WHO Indoor Air Quality Guidelines: Household Fuel Combustion

Review 7: Factors influencing the adoption and sustained use of improved cookstoves and clean household energy

Convening lead author: Elisa Puzzolo[1]

Lead authors: Eva Rehfuess[2], Debbi Stanistreet[1], Daniel Pope[1], Nigel Bruce[1,3]

Affiliations
[1] Department of Public Health and Policy, University of Liverpool, UK
[2] Institute for Medical Informatics, Biometry and Epidemiology, University of Munich, Germany
[3]World Health Organization, Public Health and Environment, Interventions for Healthy Environments

Convening lead author: those authors who led the planning and scope of the review, and managed the process of working with other lead authors and contributing authors, and ensuring that all external peer review comments were responded to.

Lead authors: those authors who contributed to one or more parts of the full review, and reviewed and commented on the entire review at various stages.

Disclaimer

Table of Contents

Summary

Background

Adoption and sustained use of cleaner, safer and more efficient household energy technologies and fuels has been for more than 30 years, and still remains, a major challenge worldwide – notwithstanding some successful experiences at small and large scales. Based on a mixed-method systematic review of 101 studies across Asia, Africa and Latin America, this document presents key findings on factors which can act as enablers and/or barriers in influencing the uptake of cleaner and more efficient household energy technologies. These comprise five intervention areas: improved solid fuel stoves (ICS) and clean fuels, i.e. liquefied petroleum gas (LPG), biogas, solar cookers and alcohol fuels (ethanol and methanol). Uptake comprises both short-term adoption and longer-term sustained use.

Aim and key questions

The aim of this review was to identify the factors that influence the large-scale uptake by households of cleaner and more efficient household energy technologies. The key questions addressed by this review were:

1. Which factors enable or limit adoption and sustained use of improved solid fuel stoves, biogas, liquefied petroleum gas, alcohol fuels and solar stoves?
2. Can any specific lessons be derived with respect to scaling-up programmes of cleaner and more efficient household energy technologies in equitable ways in relation to poverty, urban-rural location and gender?
3. What are the implications of findings for programme and policy planning, as well as future research?

Methods

A comprehensive search strategy was employed, comprising systematic searches in 27 multi-disciplinary bibliographic databases and 14 specialist websites, the grey literature, and consultation with of experts, covering the period 1980 to June 2012. Three types of evidence – qualitative studies, quantitative studies and case/policy studies – were eligible, provided that they related to a direct experience with one of the five types of intervention, and that they reported empirical information on factors influencing adoption or sustained use. Study selection, data extraction, quality appraisal and a two-stage synthesis procedure followed standardised methodologies and employed a degree of independent verification by two or more authors.

Thematic and tabular/narrative syntheses were used for qualitative and other studies respectively, with findings categorised according to seven a priori defined domains relevant to household energy uptake and equity. Domains include: (1) Fuel and technology characteristics, (2) Household and setting characteristics, (3) Knowledge and perceptions, (4) Financial, tax and subsidy aspects, (5) Market development, (6) Regulation, legislation and standards, and (7) Programmatic and policy mechanisms. Equity considerations and the extent to which evidence informed adoption versus sustained use at scale were also reported.

Findings

Based on nearly 14 000 records identified, this review selected 101 eligible studies across Asia, Africa and Latin America, with 57 studies relating to ICS and 44 to clean fuels (17 on biogas, 12

on LPG, 9 on solar cooking, 6 on alcohol fuels). Studies included peer-reviewed publications, reports, book chapters, dissertations and conference proceedings, categorised as qualitative studies (19 studies), quantitative studies (22 studies) and case/policy studies (60 studies). Quality appraisal of individual studies following established criteria found 17 out of 19 qualitative studies, 17 out of 22 quantitative studies and 47 out of 60 case studies and policy analysis scoring moderate to strong quality respectively.

For all five intervention areas, a series of factors were identified across the seven domains, some of which operate primarily at household and community level and others operating primarily at programmatic and societal level. These factors can most usefully be seen as operating on a spectrum rather than as discrete enablers and barriers, so that when present or satisfactory are enabling, and vice-versa. In terms of relative importance, while factors such as meeting household needs, fuel saving, higher income levels, effective financing and facilitative government action seemed critical and necessary for success, none are sufficient in their own right to guarantee adoption and use, and all those relevant to a given setting need to be assessed. Accordingly, these are described as 'necessary but not sufficient'. The nature of the available evidence does not support a more formal prioritisation of factors, and the relevance of most will vary according to context (setting, fuel and technology); indeed some are very specific to fuel type, especially for biogas and solar cookers.

Consistency across different types of evidence, countries and settings support the robustness of the findings and the relevance of individual factors. To assess the overall strength of the body of evidence, GRADE domains were used as a guide. Overall, the evidence was judged to provide reliable results, particularly in light of the consistency of many of the findings from different study types across a wide range of settings.

