69	0.08	
McCracken 2007		-0.41	-0.78	0.05	
Neupane 2014	Cooks (ages 30-50)	-0.30	0.57	-0.04	
Neupane 2014	Cooks (ages 50+)	0.14	-0.09	0.38	
Quin 2017		-0.01	-0.61	0.59	
		-0.11	-0.24	0.02	

Hedges' g and 95% CI — axis: -2.0, -1.0, 0.0, 1.0, 2.0 — Favours A / Favours B

$I^2 = 12.57$

An investigation of programme impacts on the adoption of cleaner cooking practices, carbon monoxide, pneumonia, COPD and blood pressure

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interventions and programme implementation that might have led to success or the lack thereof. These findings are primarily based on the conclusions and lessons learned in the individual studies as stated by their authors. Per the Campbell Policies and Guidelines, examination of qualitative research can help provide insight into heterogeneous findings across studies, address barriers and facilitators of intervention effectiveness, and highlight some of the characteristics of successful implementation.[67]

6.3.4.1 Variations in technologies: Laboratory results vs. field conditions

The technologies used in interventions varied widely; ICS were particularly variable in terms of their relative effectiveness at reducing carbon emissions as well as their relative durability. For example, field measures indicated that the *Upesi jiko* stove sold in Kenya (Foote 2013) reduced average PM2.5 concentrations by 13%. The *Upesi jiko* burned fuel more efficiently and accelerated the cooking speed, but did not vent the smoke outside the house. By contrast, the stoves distributed in Malawi (Mortimer, 2017) were among the cleanest biomass fuelled cooking stoves available. They provided a 90% reduction in emissions compared to open fires, according to laboratory tests. However, no information was provided on the effective exposure reduction under real-life conditions. Despite their effectiveness under laboratory settings, these cooking stoves frequently malfunctioned; households requested repair services on average four times during the trial. Mortimer noted that these malfunctions drove many households to return to the use of traditional cooking stoves. Many authors

identified repair and maintenance issues as one of the major barriers to sustained use.

Many studies did not report on whether technologies met WHO guidelines or ISO guidelines on cooking stoves, which were established only recently in 2018. Furthermore, Hanna (2016) suggested that the effectiveness of improved biomass cooking stoves is often overstated, based on tests in laboratory-like settings, assuming "optimal" use which is not always replicable in the field. The term "optimal use" describes the ideal conditions under which the technology should function, including specific cooking techniques, regular repair and maintenance, frequent use etc.

6.3.4.2 Typical field use varies from the "optimal" use scenario

Typical field use varied from "optimal" use, particularly when technologies did not meet the specific needs and preferences of users. In some cases, CFTs were used, but infrequently or in combination with dirtier cooking practices. In these cases, users attained few detectable benefits if any. Many studies suggested that the improved fuels and technologies were not used as frequently as "optimal use" would assume. The current study focused on findings based on typical field use. However, several studies additionally conducted an analysis within a subgroup of users who used the clean technology more frequently or even exclusively.

Foote (2013) observed that many beneficiaries still used open fires and kerosene lamps; excluding these users, the author conducted a subgroup analysis among households that consistently used improved stoves (at more than 80% of visits made by field workers). Within this subgroup, improved stove usage was associated with a significant reduction in pneumonia incidence. Similarly, Smith (2011)

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67 Campbell Collaboration. "Campbell systematic reviews: policies and guidelines". November 2019. Accessed at https://onlinelibrary.wiley.com/pb-assets/assets/18911803/Campbell%20Policies%20and%20Guidelines%20v4-1559660867160.pdf in January 2020.

performed an exposure-response model and found that a 50% reduction in carbon monoxide was associated with a lower relative risk of pneumonia. This would indicate that among those households that use improved cooking stoves enough to reduce carbon monoxide levels, there are likely to be reductions in other health risks.

Many of the conditions assumed under "optimal use" are simply not realistic in the field, or not consistent with the needs of the households.

6.3.4.3 Customized design and Inclusive planning to meet varied energy needs

Several studies suggested that inclusive planning is important to ensuring that clean cooking solutions meet the cooking needs of users at all levels – individual, household and communal – through proactive consultation with end-users at all stages, including programme design, planning and implementation. Stakeholder consultations conducted through a gender-sensitive lens can ensure tailored programming that meets the specific cooking needs of end-users. This can lead to optimal selection of the CFTs, increased awareness among locals, and improvements in stove designs before a large-scale roll out. This can boost adoption and lead to health benefits.

The implementers of the programme evaluated by Jeuland (2020) in India, involved local villagers during the pre-intervention phase to assess a range of technologies through stove pilots and consultations. Based on those consultations, the programme implementers selected Greenway Smart and Greenway Jumbo stoves and sold them at 12.5% of the market price under a carbon-finance mechanism. The programme also administered promotional campaigns, including community meetings, cooking demonstrations, wall paintings and household visits, to communicate advantages

such as reduced cooking time, fuel use and emissions. Ultimately, less than half of the households that were offered a subsidy made the decision to adopt the ICS. Notably, those that did were more likely to be from villages with strong ties to the implementing organization.[68] This suggests that collaborative planning helps boost adoption.

For example, the project in urban Senegal, evaluated by Bensch (2013), engaged locally-active women's groups to market and sell the stoves to households. Cooking demonstrations were positioned as social events to showcase the advantages of the intervention stove over the traditional unclean stove in terms of reduced emissions, fuel savings and time savings. The project led to 25% reduction in charcoal consumption.

In addition, several studies found that CFTs and programmes specifically tailored to meet local cooking preferences were much more effective than those that did not customize their approaches. McCracken (2007) noted that the locally constructed Plancha stove in Guatemala was well-tailored to local cooking needs because it contained, among other features, a metal plate used to make tortillas, and three potholes that allow several dishes to be cooked at the same time. The Plancha stove had been in prior use in Guatemala for an extended period and had thus evolved considerably with regard to local cooking practices. This study concluded that 10 months after receiving a Plancha stove, women's diastolic blood pressure was significantly reduced in comparison to women that did not receive a Plancha.

In contrast, Dohoo (2013) found that a biogas digester programme in Kenya did not satisfy

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68   Other characteristics included higher education, lower expenditures and more awareness about clean cooking fuels and technology at baseline; higher wood consumption at baseline.

all household needs; because the preparation of certain traditional dishes required extra heat some households continued to gather fuelwood. Accordingly, the programme had no significant impact on fuel collection time. Similarly, Putra (2017) found that a biogas programme in Indonesia did not successfully reduce LPG consumption. Putra suggested that this was because households continued to purchase LPG to satisfy other needs not met by the programme.

6.3.4.4 Value of programme follow-up and free repairs for sustained use of CFTs

The duration of programmes and the length of time before the endline survey varied across studies. However, several studies suggested a pattern in which users initially adopted clean fuels and technologies, but gradually reverted to dirtier fuels and technologies over time. Several authors attributed this to the lack of programme follow-up or access to stove repair facilities. Based on a randomized controlled trial in India, Hanna (2016) found that an improved biomass cooking stove programme resulted in significant reductions in carbon monoxide levels during the first year. However, these reductions gradually disappeared in the three subsequent years as users returned to their previous cooking methods. Hanna suggested that this occurred in part because the new technology was challenging to maintain, and the programme did not offer regular maintenance and repairs.

By contrast, in a randomized controlled trial of an improved biomass cooking stove in Guatemala, McCracken (2007) found that 10 months after receiving a Plancha stove, women's diastolic blood pressure significantly reduced in comparison to women that did not receive a Plancha. These impacts were attributed in part to the fact that the

programme included a robust follow-up plan and free repairs. Field workers paid weekly visits, during which households could report issues and request repairs. Similarly, the intervention evaluated by Mortimer (2017) was characterized by frequent community engagement events and free cooking stove repairs and replacements. Furthermore, to prevent a return to traditional, inefficient cooking stoves, the intervention provided each household with two clean cooking stoves at the start of the programme. Mortimer found that two years after the programme, half of the recipients were still using the improved cooking stoves for all of their cooking needs.

In contrast, Bensch (2015) offered the *Jambaar*, a fuel-efficient stove that is maintenance-free, portable and tailored to local cooking needs. About 3.5 years after the free dissemination of this ICS, 69% of the participants were continuing to utilize the stove and reported significant reductions in exposure and cooking time. [69] A six-year follow-up showed that this had fallen to 10% of the original participants as the stoves had deteriorated and were not replaced. About 62% of the original treatment group was cooking using open fires, while some had found other stove options on the market that were cheaper.

Based on these studies, it appears that interventions that included free maintenance and repairs, or had few maintenance requirements, achieved greater adoption and sustained use. Of note, however, while ICSs are considered one of the cheaper solutions to clean cooking challenges, by including the necessary follow-up activities and maintenance to achieve long-term use may make these programmes more expensive.

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[69] The chimney-less the stove is not designed to curb emissions, but this may be a result of changes in cooking behaviour, i.e., households may opt to cook outdoors if the stove is portable.

6.3.4.5 Lessons learnt from China on long-term health impacts: COPD

Three studies in China, including Chapman (2005), Peabody (2010), and Zhou (2014), examined health impacts of clean cooking interventions over the long term, with all three finding significant reductions in COPD. These studies help to shed light on some of the long-term pathways for impact. Two of the included papers examined improved biomass cooking stoves, while the third examined the impact of a combination of different clean fuels, including biogas, LPG and electricity.

Following a cohort of farmers in the Xuanwei county from 1976 to 1992, Chapman et al. (2005) studied the effect of switching to ventilated stoves among coal users. Before the intervention, residents mainly burned smoky coal, smokeless coal or wood, in unvented stoves. The incidence of indoor air pollution-related diseases was particularly high in Xuanwei county; the rates of COPD were more than twice the national average, and rates of lung cancer were among the highest in China.

The evaluation observed significant reductions in the incidence of lung cancer and COPD for households that switched from unvented stoves to stoves with chimneys. Interestingly, the risk of COPD increased in the first 10 years following stove improvements. The authors suggested that this may have been because households with members already experiencing respiratory symptoms were more likely to install a chimney. After 10 years following stove improvement, the risk of COPD for men and women had been reduced by 80% and 74%, respectively, compared to households with unvented stoves. The benefits lasted over time, and 20 years after stove improvements, COPD risks had decreased by 90% and 87% for men and women, respectively.

Zhou (2014) assessed the impact of a clean cooking intervention in which almost 1,000 households received financial and technical support to install biogas digesters and/or to improve existing biomass stoves. During the first year of the project, recipients received education courses about the benefits of improved stoves every three months, after which, they received these courses once a year. In 2011, nine years after dissemination, COPD risk declined significantly. This study additionally consisted of three treatment arms – one that provided improved ventilation only, one that provided clean fuels only and one that provided both. The combined intervention, including both ventilation and clean fuels, prompted the greatest benefit with regard to COPD incidence (adjusted OR of 0.28). In addition, Peabody (2014) evaluated the National Improved Stove Programme (NISP) launched by the Government of China, which ultimately disseminated 180 million fuel-efficient stoves. The evaluation was conducted in Shaanxi, Hubei and Zhejiang Provinces.

While all three programmes represent long-term health impact trials, they all happen to be government-led initiatives, which highlights the important role that Governments can play in increasing clean cooking uptake, and consequently reducing the economics and health burden of unclean cooking practices.

6.3.4.6 Affordability and resource considerations

Resource considerations are critical to the success of a clean cooking intervention. Understanding what other resources communities typically use for cooking, and making CFTs affordable by comparison helps boost uptake. A study conducted by the Dutch Ministry of Foreign Affairs (2014) in Rwanda found that a programme supporting rural electrification and biogas for cooking resulted

in low programme uptake. The main barriers were lack of affordability, lack of access to credit and a perception that biogas digesters led to additional workload. In this case, there had been little demand for the intervention to begin with. Pairing that with a high relative cost resulted in very low uptake.

Neupane (2014) found that a biogas programme in rural Nepal achieved high adoption, but not for the reasons the implementers expected. Most of the users who switched to biogas cited a lack of firewood access as the main reason. Less than 5% of clean fuel users cited awareness of health advantages as a reason for biogas uptake. This demonstrates the fact that CFTs can help to address local resource limitations while improving health.

Pattanayak (2019) conducted a randomized control trial on 1,000 households in the Indian Himalayas that were then tracked over 18 months. Employing market-based mechanisms, households were randomly assigned one of three rebate levels (high, medium or low), which they could use to buy an electric cooking stove and/or improved biomass stove. More than half the households purchased at least one of the stoves with the majority opting for the electric stove.[70] As expected, there was a positive correlation between rebate level and the percentage of households that made a purchase, suggesting that users were interested in purchasing the new technologies once the economic barrier was removed. The intervention also resulted in significant reductions in cooking and collection time. The authors of this study stated that "although the bundled intervention is resource-intensive, the full costs are lower than the social benefits of ICS promotion. Our findings suggest that

market analysis, robust supply chains and price discounts are critical for ICS diffusion."[71]

6.3.4.7 Value of pilot programmes

Administering flexible pilot programmes with monitoring, evaluation, and feedback loops can help donors and implementers ensure that a programme is impactful before expanding it more broadly. It can also help identify barriers early on so that programme administrators can address them. Beltramo's (2013) evaluation of a solar cooker intervention in Uganda had some very valuable implications for policy and programming. The Government of Uganda planned to conduct a gradual nationwide rollout of solar cookers and conducted a pilot programme first to see if they were effective. In the pilot programme, the solar cookers were distributed through a phased randomized controlled trial. The evaluation found that in spite of intensive training, adoption of solar cookers was low because the stoves were not very durable and did not meet the energy requirements of larger families. With low adoption, these technologies also did not lead to any noteworthy intermediate or long-term benefits. Based on the findings of this evaluation, decision makers decided not to roll out this particular technology at the nationwide level. This underscores the value of pilot programmes to ensure that a programme will be effective. By avoiding the cost of scaling up an ineffective programme, decision-makers may instead invest in other measures to effect change.

A clean cooking project in Rwanda financed under the United Nations Clean Development Mechanism conducted a pilot in 1,943 households across 15 villages using a five-month randomized control trial. Based on the

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70 Majority of the households opted for an electric stove (40%) as opposed to ICS (15%) – the meta-analysis classifies this this intervention as an electric stove intervention due to lack of data on the separate impact of ICS and electric stove.

71 Pattanayak et al,, "Experimental evidence on promotion of electric and improved biomass cookstoves", PNAS (July 2019)

results from the pilot study, a second phase expansion was conducted in the Western Province, covering 470,000 people across 101,000 households. The pilot programme helped to inform stove design improvements as well as the development of interactive education materials, which included an illustrative flipbook and personalized posters for households with targeted messaging to discourage stove stacking. In addition, the recruitment criteria for community health workers assisting with programme implementation was made stronger with regard to higher requirements in literacy, timeliness, responsiveness, smartphone competence and programme knowledge. Pilot projects can thus help to inform the implementation strategy in order to maximize health and adoption impacts.

However, pilot results are not always replicable due to differences between within-country communities. Burwen and Devine, (2012) evaluated a large-scale RCT that failed to replicate the results of an otherwise successful pilot phase. The improved cooking stove could not accommodate the larger size requirements of pots in other villages. It was also ill-suited to the kitchen layouts of non-pilot villages, leading to insufficient ventilation. Continued monitoring and feedback loops could have highlighted these disparities early on and taken into account the inter-village heterogeneity of cooking practices and kitchen layouts. A redesign of the stove could have been conducted or the roll out could have been limited to similar villages.

6.3.4.8   Varied impacts by age and other subgroups

Several studies found differential impacts within specific subgroups of the population. Of note, two of the studies examining blood pressure found that clean cooking interventions had particular benefits for older populations. Neupane (2014) found that biogas plants in Nepal significantly reduced hypertension among women over the age of 50. Similarly, Clark (2012) found that an improved biomass cooking stove in Nicaragua significantly reduced systolic blood pressure among cooks over the age of 40. Additional studies on the impacts among older populations may shed light on whether clean cooking programmes are particularly beneficial within this subgroup.

6.4   Publication bias

Publication bias arises when there is a systematic difference between the literature that is published on a certain topic compared with the literature that is not ultimately published on that topic. For example, studies with statistically significant findings may be more likely to get published than studies with null (non-significant) findings. This would result in a bias in which the research that is readily available demonstrates stronger results than the broader literature on a topic. To address this concern, the authors examined the risk of publication bias for all meta-analyses that included at least eight results.

To examine the risk of publication bias, the team produced funnel plots using CMA. The vertical axis of these funnel plots demonstrates the standard error of the individual results in a meta-analysis. Larger, more precise studies have lower standard errors and therefore appear higher in the funnel plot, while smaller studies with less accuracy are scattered more widely lower on the plot. In the absence of publication bias, one might expect to see a symmetrical spread of studies in the shape of

an inverted funnel.[72] However, in the presence of publication bias, small and less precise studies may be more likely to get published if they demonstrate strong findings, but less likely to be published if they demonstrate null results. The white dots in the subsequent funnel plots represent the actual results included in each meta-analysis, while the red dots reflect potential results imputed based on the risk of publication bias. The authors additionally used Duval and Tweedie's trim and fill function to estimate the adjusted summary statistics and confidence intervals, taking into account the possibility of publication bias.[73]

6.4.1 Risk of publication bias in adoption and time allocation outcomes

As shown in figures 27 to 30, all of the relevant adoption and time allocation findings were at low risk of publication bias. Applying Duval and Tweedie's trim-and-fill, the team found the results for fuelwood consumption, coal/charcoal consumption, fuel collection time and cooking time were all robust to the possibility of publication bias. Accordingly, the authors concluded that clean cooking interventions led to a moderate and significant reduction in wood consumption and fuel collection time; the interventions led to a small, significant reduction in cooking time. As noted already, the reduction in coal and charcoal consumption appeared moderate, but was not statistically significant.
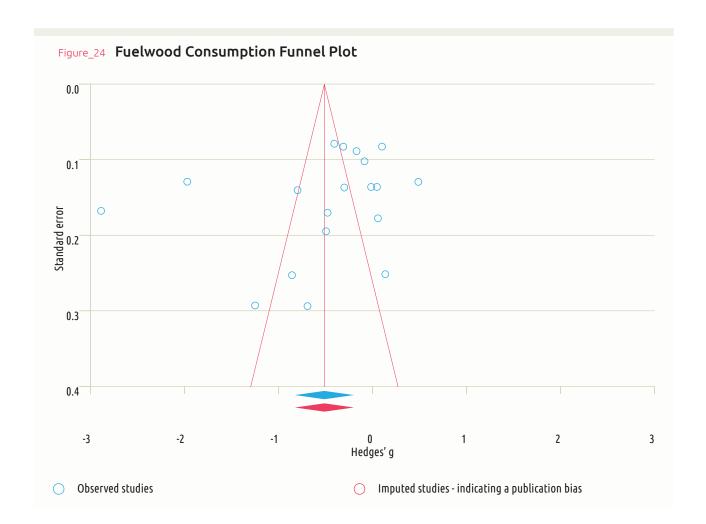
6.4.2 Risk of publication bias in effects of interventions on intermediate health outcomes and long-term impacts
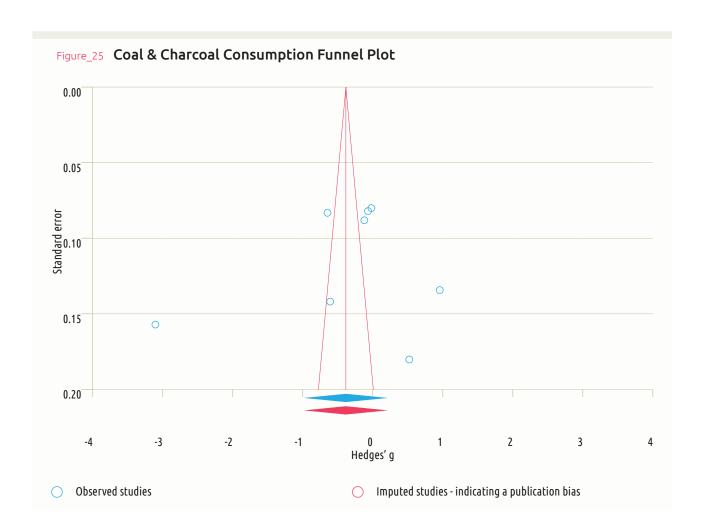
Examining the intermediate outcomes and long-term health impacts on health, the findings for carbon monoxide and blood pressure may have been subject to publication bias. While the meta-analysis found that clean cooking interventions led to a small, but significant reduction in carbon monoxide levels (SMD = -0.15; CI: -0.24, -0.06), adjustment for publication bias based on trim-and-fill suggests that these findings may not be significant in the wider range of literature. With imputed studies demonstrated in figure 31, the trim-and-fill analysis suggests an SMD of -0.07 (CI: -0.18, 0.02). While this finding is not statistically significant, it is close to the threshold. Additional research may help to discern the impact on carbon monoxide me conclusively.
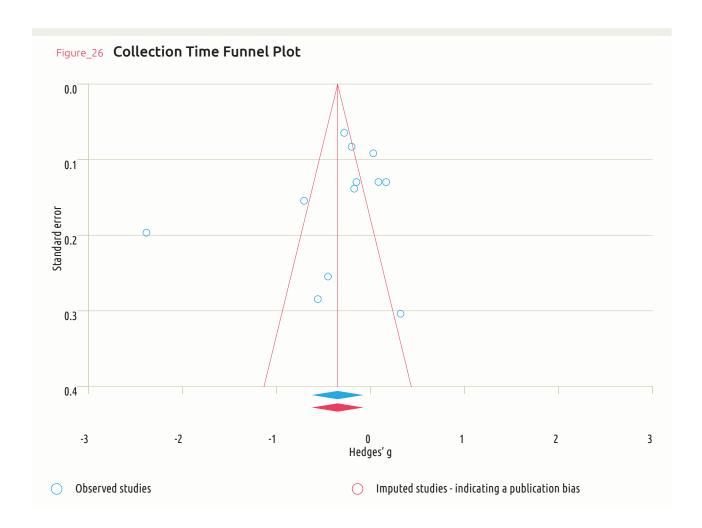
As shown in figures 32 and 33, findings on systolic and diastolic blood pressure were also subject to publication bias, suggesting that results in the wider population of literature may be smaller. In the meta-analyses neither systolic nor diastolic blood pressure were found to have had a significant impact. With the additional risk of publication bias on these findings, this review cannot deduce a detectable impact on blood pressure on average.

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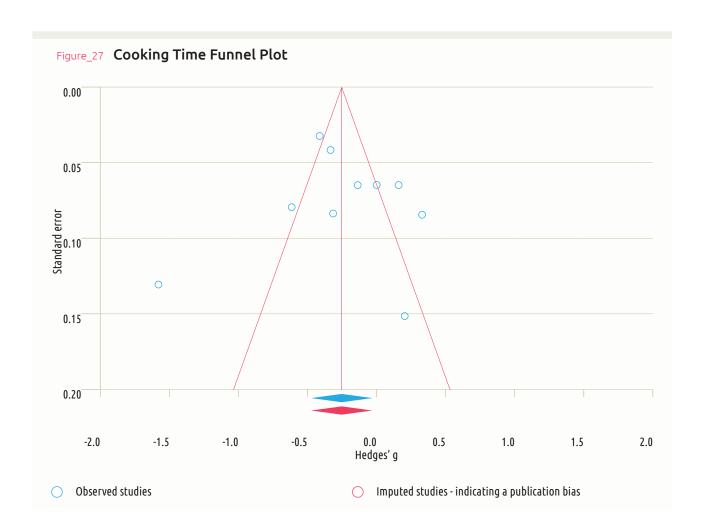
72 Sterne, Jonathan et al., 2011, Recommendations for examining and interpreting funnel plot asymmetry in meta-analyses of randomized controlled trials. https://www.bmj.com/content/343/bmj.d4002
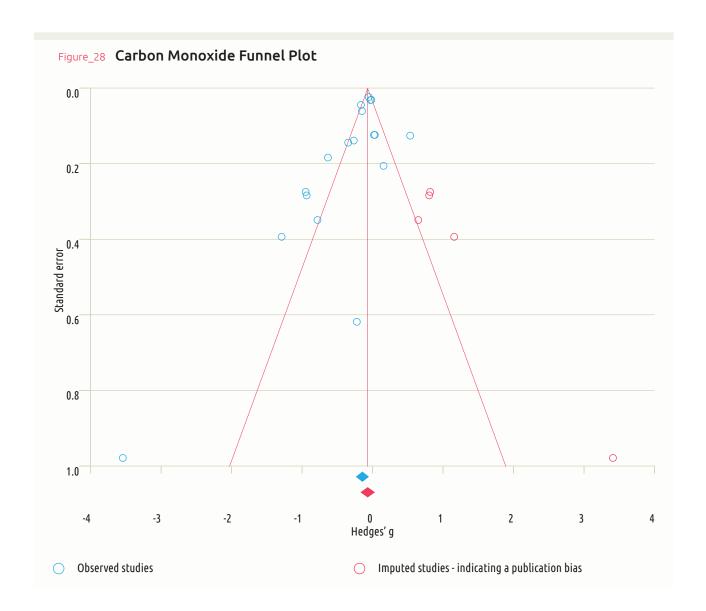
73 Shi, Linyu, 2019, The trim-and-fill method for publication bias: Practical guidelines and recommendations based on a large database of meta-analyses. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6571372/

Figure_24 **Fuelwood Consumption Funnel Plot**

Figure_25 Coal & Charcoal Consumption Funnel Plot

Figure_26 **Collection Time Funnel Plot**

Figure_27 **Cooking Time Funnel Plot**

Figure_28 **Carbon Monoxide Funnel Plot**

Standard error (y-axis): 0.0, 0.2, 0.4, 0.6, 0.8, 1.0
Hedges' g (x-axis): -4, -3, -2, -1, 0, 1, 2, 3, 4

○ Observed studies   ○ Imputed studies - indicating a publication bias

Figure_29 **Systolic Blood Pressure Funnel Plot**

Figure_30 **Diastolic Blood Pressure Funnel Plot**

7 Discussion

Summary of main results

In sum, this systematic review found that, on average, clean cooking interventions did indeed reduce fuelwood consumption,[74] fuel collection time[75] and cooking time,[76] indicating that the programmes in the included studies did successfully increase adoption of clean cooking fuels and technologies. In addition, there is some preliminary evidence that interventions may have reduced the consumption of coal and charcoal, although this finding was not statistically significant. There is also preliminary evidence of differential impacts by region and by intervention; however, additional analysis is needed to verify these findings.

The review found evidence that CFT interventions led to a reduction in COPD, as well as in carbon monoxide levels; however, the review did not detect any significant impacts on pneumonia, ARI, blood pressure or hypertension; this may be due to the limited number of studies on these health outcomes. Based on three of the included studies, the review found that CFT interventions reduced the odds of COPD by 77% (Odds Ratio: .23, CI: 0.17, 0.31). However, because all three of these studies took place in China, additional research is needed to verify whether these findings are consistent with interventions in other countries. Impacts on pneumonia, blood pressure and hypertension were not statistically significant, although the

number of included studies examining each of these outcomes was quite low. Based on an analysis of heterogeneous findings, there was some preliminary evidence of impact within specific subpopulations; i.e., two studies found that interventions had greater impact on the health of older populations, including by reducing blood pressure and the risk of hypertension. In addition, the review found a small but significant reduction in carbon monoxide levels, an intermediate outcome that could lead to a long-term health impact.

Based on qualitative analysis of the individual studies, many authors suggested that interventions often lead to short-term adoption, but struggle to achieve sustained long-term use. This is consistent with this review's findings; while the authors found that there is evidence of adoption of CFTs, there is less evidence of long-term health impacts that require sustained use o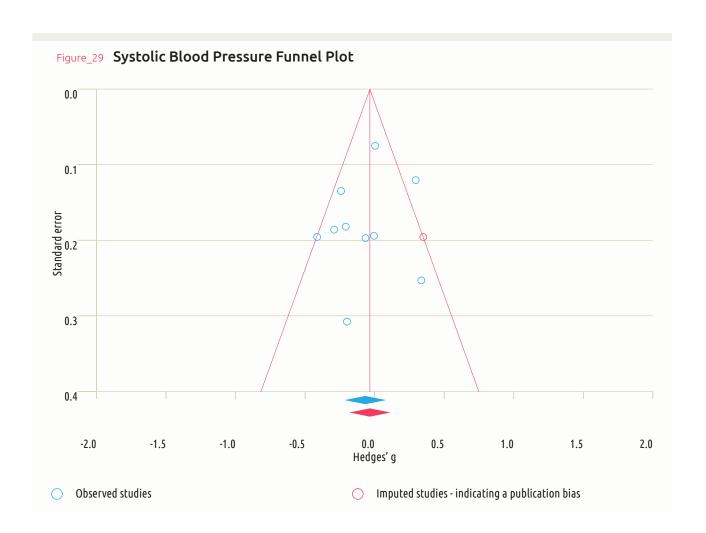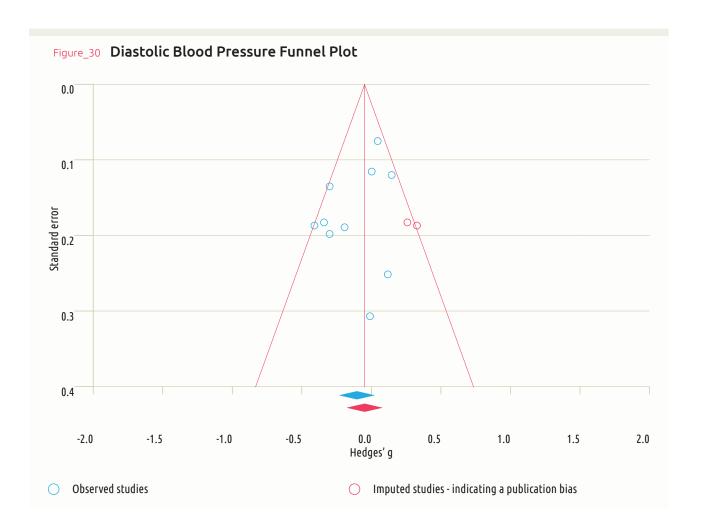f CFTs. Based on the theory of change diagram in figure 1, the key breakdown appears to be related to "sustained use, repairs and maintenance". Additional evaluations of long-term health impacts and causal linkages could help inform on what types of programmes have been successful in this regard, and what are some of the ways to address this key challenge.

Last, this review found a literature bias in which the majority of the evaluation literature focuses on improved biomass cooking stoves. This makes it challenging to assess the effectiveness of other technology and fuel solutions such as LPG, LNG, biogas cooking stoves and electric cooking stoves.

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74   Hedges's g = -0.52; CI: -0.83, -0.20.
75   Hedges's g = -0.35; CI: -0.63, -0.08.
76   Hedges's g = -0.25; CI: -0.48, -0.03.

Out of the 86 studies included in this review, 52 focused on improved biomass cooking stove solutions. With few studies examining the impacts of LPG, biogas and electricity for cooking, the current review could not draw conclusions on these other technologies.

The findings of this review indicate that while, on average, clean cooking policies and programmes have successfully led to short-term adoption, there is limited evidence of long-term health impacts. Stronger evidence on long-term health impacts of interventions and pathways for change could help to inform about effective policies and programming.

The authors propose two hypotheses for why the clean cooking interventions under examination might not have led to health benefits in terms of ARI, pneumonia, blood pressure or hypertension.

1. The first hypothesis is that the interventions included might not have been clean enough to improve health. As noted, the majority of interventions focused on improved biomass cooking stoves. Many of these studies did not specify the quality of the device or what tier of clean cooking access it provided. The WHO Guidelines on Indoor Air Quality suggest that although improved biomass cooking stoves effectively reduce air pollution compared with traditional stoves, many of these technologies do not meet WHO standards.[77] For this reason, the air quality improvement may have been insufficient to lead to health gains.

2. A second possibility is that lack of sustained use of the clean technologies reduced health impacts. Many authors of

the included studies noted that after initial adoption, users often abandoned new technologies, particularly improved biomass cooking stoves, in favour of their traditional cooking methods. The reason most often cited were that the technologies broke or malfunctioned, and users were either unable or unwilling to invest in repairs and maintenance. This lack of sustained long-term use may have decreased the effectiveness of interventions.

Additional study is needed to determine whether these hypotheses are correct.

7.2 Quality of evidence

The majority of studies included in this systematic review were assessed to be at low risk of bias, ranking in either the low or medium risk categories based on the ROBINS-I tool. However, three types of bias were particularly common among studies. More than half of the studies were at moderate or high risk of bias due to participant selection, 40% presented moderate-to-high risks of baseline confounding, and 36% presented risks in the measurement of outcomes. These factors compromise the quality of available evidence on this subject.

Additionally, there was quite a bit of heterogeneity between studies. While this is to be expected given the diversity of countries and contexts in the study, it may limit the generalizability of findings.

7.3 Limitations and potential bias in the review process

There are no major or bias concerns in the searching and screening process of this systematic review; however, limiting the review

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77 World Health Organization (2014). WHO Guidelines for Indoor Air Quality: Household Fuel Combustion. Available at https://www.who.int/airpollution/publications/household-fuel-combustion/en/

to English may present a language bias. The selection of electronic databases, including Scopus, Embase and Pubmed, are likely to capture much of the relevant literature on the topic without bias. The process of screening resulted in a high rate of inter-rater agreement, which also indicates a low likelihood of bias. The additional search for gray literature and unpublished literature by using hand searches and contacting authors was designed to further reduce the risk of bias. While some studies were excluded from the meta-analysis due to missing data or inconsistency in effect sizes reported, it is unlikely that these results were systematically different from those which were included.

Due to resource constraints, this review only included studies in English; while the authors do not expect that this is likely to raise large bias concerns, it may have resulted in the exclusion of valuable literature, particularly from China and Latin America. The authors conducted a preliminary search for relevant papers in Chinese, French, Russian and Spanish. This process consisted of a basic Google search using a modified version of the search terms to get a sense of whether there was relevant literature in any of these languages. The research team did not find any qualifying papers in French or Russian, but found several in Chinese and Spanish. These papers were not included in the analysis as the review methodology did not take account of foreign language searches. However, the team concludes that there may be relevant literature in these languages that could help inform future programming.

One limitation of this review is that it does not include comparative analysis based on the duration of the clean cooking intervention or the length of time between the intervention and the final endline survey. Many studies do not clearly state these details. Because many households gradually revert to the use

of traditional biomass after a clean cooking intervention, deeper analysis of patterns over time could help shed light on long-term trends and provide insight for achieving long-term transition.

7.4 Agreements and disagreements with other studies and research

The health findings of this systematic review are fairly consistent with the findings of other systematic literature on the topic, as presented in table 1. In some cases, the team's findings are smaller and less significant. This may be due to the fact that the current review only examined studies with an explicit policy or programme intervention in order to examine the causal linkages from intervention to adoption to health impacts. Generally, there is stronger evidence of health benefits of studies in which households have already adopted consistent, sustained clean cooking practices.

Dherani (2008),[78] found that cooking with unclean solid biomass was associated with a higher risk of pneumonia by a factor of 1.8. In contrast, the current review did not find that CFT interventions led to detectable reduction in pneumonia. It may be the case that some technologies did not sufficiently reduce air pollution or that programmes did not achieve exclusive sustained use of CFTs. Although Mortimer (2017) reported high uptake, Foote (2013) and Smith (2011) encountered barriers to adoption. In addition, Foote found that among households that did adopt clean cooking practices, pneumonia incidents were lower. Saleh (2020),[79] on the other hand, also

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78 Mukesh Dherani and others, 2008, "Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: A systematic review and meta-analysis", *Bulletin of the World Health Organization*.

79 Saleh et al., 2020, "Air pollution interventions and respiratory health: A systematic review", *International Journal of Tuberculosis and Lung Disease*, vol. 24.

found that air pollution interventions did not lead to a significant impact on pneumonia. Similar to Thakur (2018),[80] the current review found that CFT interventions significantly reduced the likelihood of COPD. Consistent with the findings of both Pope (2017)[81] and Quansah (2017),[82] this review also found that CFT interventions resulted in a significant reduction of carbon monoxide levels.

With regard to adoption, Sikomvich (2019)[83] found that clean cooking technologies (not including improved biomass cooking stoves) in low- and middle-income countries led to significant time savings. This is consistent with the authors' findings that CFT interventions led to reduced fuel collection time and reduced cooking time.

The authors did not find any comparable systematic literature on fuel consumption.

7.4.1 Findings in the context of development trends and WHO guidance

This section serves to contextualize the findings of this systematic review in the broader development discussion. This review identified three critical literature gaps that would help to inform future programming. The authors discuss these literature gaps in the context of

the WHO's Guidance on Indoor Air Quality as well as recent evidence on promising practices.

First, the review found that the vast majority of impact evaluations focus on improved biomass cooking stoves, making it difficult to quantify the impacts of other clean cooking solutions. This literature gap is surprising, considering the fact that globally there have been many large-scale projects for distribution of LPG.[84] In addition, it is particularly problematic because the WHO IAQ guidelines currently give priority to the cleanest fuels and technologies, including LPG/LNG, biogas digesters, and electric cooking solutions.[85] Specifically, the WHO guidelines indicate that among households cooking with LPG, 94% meet the Air Quality Guidelines for PM2.5, while 99% meet the guidelines for carbon monoxide.[86] WHO furthermore recommends accelerating initiatives to extend access to LPG, electricity and natural gas.[87] Assessing the performance of LPG, biogas, and electric cooking in the field would help to inform on the best pathways forward.

Second, within evaluations of improved biomass cooking stoves, there is limited analysis of the quality or tier of access. Many of the studies included in this review did not explicitly state the tier level that the technology provided and whether it met WHO guidelines. Based on the qualitative discussions of the study authors as well as the reported carbon monoxide levels where available, it is likely that many of the improved biomass cooking stoves did not meet these standards. This is consistent

80 Megha Thakur et al., 2018, "Impact of improved cookstoves on women's and child health in low- and middle-income countries: A systematic review and meta-analysis", *Thorax, v*ol. 73.

81 Daniel Pope et al., 2017, "Real-life effectiveness of 'improved' stoves and clean fuels in reducing: PM2.5 and CO: Systematic review and meta-analysis", *Environment International*, vol. 101, pp. 7-18.

82 Reginald Quansah et al., 2017, "Effectiveness of interventions to reduce household air pollution and/or improve health in homes using solid fuel in low-and-middle income countries: A systematic review and meta-analysis", *Environment International*, vol. 103, pp. 73-90.

83 Suzzane M. Simkovich et al., 2019, "A systematic review to evaluate the association between clean cooking technologies and time use in low- and middle-income countries", *International Journal of Environmental Research and Public Health*.

84 Ashlinn Quinn et al., 2018, An analysis of efforts to scale up clean household energy for cooking around the world"", *Energy for Sustainable Development,* vol. 46, pp. 1-10.

85 Ibid.

86 World Health Organization, 2014, WHO Guidelines for Indoor Air Quality: Household Fuel Combustion. Available at https://www.who.int/airpollution/publications/household-fuel-combustion/en/

87 World Health Organization, 2016, Burning opportunity: Clean household energy for health, sustainable development, and wellbeing of women and children"".

with a study by WHO, which found that despite achieving large reductions in PM 2.5 compared to traditional biomass stoves, improved biomass stoves reviewed did not achieve WHO standards f clean cooking.[88] At the same time, the Clean Cooking Alliance suggests that improved biomass cooking stoves still present substantial benefits for cooking stoves are worth promoting in the medium and long terms.

Third, there is a gap in detailed household data on adoption and disuse behaviours. For these indicators, many of the studies included in the current review used self-reported data, which will inform future studies. New programmes are using integrated smart meters and sensor technology to monitor the real-time use of different cooking technologies. Furthermore, this study found that actual pollution mitigation was only 25% of that projected; climate credits significantly incentivized the use of cleaner technologies.[89] The Clean Cooking Alliance suggests that these data initiatives could help to deepen the sector's understanding of end-users and ultimately help to improve programming.[90]

7.5 Implications for policy and practice

Based on the findings of this systematic review, the authors deduced the following list of implications for policy and practice. This list draws on the qualitative findings and lessons learnt as reported in the individual studies as well as the quantitative findings of the meta-analyses in this review. In addition, this list incorporates some of the guidance from the broader development community, particularly the recommendations of the World Health Organization.

With limited evidence of health benefits associated with improved biomass cooking stoves, programmes and policies should prioritize the most stringently cleanest fuels and technologies in terms of lowering emissions; this includes LPG, gas and electric cooking solutions. This systematic review found that while programmes promoting improved biomass cooking stoves did achieve adoption and early benefits of time allocation, there were limited benefits in terms of health. This may be due to the fact that although improved biomass cooking stoves reduce emissions compared with tradition cooking stoves, they often do not meet WHO standards in terms of the reductions in PM 2.5 and carbon monoxide emissions.[91] This limits their ability to improve health. While the current review did not find enough studies to quantify the impacts of LPG, gas and electric cooking solutions, the broader development literature and historical evidence suggest that these solutions have lower emissions, and therefore greater health benefits. In its Indoor Air Quality Guidelines, WHO suggests that LPG is particularly effective in reducing air pollution.[92] The agency furthermore recommends accelerating efforts to extend access to gas, electricity and associated cooking devices.[93] Improved biomass cooking stoves may, however, serve as a bridge technology in areas where it is not feasible to scale up LPG and electricity initiatives. The Clean Cooking Alliance suggests that while high-tier clean cooking solutions are better for health, they remain unaffordable for much of

88 World Health Organization, 2014, *WHO Guidelines for Indoor Air Quality: Household Fuel Combustion*. Available at https://www.who.int/airpollution/publications/household-fuel-combustion/en/

89 Tara Ramanathan et al., 2016, *Nature Climate Change*. Macmillan Publishers.

90 Clean Cooking Alliance, 2020, Systemic Challenges and Opportunities.

91 World Health Organization (2014). WHO Guidelines for Indoor Air Quality: Household Fuel Combustion. Available at https://www.who.int/airpollution/publications/household-fuel-combustion/en/

92 Ibid

93 World Health Organization, 2016, Burning Opportunity: Clean household energy for health, sustainable development, and wellbeing of women and children.

the population.[94] The current review finds that ICS indeed provide some benefits in way of time allocation and reduced carbon monoxide. These technologies may provide benefits for poor communities, while policymakers develop long-term strategies for transition to clean cooking fuels and technologies.

Many programmes, particularly those promoting improved biomass cooking stoves do not to achieve sustained use due to maintenance issues and lack of repair facilities. To address this issue, implementers may prioritize solutions that require less maintenance, and/or make provisions for long-term repairs. Although the results of this review suggest that the included clean cooking interventions indeed led to adoption, the authors of many of the studies noted that users later abandoned new technologies due to malfunction, inconvenient maintenance requirements, and/or lack of repair facilities. They suggested that the need for maintenance and repair is likely a disincentive for sustained use. Likewise, several authors suggested that other programmes succeeded specifically because they provided free maintenance and repairs. This is particularly informative for improved biomass cooking stove technologies, which often require maintenance, repairs, and replacement parts that are not easily available on the market. Taking these challenges into account, policymakers and implementers may prioritize CFTs that require less maintenance and repair in order to achieve sustained use. For more complex technologies, particularly ICS, free repairs could help boost sustained use. However, ICS is often selected due to its cost-effectiveness; bundling the technology with repair services would increase the cost of the programme.

Monitoring and evaluation using precise methods and technologies such as real-time

sensors could better inform programme and policy implementation by tracking adoption behaviours and programme impacts. The current review found an evidence gap in the measurement of adoption and disuse of different cooking fuels and technologies. Many studies measured these indicators using self-reported data. More recent studies using sensor technologies suggest that there is little correlation between reported data and actual usage.[95] As a result, self-reported data may lead to inaccurate conclusions. Making greater use of sensor technologies to track and monitor real-time usage could help policymakers and programme implementers better understand the factors that drive uptake of CFTs or the lack thereof. This could help decision-makers respond to challenges faster as well as identify which technologies deliver the best results.

Small, flexible pilot programmes with evaluations and feedback loops can help implementers adapt programmes to local needs before bringing projects to scale. As stated by Aung,[96] "laboratory studies cannot capture variability observed in the field, including types of foods cooked, fuelwood types and moisture, and user practices." Given the field challenges associated with clean cooking interventions, pilot testing can help decision-makers ensure that a programme or technology is appropriate for the local community. Additionally, randomized controlled evaluations can help detect whether interventions are indeed having an effect. If large-scale trials are not feasible, community-based pilot testing can help implementers identify and address potential issues before a

95   Tara Ramanathanet al., 2016. *Nature Climate Change*. Macmillan Publishers

96   T. W. Aung et al., 2016, "Health and climate-relevant pollutant concentrations from a carbon-finance approved cookstove intervention in rural India" in *Environmental Science & Technology*, vol. 50, No. 13; pp. 7228–7238. American Chemical Society. Available at https://doi.org/10.1021/acs.est.5b06208

94   ???????

programme is brought to scale, at which point it would be very costly to make adjustments.

Inclusive planning and programming have demonstrated effective results in terms of successful adoption. Numerous studies in this review cited inclusive planning and tailored programming as key to the success of a clean cooking intervention. Household energy needs vary, based on cooking preferences as well as lighting and heating needs. Even within cooking preferences, interventions are more likely to be successful if they are designed for the specific dishes and practices that are common to the local context. Furthermore, several studies suggest that communities that are involved throughout the project design and implementation are more likely to remain engaged throughout the course of the intervention.

7.6   Implications for research

This systematic review identified several research gaps. First, while the authors searched for literature on various types of clean cooking interventions, including LPG, LNG, biogas digesters, electric cooking stoves, etc., the vast majority of the literature centered on improved biomass cooking stoves. This may be due to the fact that ICS are easy to deploy and therefore easier to evaluate. For example, ICS programmes can be more easily distributed randomly than LPG pipelines, which are typically planned and placed based on other considerations such as economic activity. Having more literature on various types of clean cooking interventions could help decision-makers compare the relative benefits in order to determine the most suitable pathway for a given context.

A second gap is that there is not much quantitative literature examining the long-term impacts of clean cooking interventions.

The majority of the literature examines impacts less than two years after an intervention, while only a handful of studies go beyond this timeline to capture long-term impacts. Health conditions such as COPD and hypertension may develop over many years, so long-term evaluations would better detect potential health impacts. Long-term evaluations could also help inform on what types of projects lead to sustained use.

Consistent subgroup analysis could help identify emerging patterns on who benefits the most from clean cooking interventions. Several studies had interesting findings within various subgroups, particularly among older populations. Given that many health issues arise among the elderly, additional subgroup analysis could help inform on whether clean cooking interventions have a unique impact on different age groups.

Few studies examined the issue of household ventilation and other sources of air pollution, such as smoke from a neighbour's house, waste combustion and indoor tobacco smoking to name a few.[97] Examining these factors could provide better information for future programmes.

Last, while the current review found that CFT interventions reduced the time spent gathering fuel and cooking, further study is needed to assess how women used this additional time. Much of the development literature suggests that having additional free time could enable women to pursue other productive activities, thus gaining economic standing and autonomy. However, the research team found very little evidence of this topic. Greater examination of time-use patterns could help inform pathways for attaining gender empowerment and economic gain.

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97   A number of studies include control for tobacco smoking but not necessarily other possible sources of air pollution.

Annexes

Annex 1.   Key words used for PICO search

(Cook*) and ("clean cook*" or Electric* or "Induction stove" or Biogas or Biodigester or Biofuel or "Liquid petroleum gas" or "Liquefied petroleum gas" or LPG or "Improved cooking stove" or ICS or Ethanol or "Modern fuel" or "Clean fuel" or Solar or Photovoltaic or Briquette or Pellet or "Natural gas" or LNG or "Gasifier stove" or Subsidy)) AND (Control* or Treatment or Compare* or Counterfactual or Evaluate* or Impact or Random or Placebo or Intervention or Before or After)) AND (Accept* or Adopt* or Use* or Usage or Uptake or Choose* or Choice or Switch or "Fuel expenditure" or "Household fuel" or "Domestic fuel" or "Cooking fuel" or "Energy ladder" or "Charcoal expenditure" or "Charcoal usage" or "Fuelwood expenditure" or "Fuelwood usage" or COPD or "Chronic Obstructive Pulmonary Disease" or Cough* or Bronchitis or bronchiolitis or Pneumonia or "Blood pressure" or "Carbon Monoxide" or ALRI or ARI or "Respiratory illness" or "Respiratory infection" or "Respiratory disease" or "Fast breath*" or "Rapid breath*" or "Raised respiratory rate" or "Lung disease" or "Streptococcus pneumoniae" or "Pneumococcus" or "Haemophilus influenza" or "H. influenza")) AND ("Randomized Controlled Trial" or RCT or "Difference*in*difference" or "Propensity score matching" or PSM or "Instrumental variable" or "Instrumental variable" or "Regression discontinuity" or Regression or Logit or Probit or "Cross-section*" or "Cross section*" or "P value" or Statistic* or "hazard ratio" or "Risk ratio" or "odds ratio" or "confidence interval")

Annex 2.   List of databases used to hand search for gray literature

Database /website		
3ie impact	Department for International Development (United Kingdom)	Economic Development and Cultural Change
Google	GIZ	Journal of Development Economics
Google Scholar	Independent Evaluation Group (World Bank)	Journal of Development Effectiveness
ResearchGate	Inter-American Development Bank	Journal of Development Studies
PubMed	Millennium Challenge Corporation	Journal of International Development
African Development Bank	USAID Development Experience Clearinghouse	National Bureau of Economic Research
Asian Development Bank	WHO	Science Direct
Australian Agency for International Development	World Bank	World Development
Canadian International Development Agency	IPA	
Danish International Development Agency	JPAL	

A Systematic Review of **the Impacts of Clean and Improved Cooking Interventions on** Adoption Outcomes and Health Impacts

Annex 3.   Selection criteria for systematic review

The selection criteria for this review follows the PICOS format, detailing Population, Intervention, Comparison, Outcomes, and Study Designs. To be eligible for inclusion in the review, the study had to meet the following criteria:

Subject

- Clean cooking

Population

- Low- and middle-income countries

- Communities that received a clean cooking intervention

Type of intervention

Given its focus on informing policies, this review only includes studies in which there was an explicit programme or policy intervention. For example, studies that compare users with non-users, without making a reference to an overarching intervention, were excluded. Included in this systematic review was any clean cooking intervention including the following fuels and technologies:

- Improved biomass cooking stoves

- Biogas or biofuel

- Liquid petroleum gas

- Natural gas

- Ethanol

- Electric cooking/induction stoves

- Solar cookers

- Subsidy programmes to subsidize any of the listed fuels and/or technologies

Comparison

- Valid counterfactual using either control group, before-after design or quasi-experimental methods

Outcomes defined

In accordance with the theory of change detailed in Figure 1, this systematic review included studies that examined any of the following outcomes related to adoption, intermediate outcomes, and long-term health impacts:

Adoption of clean fuels and technologies

- Fuelwood consumption

- Coal consumption

- LPG consumption

- Usage/o Outcomes

- Time allocation

- Fuel collection time

- Cooking time

Long-term impacts

- Pneumonia

- Acute respiratory infections (ARI)

- Chronic obstructive pulmonary disease (COPD)

- Blood pressure

The team attempted to gather evidence on the continued use of clean cooking fuels and technologies, particularly evidence on repairs and repurchase; however, very few studies examined these outcomes quantitatively.

The team also initially attempted to identify which improved biomass cooking stoves met WHO requirements and which did not; however, many studies do not provide this data. Additionally, many technologies that meet WHO standards assuming perfect usage and regular maintenance, are not as efficient under typical field conditions. For this reason, this review includes all improved biomass cooking stoves designed to reduce pollution and fuel usage.

Study design

This systematic review included only studies with a valid counterfactual using any of the study designs listed below. In all cases, studies needed to conduct a balance test to demonstrate that baseline characteristics were balanced and use appropriate statistical methods to control for characteristics in which balance was not achieved. Study designs included:

◆ Randomized control trials in which individuals or groups were randomly assigned to treatment and control groups;

◆ Quasi-experimental designs in which the investigator used statistical methods to control for confounding factors. Methods may include statistical matching (e.g., propensity score matching or covariate matching), difference-in-difference design, instrumental variables or multivariate regression to control for selection bias, baseline characteristics and other confounding factors. Quasi-experimental designs may include:

  ▪ Natural experiments in which treatment and control were assigned based on non-random factors, but in which authors used one of the above-mentioned methods to control for possible bias;

  ▪ Before-after studies;

  ▪ Cross-sectional studies in which balance was established and appropriate statistical methods were used to address confounding factors;

  ▪ Regression discontinuity design.

Other criteria

Time and duration:

◆ This review only includes studies that examined outcomes at a minimum of two weeks after the initial intervention.

Language:

◆ Due to resource constraints, this systematic review was conducted exclusively in English. Therefore, it only includes studies published in, or translated into English.

Annex 4.   Study search strategy

Electronic searches

In searching for qualifying studies, the research team employed a PICOS search format, as detailed in the selection criteria section, in several databases. The PICOS search terms, as detailed in Annex 1, were selected based on the specific goals of the current study, with consideration for the search term selection of prior systematic reviews. The team conducted the PICOS search in electronic databases including Scopus, Embase, and PubMed on 4 May 2020. Scopus is an abstract and citations database that includes thousands of journals and results from scientific web pages. Embase and PubMed are both databases focused on peer-reviewed biomedical literature. For all hits from these three sources, the research team downloaded titles, abstracts and relevant reference information. These were then compiled into Excel. Duplicates were removed.

Hand searches

To help identify gray literature, recent papers, and other studies that might not have been published in traditional journals, the team supplemented the electronic search with hand searches in various databases as well as "snowball searches". These hand searches were completed during May 2020. It is estimated that more than half of the studies reported in conference abstracts are not ultimately published, and those that are published are systematically different.[98] Hand searches help to capture some of this gray literature. The hand searches were conducted using a modified version of the search terms in Annex 1 to search in Google, Google Scholar and various donor websites listed in Annex 2. Depending on the formats of the websites or search engines, the research team additionally adjusted search terms for the search filters as needed. The authors found few qualifying studies this way. The hand searches also consisted of "snowballing", an iterative process of searching the references of relevant papers in order to identify other relevant studies. This process continued until the team could find no additional qualifying papers that were not already in the list.

Based on the Campbell Search Strategy Guidelines, other systematic reviews present some of the best sources of references for potentially relevant studies. Accordingly, the team did a snowball search of each of the relevant systematic reviews identified in table 1. This search yielded many relevant studies. The team additionally conducted snowball searches after the initial round of screening to search the references of the studies identified for inclusion in the systematic review. The team found the snowballing methodology to be highly beneficial in terms of rendering relevant papers.

All papers found through hand searches were downloaded in PDF form into a folder. Key data, including author, title, year of publication, country of study and link to paper, were recorded in an Excel spreadsheet.

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98   Scherer R. W, P. Langenberg and E. von Elm, 2007, full publication of results initially presented in abstracts. The Cochrane database of systematic reviews.

Search for unpublished studies

To minimize the possibility of publication bias, the research team made efforts to search for both published and unpublished literature. In addition to the hand searches to look for gray literature, the team also reached out to the author of each eligible paper and inquired whether the author had written or knew of any published or unpublished studies that met the criteria for inclusion in the systematic review.

Studies in other languages

Early in developing the study design, the team discussed the possibility of searching for papers in several languages, particularly in all official United Nations languages. Unfortunately, due to resource constraints it was not possible to conduct a complete search in languages other than English. The team did, however, conduct some preliminary research to assess whether there were likely to be many relevant studies in any particular language. In this process, a single analyst, used a modified version of the search terms in Google to try to get a sense of whether there was relevant literature in that language.

The purpose of this exercise was not to identify papers for the current review, but rather to identify areas for future research. Preliminary searches were conducted in Chinese, French, Russian and Spanish. Due to resource constraints, the team was unable to search for papers in Arabic.

Selection of studies

Title and abstract screening

To facilitate the screening and selection of studies, the team uploaded the spreadsheet containing titles, abstracts and reference information from the electronic search into Abstrackr,[99] a free open-source software, developed by researchers at Brown University. This software, recommended in the Campbell Search Strategy Guidelines, facilitates review and screening of titles and abstracts for systematic review by using text mining functionality and machine learning to identify papers that are likely to qualify, and present these papers first. This function helped pre-screening of relevant papers. Once uploaded in Abstrackr, a team of three analysts double-screened all titles and abstracts. In the pilot stage, the first 100 titles and abstracts were screened by all three screeners in order to ensure agreement across the team on what types of papers qualified. This pilot stage needed to achieve a kappa rate of at least 0.7 in order for the review to continue. If the rate of agreement was lower, the team would complete an additional pilot stage of 100 titles and abstracts before proceeding to double-coding.

After the pilot stage, two analysts independently screened each title and abstract, and recorded reasons for exclusion where relevant. In cases of disagreement, the full team reviewed the title and abstract to come to consensus. In this stage, studies were screened based on the inclusion of criteria pertaining to population, intervention, comparison, outcomes and study design. However,

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99   Byron C. Wallace et al., 2012, "Deploying an interactive machine learning system in an evidence-based practice center: Abstrackr",
      in Proceedings of the ACM International Health Informatics Symposium (IHI), pp. 819-824.

because study design and comparison are not always explicit in the title and abstract of a study, where analysts were uncertain of these characteristics the studies were included for further review at the full-text screening stage. For the papers attained through hand search, after an initial analyst identified qualifying studies, a second analyst reviewed the selections to verify.

Full text screening

After identifying qualifying titles and abstracts, the team downloaded all qualifying studies, noting if any were unavailable. The team then conducted a full text screening to ensure that the identified papers qualified, particularly on the basis of study methodologies which are often not explicitly stated in the abstract. During the full-text screening phase, each paper was reviewed by one of the analysts on the team, and reasons for exclusion were recorded where relevant. All studies identified for inclusion at the full-text review stage were then coded and analysed.

Annex 5.   Data collection and analysis

Data extraction and management

Two analysts independently reviewed each qualifying study, extracting all relevant data to ensure that data and outcomes were correctly interpreted and extracted. The two analysts then compared findings to resolve any disagreements or differences in interpretation. For any matters for which the analysts could not reach agreement, a third analyst reviewed the study to provide input and reach consensus. In addition, the team leader reviewed a random selection of studies to assure accuracy of data included. Data extracted included:

Metadata

- Author

- Author contact information

- Title

- Study dates

Population

- Country

- Geographic region

- Sample size

- Proportion of sample that is female

- Subgroup of analysis (if any)

- Method of sampling

- Programme duration

Intervention

- Type of treatment (technology/fuel type)

- Details of treatment (including any supplemental programme components)

Comparison

♦ Method and unit of assignment to treatment and control (where applicable)

♦ Assessment of balance

Outcomes

♦ List of outcomes

♦ Effect size for included outcomes

♦ Supplemental data to standardize effect sizes (pooled standard deviation, standard error, confidence interval, T statistic, P value, number of observations etc.)

Study design

♦ Study Design

This data was later used in both the meta-analysis and the narrative synthesis. The systematic review included meta-analyses of the following outcomes:

Adoption of clean fuels and technologies

♦ Fuelwood consumption

♦ Coal consumption

♦ LPG Consumption

♦ Usage/maintenance of clean cooking technologies

Intermediate outcomes

♦ Time allocation

▪ Fuel collection time

▪ Cooking time

♦ Carbon monoxide – ambient and personal exposure

Long-term Impacts

♦ Pneumonia

- Chronic obstructive pulmonary disease (COPD)

- Acute respiratory infections (ARI)

- Blood pressure measured in terms of:

  - Systolic blood pressure

  - Diastolic blood pressure

  - Hypertension

In order to be included in the meta-analysis a study had to meet the following additional criteria:

- Include an effect size for one of the above-listed outcomes;

- Include sufficient data about this effect size to enable calculation of a standardized mean difference;

- Effect sizes included in meta-analysis must be independent.

When studies did not provide sufficient data for inclusion in the meta-analysis, per the Cochrane Collaboration Guidance, analysts contacted authors to request the additional data needed.[100] After two weeks, analysts reached out a second time to any authors who did not respond. If an author did not respond a second time and analysts could not find sufficient data, the study was excluded from the meta-analysis.

Assessment of the risk of bias in included studies

For each included study, the research team analysed the potential for any bias confounding facts that could impact the accuracy of results. The team analysed the potential for bias using a modified version of the Risk of Bias in Non-randomized Studies (ROBINS) tool.[101] This tool is specifically designed to assess the comparative effectiveness of interventions from studies that did not used randomized assignment to treatment and control groups.[102] The types of bias assessed included:

1. Bias due to participant selection:

   a. Was selection randomized, or was there bias due to self-selection, selection based on pre-specified characteristics or other bias?

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100 Cochrane 2011, "Methods for obtaining unpublished data". Available at https://www.cochrane.g/MR000027/METHOD_methods-f-obtaining-unpublished-data
101 Cochrane Methods. Robins-I Tool. Available at https://methods.cochrane.org/methods-cochrane/robins-i-tool
102 Jonathan Sterne, 2016, ROBINS-I: a tool for assessing risk of bias in non-randomized studies of interventions. BMJ 2011;343:d5928. Available at https://www.bmj.com/content/343/bmj.d5928#:~:text=The%20risk%20of%20bias%20tool%20covers%20 six%20domains%20of%20bias,the%20domain%2C%20%20different%20outcomes

b. Were the treatment and control groups adequately comparable?

2. Bias due to baseline confounding:

    a. Did the study account for potential confounding factors by including appropriate controls?

    b. Were there any major confounding factors such as simultaneous implementation with an additional programme?

3. Bias due to missing data:

    a. Did the study have a high level of attrition or missing data that could bias results?

    b. Did the study adequately address missing data or missing observations?

4. Bias due to departures from the intended interventions:

    a. Were there major changes in the intervention during implementation that could bias results?

    b. Was the programme implemented inconsistently in a way that may bias results?

5. Measurement bias in key outcomes:

    a. Are there any issues in the measurement of outcomes that could lead to measurement bias?

    b. Were the methods of measurement of outcomes comparable across interventions/studies?

The research team considered each of these questions in assessing potential bias concerns. In cases of potential bias, the team further identified what statistical methods were used to mitigate bias and rated the risk of bias as low, moderate or high. Any studies that raised major bias concerns were excluded. Given the challenges of implementing randomized control trials, some amount of bias was expected in quasi-experimental methodologies, particularly in the assignment to treatment and control groups; quasi-experimental studies that adequately addressed these potential bias concerns using statistical techniques qualified for the systematic review.

Criteria for determination of independent findings

In order to ensure independence of findings in the meta-analysis, the research team used the following guidelines:

1. **Each meta-analysis only included one result per sample. In most cases, this effectively meant that only one effect size per study was included in a meta-analysis**. For example,

if a study measured consumption of fuelwood in terms of kg/week as well as kg/meal, the meta-analysis for consumption of fuelwood would only include one of these two variables. In these cases, the research team selected the outcome based on (a) which outcome the author prioritized (if any), and (b) which indicator was most consistent with the indicators used in other studies. In cases where the author examined outcomes for different subgroups of the sample, multiple effect sizes were included in the same meta-analysis as long as the samples were not overlapping. For example, COPD effect sizes for subgroups of women in different age groups could be included, but not in conjunction with the COPD effect size for all women, as that would constitute overlapping samples. In such cases, the review team included each of the subgroups to allow for more granular analysis of the effect sizes in the specific subsamples. Similarly, several papers included multiple studies in different countries or different regions of the same country, for which the sample was completely different and non-overlapping. In these cases, each study was considered independent, and accordingly one effect size from each of the studies could be included in the same meta-analysis.

2. **Where an outcome is measured at multiple points in time, only one was included per meta-analysis**. If the author included an analysis of the same outcome at multiple points in time, to retain the integrity of independent findings, the research team only included one. In the interest of assessing long-term impact, the team generally included the measure that was taken after the longest duration. For example, if a researcher measured usage of an improved cooking stove at six months, one year and two years after an intervention, the team included the results after two years in order to examine long-term findings.

3. **If an author included multiple outcomes of interest that were eligible for different meta-analyses, one could be included in each meta-analysis**. For example, if one study examined both LPG consumption and pneumonia, because these outcomes fall into separate meta-analyses, both were analysed. The study's inclusion in two separate meta-analyses does not violate independence as long as the same study (of the same sample) does not appear more than once in the same meta-analysis.

4. **For authors who had written multiple studies based on the same sample, only one was included in a meta-analysis**. Because many authors produce multiple papers based on the same data, to retain independence, each meta-analysis only included an outcome from one of these studies. If an author had multiple papers that were updated versions of the same or very similar content, the research team selected the most recent paper provided the methodology was similar, if not better. If the content of the papers was significantly different, the research team selected the most relevant study.

5. **In studies with more than two groups, e.g., Studies with two treatment arms and one control group, only one treatment arm was included in the analysis**. In order to retain independence and avoid duplicate samples, the authors included only the study arm that was most consistent with the other studies in order to ensure a valid comparison.

Additional statistical analysis

Using Comprehensive Meta-Analysis (CMA) software,[103] the authors conducted the meta-analysis, the details of which are included below:

Assessment of publication bias

Publication bias occurs when the published literature on a topic is systematically different from the complete literature population.[104] For example, studies demonstrating statistically significant findings may be more likely to get published than those that find null results. This results in a bias in which the publications that are readily available suggest stronger findings than the complete body of research would have suggested. To investigate publication bias, the review team used CMA to create funnel plots, demonstrating the observed results from the included studies together with imputed results for possible studies that might not have been published. In addition, the team employed Duvall and Tweedie's trim and fill function to estimate the adjusted value and confidence interval of the summary statistics with the imputed studies, to investigate whether the findings were likely to have been influenced by publication bias.[105]

Assessment of heterogeneity

To assess heterogeneity among studies, the team used CMA to calculate and report on the I^2 statistic for each meta-analysis. Generally, an I^2 statistic of above 50% is considered moderate-to-high. The Cochrane Handbook recommends the following more specific guidance on interpreting I^2:

1. 0% to 40% – may not be important;

2. 30% to 60% – may represent moderate heterogeneity;

3. 50% to 90% – may represent substantial heterogeneity;

4. 75% to 100% – considerable heterogeneity.

Because of the global nature of the current review, and the wide variation in contexts and interventions, the team expected a certain degree of heterogeneity, and used random effects models to address this issue.

Subgroup analysis using moderators

The team used two moderators to examine how impacts varied based on different factors:

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103 Comprehensive Meta-Analysis (Version 3) [Computer software], 2020, Englewood, NJ: Biostat. Available at https://www.meta-analysis.com/

104 H. R. Rothstein, A. J. Sutton and M. Borenstein (Eds.) © 2005, *Bias in Meta-Analysis – Prevention, Assessment and Adjustments,* John Wiley & Sons, Ltd. Available at https://www.meta-analysis.com/downloads/PBPreface.pdf

105 Shi, Linyu, 2019, The trim-and-fill method for publication bias: "Practical guidelines and recommendations based on a large database of meta-analyse". Available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6571372/

1. The first moderator was type of intervention, including improved biomass cooking stoves, biogas, biofuel, liquid petroleum gas, natural gas, ethanol, electric cooking/induction stoves and solar cookers;

2. The second moderator was geographic region based on the United Nations categories, including Africa, Asia and the Pacific, Western Asia, Europe, and Latin America and the Caribbean.

For any meta-analyses including at least 10 results, the research team used CMA to group results by these two moderators, in order to assess whether the summary statistics varied by intervention type or region.

Treatment of qualitative research

While the systematic review did not include studies that were purely qualitative, the team made efforts to incorporate and analyse some of the qualitative information in order to validate and further elaborate on quantitative findings. Campbell guidelines suggest that qualitative information can be valuable in terms of:[106]

1. Defining interventions more specifically;

2. Providing insights into heterogeneous findings across studies;

3. Addressing some of the factors that obstruct or facilitate intervention effectiveness; and

4. Highlighting characteristics of successful implementation as well as reasons for poor implementation.

Because clean cooking interventions vary widely, it is difficult to capture intervention characteristics through quantitative data alone. For example, two programmes might use similar technology, but have very different monitoring and follow-up plans. In addition, programmes might have supplemental characteristics such as training and awareness campaigns or initiatives to more deeply engage local communities in planning. To capture these factors better, the authors included a subsection on heterogeneous findings on each of the analysed results. This section discusses some of the qualitative characteristics that may have affected programme success or the lack thereof. In addition, the authors discuss the implementation, external validity and costs of the various interventions and studies. This qualitative information also helped to provide information on the implications for policy and practice.

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106 Campbell Collaboration, 2019, "Campbell systematic reviews: Policies and guidelines". Available at https://training.cochrane.org/handbook

Annex 6.   Description of included studies

The complete list of studies included in this systematic review is detailed in table A6-1.

List of studies in the narrative synthesis

Study name	Intervention	Region	Country	Study Design	Number of households*	Health	Adoption
Adrianzen, 2010	ICS (Traditional Biomass)	Latin American and the Caribbean	Peru	Controlled experiment	194	✓	✓
Aguilar, 2018	ICS (Traditional Biomass)	South-East Asia	Philippines (the)	Controlled experiment	60	✓	
Alem, 2015	LPG – Multipronged Intervention	Sub-Saharan Africa	Tanzania	RCT	722		✓
Anderman, 2015	Biogas Digesters	South and South-West Asia	India	Controlled experiment	199		✓
Aung, 2016	ICS (Traditional Biomass)	South and South-West Asia	India	RCT	187		✓
Barstow, 2016	ICS (Traditional Biomass)	Sub-Saharan Africa	Rwanda	Before and after	187		✓
Bedi, 2015	Biogas Digesters	Sub-Saharan Africa	Rwanda	Cross-sectional	600		✓
Beltramo, 2013	Solar Oven/ Cooker	Sub-Saharan Africa	Senegal	RCT	790	✓	✓
Bensch, 2013	ICS - Multipronged Intervention	Sub-Saharan Africa	Burkina Faso	Cross-sectional	1,473	✓	✓
Bensch, 2013	ICS (Traditional Biomass)	Sub-Saharan Africa	Senegal	Cross-sectional	624		✓
Bensch, 2015	ICS (Traditional Biomass)	Sub-Saharan Africa	Senegal	RCT	253	✓	✓
Bensch, 2019	ICS (Traditional Biomass)	Sub-Saharan Africa	Senegal	RCT	253		✓
Berkeley Air Monitoring Group, 2015 A (Before and After)	ICS (Traditional Biomass)	South-East Asia	Cambodia	Before and after	48		✓
Berkeley Air Monitoring Group, 2015 B (Cross-Sectional)	ICS (Traditional Biomass)	South-East Asia	Cambodia	Cross-sectional	48		✓

Study name	Intervention	Region	Country	Study Design	Number of households*	Health	Adoption
Bruce, 2007 A (Kenya)	ICS & LPG - Multipronged Intervention	Global	Kenya	Before and after	160	✓	
Bruce, 2007 B (Nepal)	ICS & LPG - Multipronged Intervention	Global	Nepal	Before and After	192	✓	
Bruce, 2007 C (Sudan)	ICS - Multipronged Intervention	Global	Sudan	Before and after	197	✓	
Burwen, 2012	ICS (Traditional Biomass)	Sub-Saharan Africa	Ghana	RCT	768	✓	✓
Calzada, 2018	LPG/Subsidy	Latin American and the Caribbean	Peru	PSM	458	✓	✓
Chapman, 2005	ICS (Traditional Biomass)	East and North-East Asia	China	Panel	2,0453*	✓	
Cheng, 2015	ICS - Multipronged Intervention	East and North-East Asia	China	Before and after	371	✓	
Christiaensen, 2012	Biogas Digesters	East and North-East Asia	China	Controlled experiment	2,700	✓	✓
Clark, 2009	ICS (Traditional Biomass)	Latin American and the Caribbean	Honduras	Cross-sectional	79*	✓	
Clark, 2012	ICS (Traditional Biomass)	Latin American and the Caribbean	Nicaragua	Before and after	74*	✓	
Critchley, 2015	ICS (Traditional Biomass)	Sub-Saharan Africa	Kenya	Before and after	38	✓	✓
Diaz, 2008	ICS (Traditional Biomass)	Latin American and the Caribbean	Guatemala	RCT	180	✓	
Dohoo, 2012	Biogas Digesters	Sub-Saharan Africa	Kenya	Cross-sectional	62		
Dohoo, 2013	Biogas Digesters	Sub-Saharan Africa	Kenya	Controlled experiment	62	✓	✓
Dutch Ministry of Foreign Affaires, 2014	Biogas Digesters	Sub-Saharan Africa	Rwanda	PSM	600		✓

Study name	Intervention	Region	Country	Study Design	Number of households*	Health	Adoption
Ezzati, 2002	ICS (Traditional Biomass)	Sub-Saharan Africa	Kenya	Panel	55	✓	✓
Foote, 2013	ICS (Traditional Biomass)	Sub-Saharan Africa	Kenya	Panel	200	✓	
Gizachew, 2018	ICS (Traditional Biomass)	Sub-Saharan Africa	Ethiopia	Cross-sectional	55		✓
Granderson, 2009	ICS (Traditional Biomass)	Latin American and the Caribbean	Guatemala	Controlled experiment	12		✓
Greene, 2014	ICS (traditional biomass)	East and North-East Asia	Mongolia	PSM	959	✓	✓
Guarnieri, 2015	ICS (Traditional Biomass)	Latin American and the Caribbean	Guatemala	RCT	306	✓	
Hanna, 2016	ICS (Traditional Biomass)	South and South-West Asia	India	RCT	2,575	✓	✓
Hartinger, 2016	ICS (Traditional Biomass)	Latin American and the Caribbean	Peru	Clustered RCT	534	✓	
Hosgood, 2008	ICS (Traditional Biomass)	East and North-East Asia	China	Panel	8,418*	✓	
Jagger, 2019	ICS - Multipronged Intervention	Sub-Saharan Africa	Rwanda	Panel, DiD	144	✓	✓
Jamali, 2017 A (Sindh, Pakistan)	ICS (Traditional Biomass)	South and South-West Asia	Pakistan	Controlled experiment	292	✓	
Jamali, 2017 B (Punjab, Pakistan)	ICS (Traditional Biomass)	South and South-West Asia	Pakistan	Controlled experiment	313	✓	
Jeuland, 2020	ICS - Multipronged Intervention	South and South-West Asia	India	Clustered RCT - Step wedge	600		✓
Johnson, 2013	ICS (Traditional Biomass)	Latin American and the Caribbean	Peru	Before and after	26		✓
Khushk, 2005	ICS (Traditional Biomass)	South and South-West Asia	Pakistan	Cross-sectional	159	✓	
Lafave, 2019	ICS - Multipronged Intervention	Sub-Saharan Africa	Ethiopia	RCT	504	✓	✓

Study name	Intervention	Region	Country	Study Design	Number of households*	Health	Adoption
Lamichhane, 2017	Combined Clean Fuels (Biogas, Ethanol, LPG and/or Electricity)	South and South-West Asia	India	PSM	16,157*	✓	
Lan, 2002	ICS (Traditional Biomass)	East and North-East Asia	China	Panel	21,232*	✓	
Laramee, 2013	Biogas Digesters	Sub-Saharan Africa	Tanzania	Cross-sectional	40		✓
Lewis, 2016	Biogas Digesters	South and South-West Asia	India	Cross-sectional	105	✓	✓
Ludwinski, 2011	ICS (Traditional Biomass)	Sub-Saharan Africa	Guatemala	Panel, DiD	351	✓	✓
McCracken, 2007 A (RCT)	ICS (Traditional Biomass)	Latin American and the Caribbean	Guatemala	RCT	120	✓	
McCracken, 2007 B (Before and after)	ICS (Traditional Biomass)	Latin American and the Caribbean	Guatemala	Before and after	55	✓	
Mortimer, 2017	ICS (Traditional Biomass)	Sub-Saharan Africa	Malawi	Clustered RCT	8,626	✓	
Mudombi, 2018	Combined Clean Fuels (Biogas, Ethanol, LPG and/or Electricity)	Sub-Saharan Africa	Mozambique	Cross-sectional	341		✓
Muriuki, 2015	Biogas Digesters	Sub-Saharan Africa	Kenya	Before and after	200		✓
Neupane, 2014	Biogas Digesters	South and South-West Asia	Nepal	PSM	519	✓	
Northcross, 2016	Combined Clean Fuels (Biogas, Ethanol, LPG and/or Electricity)	Sub-Saharan Africa	Nigeria	RCT	50		✓
Ochieng, 2013 A (Cross-sectional)	ICS (Traditional Biomass)	Sub-Saharan Africa	Kenya	Cross-sectional	145		✓

Study name	Intervention	Region	Country	Study Design	Number of households*	Health	Adoption
Ochieng, 2013 B (Before and after)	ICS (Traditional Biomass)	Sub-Saharan Africa	Kenya	Before and after	50		✓
Oluwole, 2013	ICS (Traditional Biomass)	Sub-Saharan Africa	Nigeria	Before and after	59	✓	
Onyeneke, 2017	ICS (Traditional Biomass)	Sub-Saharan Africa	Nigeria	PSM, DiD	280		✓
Onyeneke, 2019	ICS (Traditional Biomass)	Sub-Saharan Africa	Nigeria	PSM	400	✓	✓
Pattanayak, 2019	ICS & Electric Stove - Multipronged Intervention	South and South-West Asia	India	RCT	1,063		✓
Peabody, 2010	ICS (Traditional Biomass)	East and North-East Asia	China	Cross-sectional	6,923*	✓	
Pillarisetti, 2014	ICS (Traditional Biomass)	South and South-West Asia	India	Before and after	200		✓
Pine 2011	ICS (Traditional Biomass)	Latin American and the Caribbean	Mexico	Panel	259	✓	✓
Putra 2017	Biogas Digesters	South-East Asia	Indonesia	PSM	351		✓
Quinn 2017	ICS & LPG - Multipronged Intervention	Sub-Saharan Africa	Ghana	Before and after	44	✓	
Rennert, 2015	ICS (Traditional Biomass)	Latin American and the Caribbean	Honduras	Before and after	30	✓	
Romieu, 2009	ICS (Traditional Biomass)	Latin American and the Caribbean	Mexico	RCT	668	✓	✓
Sagbo 2014	ICS (Traditional Biomass)	Latin American and the Caribbean	Haiti	PSM	146		✓
Schilmann 2014	ICS (Traditional Biomass)	Latin American and the Caribbean	Mexico	RCT	668	✓	
Shen 2009	ICS (Traditional Biomass)	East and North-East Asia	China	Panel	42,422*	✓	

Study name	Intervention	Region	Country	Study Design	Number of households*	Health	Adoption
Silk 2012	ICS - Multipronged Intervention	Sub-Saharan Africa	Kenya	Panel	1,500		✔
Singh 2012	ICS (Traditional Biomass)	South and South-West Asia	Nepal	Before and after	47	✔	
Smith 2011	ICS (Traditional Biomass)	Latin American and the Caribbean	Guatemala	RCT	534	✔	
Smith-Sivertsen 2009	ICS (Traditional Biomass)	Latin American and the Caribbean	Guatemala	RCT	534	✔	
Thomas 2013	ICS (Traditional Biomass)	Sub-Saharan Africa	Rwanda	RCT	257		✔
Thompson 2018	LPG - Multipronged Intervention	Latin American and the Caribbean	Guatemala	Controlled experiment	266		✔
Tielsch, 2016	ICS (Traditional Biomass)	South and South-West Asia	Nepal	Clustered RCT - Step wedge	3,376	✔	
Usmani, 2017	ICS (Traditional biomass)	South-East Asia	Cambodia	RCT	61		✔
Wilson, 2016	ICS - Multipronged Intervention	Northern Africa	Sudan	Before and after	180		✔
Yasmin, 2019	Biogas Digesters	South and South-West Asia	Pakistan	PSM	630		✔
Yu, 2011	ICS - Multipronged Intervention	East and North-East Asia	China	DiD	5,500	✔	✔
Zaman, 2017	ICS (Traditional Biomass)	South and South-West Asia	Bangladesh	RCT	300	✔	
Zhou, 2014	Combined clean fuels (biogas, ethanol, LPG and/or electricity)	East and North-East Asia	China	Panel	996*	✔	

* The number of participants included in the study was recorded instead of the number of households when the latter was not available.

Annex 7.   Effect size equations and transformations

The Hedges's g formula is:

$$\text{Hedges's g} = \frac{M_1 - M_2}{SD*pooled}$$

Where M1-M2 is the difference in means between the treatment and control group, and SD*pooled is the weighted and pooled standardized deviation.

In calculating Standardized Mean Differences (SMDs), the team applied the guidance of Cochrane Handbook.[107]

Continuous variables

For continuous variables, the team used the following formula to calculate SMDs:

$$SMD = \frac{\text{Difference in mean outcome between groups}}{\text{Standard deviation of outcome among participants}}$$

This formula was used for all continuous variables with effect sizes reported in regression coefficient. The pooled standard deviation was calculated as follows:

$$S_{pooled} = \sqrt{\frac{S_T^2 (n-1) + S_C^2 (n_C - 1)}{n_r + n_C - 2}}$$

where sT and sT are the standard deviations in the treatment and control group, respectively; nT and nC are the sample size of the population from which the groups were drawn out.

For any studies that did not report sufficient data for the team to calculate SD, the team contacted the author to further inquire about the data.

In cases where SD was only reported either post- or pre-, it was assumed that the SD was similar in both periods. Similarly, for any studies that did not report the distribution of sample size between treatment and control groups, it was assumed that these groups were of equal size. In addition, the team performed basic transformations as needed, such as converting confidence intervals to SD.

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107 https://training.cochrane.org/handbook/current/chapter-06#_Ref421277795

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Binary variables

Among the binary variables, pneumonia and severe pneumonia were measured in relative risk the equation for which is as follows:

$$\text{Rate ratio} = \frac{\text{Incidence rate in experimental group}}{\text{Incidence rate in comparator group}}$$

All studies included in these meta-analyses provided effect sizes in relative risk.
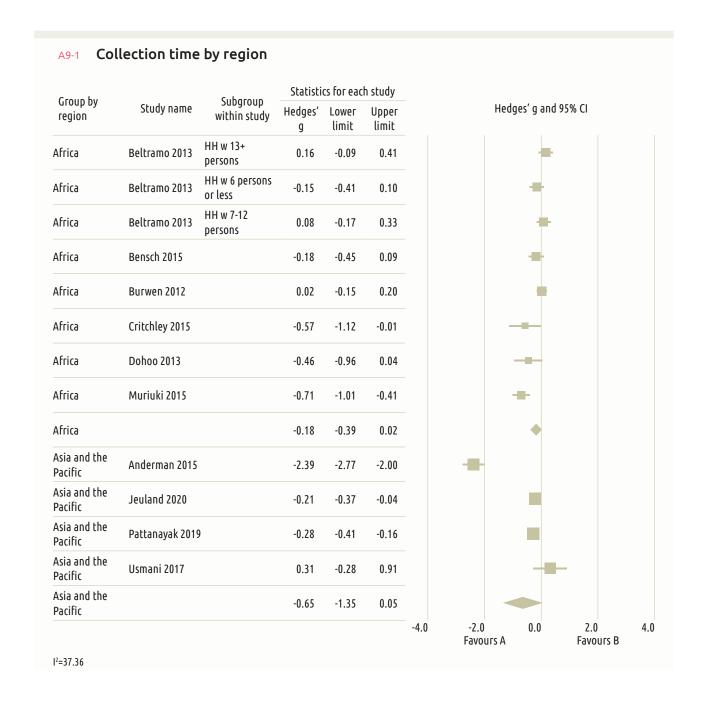
COPD and hypertension were measured in odds ratio, the equation for which is:

$$\text{Odds ratio} = \frac{\text{Odds of event in experimental group}}{\text{Odds of event in comparator group}}$$

For a couple of studies, the team converted risk ratio to odds ratio using the 2x2 table of two group randomized trial with dichotomous outcome as detailed in the Cochrane guidelines.

Annex 8.   Differences between protocol and review

Based on the initial peer review, the research team drastically expanded its search strategy for this systematic review by adding electronic databases to the search as well as documenting the screening process better using Abstrackr. While the outcomes of interest were the same, the team further elaborated on the specific metrics that would be included in the measure of outcomes. Last, while the team initially intended to examine only interventions that met WHO criteria for clean cooking, before initiating the search they decided to drop this criterion because it does not best capture typical field use of technologies.

Annex 9.   Moderator analysis

A9-1   Collection time by region

Group by region	Study name	Subgroup within study	Statistics for each study			Hedges' g and 95% CI
			Hedges' g	Lower limit	Upper limit	
Africa	Beltramo 2013	HH w 13+ persons	0.16	-0.09	0.41	
Africa	Beltramo 2013	HH w 6 persons or less	-0.15	-0.41	0.10	
Africa	Beltramo 2013	HH w 7-12 persons	0.08	-0.17	0.33	
Africa	Bensch 2015		-0.18	-0.45	0.09	
Africa	Burwen 2012		0.02	-0.15	0.20	
Africa	Critchley 2015		-0.57	-1.12	-0.01	
Africa	Dohoo 2013		-0.46	-0.96	0.04	
Africa	Muriuki 2015		-0.71	-1.01	-0.41	
Africa			-0.18	-0.39	0.02	
Asia and the Pacific	Anderman 2015		-2.39	-2.77	-2.00	
Asia and the Pacific	Jeuland 2020		-0.21	-0.37	-0.04	
Asia and the Pacific	Pattanayak 2019		-0.28	-0.41	-0.16	
Asia and the Pacific	Usmani 2017		0.31	-0.28	0.91	
Asia and the Pacific			-0.65	-1.35	0.05	

Favours A   Favours B

I^2=37.36

A9-2 Cooking time by region

Group by region	Study name	Subgroup within study	Statistics for each study			Hedges' g and 95% CI
			Hedges' g	Lower limit	Upper limit	
Africa	Beltramo 2013	HH w 13+ persons	-0.00	-0.25	0.25	
Africa	Beltramo 2013	HH w 6 persons or less	0.16	-0.10	0.41	
Africa	Beltramo 2013	HH w 7-12 persons	-0.14	-0.39	0.11	
Africa	Jagger 2019		0.33	-0.00	0.66	
Africa	Ochieng 2019		0.00	-0.19	0.20	
Africa			-0.62	-0.93	-0.31	
Asia and the Pacific	Anderman 2015		-0.62	-0.93	-0.31	
Asia and the Pacific	Jeuland 2020		-0.34	-0.50	-0.17	
Asia and the Pacific	Pattanayak 2019		-0.41	-0.54	-0.29	
Asia and the Pacific	Usmani 2017		0.20	-0.39	0.79	
Asia and the Pacific			-0.38	-0.55	-0.22	
Latin America and Caribbean	Thompson 2018		-1.58	-2.09	-1.07	
Latin America and Caribbean			-1.58	-2.09	-1.07	

-4.0   -2.0   0.0   2.0   4.0

Favours A   Favours B

I^2=79.30

A9-3 **Wood consumption by intervention type**

Group by intervention	Study name	Subgroup within study	Statistics for each study			Hedges' g and 95% CI
			Hedges' g	Lower limit	Upper limit	
Biogas Digesters	Dohoo 2013		0.13	-0.36	0.62	
Biogas Digesters	Dutch Ministry of Foreign Affairs 2014		-0.32	-0.48	-0.15	
Biogas Digesters	Muriuki 2015		-1.98	-2.23	-1.72	
Biogas Digesters	Putra 2017		-2.89	-3.22	-2.56	
Biogas Digesters			-1.27	-2.57	0.04	
Electric	Pattanayak 2019		-0.09	-0.29	0.11	
Electric			-0.09	-0.29	0.11	
ICS (traditional biomass)	Adrianzen 2010		-0.50	-0.88	-0.12	
ICS (traditional biomass)	Bensch 2013		-0.41	-0.56	-0.26	
ICS (traditional biomass)	Bensch 2015		-0.80	-1.08	-0.53	
ICS (traditional biomass)	Burwen 2012		-0.17	-0.35	0.00	
ICS (traditional biomass)	Gizachew 2018		-1.25	-1.83	-0.68	
ICS (traditional biomass)	Jeuland 2020		0.10	-0.06	0.26	
ICS (traditional biomass)	Johnson 2013		-0.70	-1.27	-0.12	
ICS (traditional biomass)	Ludwinski 2011		-0.86	-1.36	-0.37	
ICS (traditional biomass)	Ochieng 2013		-0.48	-0.82	-0.15	
ICS (traditional biomass)	Yu 2011	Behavioral intention only	0.05	-0.29	0.40	
ICS (traditional biomass)	Yu 2011	Stove and behavioral intention	0.48	0.23	0.74	
ICS (traditional biomass)			-0.37	-0.62	-0.12	
Solar oven/ cooker	Beltramo 2013	HH w 13+ persons	-0.02	-0.28	0.25	
Solar oven/ cooker	Beltramo 2013	HH w 6 persons or less	0.04	-0.22	0.31	
Solar oven/ cooker	Beltramo 2013	HH w 7-12 persons	-0.30	-0.57	-0.04	
Solar oven/ cooker			-0.09	-0.30	0.12	

I^2=27.13

A9-4　Wood consumption by region

Group by region	Study name	Subgroup within study	Hedges' g	Lower limit	Upper limit	Hedges' g and 95% CI
Africa	Beltramo 2013	HH w 13+ persons	-0.02	-0.28	0.25	
Africa	Beltramo 2013	HH w 6 persons or less	0.04	-0.22	0.31	
Africa	Beltramo 2013	HH w 7-12 persons	-0.30	-0.57	-0.04	
Africa	Bench 2013		-0.41	-0.56	-0.26	
Africa	Bench 2015		-0.80	-1.08	-0.53	
Africa	Burwen 2012		-0.17	-0.35	0.00	
Africa	Dohoo 2013		0.13	-0.36	0.62	
Africa	Dutch Ministry of Foreign Affairs 2014		-0.32	-0.48	-0.15	
Africa	Gizachew 2018		-1.25	-1.83	-0.68	
Africa	Muriuki 2015		-1.98	-2.23	-1.72	
Africa	Ochieng 2013		-0.48	-0.82	-0.15	
Africa			-0.50	-0.82	-0.17	
Asia and the Pacific	Jeuland 2020		0.10	-0.06	0.26	
Asia and the Pacific	Pattanayak 2019		-0.09	-0.29	0.11	
Asia and the Pacific	Putra 2017		-2.89	-3.22	-2.56	
Asia and the Pacific	Yu 2011	Behavioral intervention only	0.05	-0.29	0.40	
Asia and the Pacific	Yu 2011	Stove and behavioral intervention	0.48	0.23	0.74	
Asia and the Pacific			-0.46	-1.39	0.46	
Latin America and Caribbean	Adrianzen 2010		-0.50	-0.88	-0.12	
Latin America and Caribbean	Johnson 2013		-0.70	-1.27	-0.12	
Latin America and Caribbean	Ludwinski 2011		-0.86	-1.36	-0.37	
Latin America and Caribbean			-0.65	-0.91	-0.38	

-4.0　-2.0　0.0　2.0　4.0
Favours A　　　　Favours B

I^2=15.79

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A9-5   Collection time by Intervention

Group by intervention	Study name	Subgroup within study	Statistics for each study			Hedges' g and 95% CI
			Hedges' g	Lower limit	Upper limit	
Biogas Digesters	Anderman 2015		-2.39	-2.77	-2.00	
Biogas Digesters	Dohoo 2013		-0.46	-0.96	0.04	
Biogas Digesters	Muriuki 2015		-0.71	-1.01	-0.41	
Biogas Digesters			-1.19	-2.36	-0.01	
Electric	Pattanayak 2019		-0.28	-0.41	-0.16	
Electric			-0.28	-0.41	-0.16	
ICS (traditional biomass)	Bensch 2015		-0.18	-0.45	0.09	
ICS (traditional biomass)	Burwen 2012		0.02	-0.15	0.20	
ICS (traditional biomass)	Critchley 2015		-0.57	-1.12	-0.01	
ICS (traditional biomass)	Jeuland 2020		-0.21	-0.37	-0.04	
ICS (traditional biomass)	Usmani 2017		0.31	-0.28	0.91	
ICS (traditional biomass)			-0.12	-0.30	0.06	
Solar oven/ cooker	Beltramo 2013	HH w 13+ persons	0.16	-0.09	0.41	
Solar oven/ cooker	Beltramo 2013	HH w 6 persons or less	-0.15	-0.41	0.10	
Solar oven/ cooker	Beltramo 2013	HH w 7-12 persons	0.08	-0.17	0.33	
Solar oven/ cooker			0.03	-0.16	0.21	

-4.0   -2.0   0.0   2.0   4.0

Favours A   Favours B

$I^2 = 44.14$

Carbon Monoxide by Intervention Type

Group by intervention	Study name	Subgroup within study	Statistics for each study			Hedges' g and 95% CI
			Hedges' g	Lower limit	Upper limit	
ICS (traditional biomass)	Bruce 2007b		-0.64	-1.00	-0.28	
ICS (traditional biomass)	Cheng 2015		-0.23	-1.44	0.98	
ICS (traditional biomass)	Clark 2009		-0.94	-1.50	-0.39	
ICS (traditional biomass)	Clark 2012		-1.30	-2.06	-0.53	
ICS (traditional biomass)	Greene 2014		-0.35	-0.63	-0.07	
ICS (traditional biomass)	Hanna 2016	Children	-0.02	-0.08	0.04	
ICS (traditional biomass)	Hanna 2016	Primary cooks	-0.04	-0.10	0.02	
ICS (traditional biomass)	Khushk 2015		-0.27	-0.54	0.00	
ICS (traditional biomass)	Oluwole 2013		-3.55	-5.46	-1.63	
ICS (traditional biomass)	Onyeneke 2017		-0.15	-0.27	-0.04	
ICS (traditional biomass)	Peabody 2010		-0.06	-0.10	-0.01	
ICS (traditional biomass)	Singh 2012		-0.79	-1.47	-0.10	
ICS (traditional biomass)	Smith 2009		-0.17	-0.26	-0.08	
ICS (traditional biomass)			-0.20	-0.29	-0.11	
Solar oven/cooker	Beltramo 2013	HH w 13+ persons	0.02	-0.23	0.26	
Solar oven/cooker	Beltramo 2013	HH w 6 persons or less	0.53	0.28	0.77	
Solar oven/cooker	Beltramo 2013	HH w 7-12 persons	0.03	-0.21	0.27	
Solar oven/cooker			0.19	-0.14	0.52	
Subsidy (LPG)	Bruce 2007a		-0.95	-1.49	-0.42	
Subsidy (LPG)	Bruce 2007c		0.15	-0.25	0.55	
Subsidy (LPG)			-0.39	-1.47	0.70	

-4.0 -2.0 0.0 2.0 4.0

Favours A   Favours B

$I^2 = 62.94$

Carbon Monoxide by Region

Group by region	Study name	Subgroup within study	Statistics for each study			Hedges' g and 95% CI
			Hedges' g	Lower limit	Upper limit	
Africa	Beltramo 2013	HH w 13+ persons	0.02	-0.23	0.26	
Africa	Beltramo 2013	HH w 6 persons or less	0.53	0.28	0.77	
Africa	Beltramo 2013	HH w 7-12 persons	0.03	-0.21	0.27	
Africa	Bruce 2007a		-0.95	-1.49	-0.42	
Africa	Bruce 2007c		0.15	-0.25	0.55	
Africa	Oluwole 2013		-3.55	-5.46	-1.63	
Africa	Onyeneke 2017		-0.15	-0.27	-0.04	
Africa			-0.11	-0.42	0.20	
Asia and the Pacific	Bruce 2007b		-0.64	-1.00	-0.28	
Asia and the Pacific	Cheng 2015		-0.23	-1.44	0.98	
Asia and the Pacific	Greene 2014		-0.35	-0.63	-0.07	
Asia and the Pacific	Hanna 2016	Children	-0.02	-0.08	0.04	
Asia and the Pacific	Hanna 2016	Primary	-0.04	-0.10	0.02	
Asia and the Pacific	Khushk 2015		-0.27	-0.54	-0.00	
Asia and the Pacific	Peabody 2010		-0.06	-0.10	-0.01	
Asia and the Pacific	Singh 2012		-0.79	-1.47	-0.10	
Asia and the Pacific			-0.11	-0.20	-0.03	
Latin America and Caribbean	Adrianzen 2010		-0.94	-1.50	-0.39	
Latin America and Caribbean	Johnson 2013		-1.30	-2.06	-0.53	
Latin America and Caribbean	Ludwinski 2011		-0.17	-0.26	-0.08	
Latin America and Caribbean			-0.73	-1.47	0.00	

Favours A   Favours B

I^2=55.83

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