Conclusions

Although there are limitations to the available studies (notably for some clean fuels) overall this is a moderately strong and consistent set of evidence, and it is concluded that the findings are sufficiently robust to use as a basis for policy planning and evaluation. There is a lack of studies on newer ICS technologies, but the findings may be expected to apply to the various features of these technologies and the means through which these are promoted. While some factors are critical for success, none are sufficient alone to guarantee adoption and/or sustained use, and all factors relevant to a given setting, technology and fuel should be assessed. Implementation of findings could be achieved through a planning and evaluation tool, designed to assess all setting-relevant factors, which will require development and testing. This can provide the basis for further strengthening the evidence base through evaluation of new projects and programmes, for which prospective studies will be especially valuable.

1. Introduction and scope

The substantial health benefits expected from cleaner burning household energy technologies and fuels that meet (or closely approach) the WHO air quality guidelines (AQGs) will not be realised if households do not adopt them, do not use them more or less exclusively, and maintain and replace them when needed. Past experience for improved stoves suggests that achieving these goals is challenging, although there are also examples of more successful adoption and sustained use. The critical nature of this issue is brought into focus by the fact that those suffering the greatest burdens of adverse consequences on health, time, personal safety, and the local environment are generally also the poorest, facing multiple demands on very limited resources. This presents additional challenges for ensuring equity of access to these fuels and technologies.

The focus of this review is on low and middle income countries, as that is where the challenges for adoption are greatest. In developed countries, a mix of regulatory mechanisms, markets and overall higher levels of wealth should provide the means for adoption, sustained use and maintenance where clean-burning stoves and clean fuels are not already the norm. That said, poorer communities in developed countries known to experience energy poverty and those countries in transition may need more attention, and some of the conclusions of this review may be relevant to these population groups.

To date, the totality of experience of more than 30 years of national and international efforts to promote adoption of cleaner household energy has not been systematically reviewed. A recent review by Lewis and Pattanayak (2012) did address the topic (1). Based on eleven regression analyses in eight studies and the basic meta-analytical technique of vote-counting, the review found 18 variable groups across the three categories: price, socio-economic status and demographics associated with adoption. As the authors do not offer any explanation of the likely mechanisms that underlie these associations, it is difficult to draw conclusions with respect to the development of programmes and policies.

Given the importance of sustained adoption to achieving the health benefits of reduced HAP exposure, a new systematic review is summarised here; this includes all available study types and a broad perspective spanning individual household circumstances and user perspectives through to national and international policy and financing. The implications of the findings for implementation of these guidelines are considered further in Section 7.

2. Methods

2.1 Aim and questions to be answered

The aim of this systematic review was to review the factors that influence the large-scale uptake by households of cleaner and more efficient household energy technologies. The questions addressed by this review are

1. Which factors enable or limit adoption and sustained use of improved solid fuel stoves, biogas, liquefied petroleum gas, alcohol fuels and solar stoves?
2. Can any specific lessons be derived with respect to scaling up programmes of cleaner and more efficient household energy technologies in equitable ways in relation to poverty, urban-rural location and gender?
3. What are the implications of findings for programme and policy planning, as well as future research?

2.2 Inclusion and exclusion criteria

This systematic review of factors for adoption and sustained use at scale is based on a comprehensive search strategy comprising systematic searches in 27 multi-disciplinary bibliographic databases and 14 specialist websites, searches of the grey literature and involvement of experts covering the period 1980 to 2012. It was carried out to a specification for the UK Department for International Development (DFID), and a full report (2) with additional detail on the extracted studies and findings is available separately [http://eppi.ioe.ac.uk/cms/Default.aspx?tabid=3426]. Studies were selected if they related to projects, programmes or initiatives of cooking fuel and technology options at household level, and met the following inclusion and exclusion criteria (Table 1)

Table 1: Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
• Primary studies/analyses conducted in low- and middle-income countries defined according to World Bank income regions[1]; • Use of solid fuels or kerosene for cooking prior to intervention; • Interventions which include the following cooking fuel and technology options: (a) Solid fuel stoves described as improved[2]; (b) Clean fuels (replacing solid fuels or kerosene); • Studies which relate to direct experience with these interventions and/or projects, programmes and initiatives, rather than non-empirical considerations prior to their development and implementation.	• Studies not based on empirical evidence or based on indirect evidence (e.g. opinions of stakeholders); • Studies that lack specificity (i.e. studies related to general energy sector reform rather than specific information on adoption and use of named improved stoves or clean fuels in homes); • Studies that focus on technology effectiveness rather than household uptake and/or scaling up; • Studies undertaken in humanitarian settings such as refugee camps (as this is a very distinct setting and insights gained would not be transferable to the general population).

2.3 Search strategy and study selection

Studies conducted between 1980 and June 2012 were included, if they were available in English, Spanish, Portuguese, French, German and Italian; resources did not permit searching the Chinese literature. The main search strategy on improved solid fuel stoves and LPG was conducted in July 2011 (covering 1980-2011) and a separate supplementary search on biogas, alcohol fuels and solar cookers was conducted in June 2012 (covering 1980-2012).

The search terms are listed in
Initial selection was based on titles and abstracts, and conducted by one author, with 10% independent random checks of included abstracts and 10% of excluded abstracts. All selected studies were then independently screened for relevance by two or more authors, with all decisions for inclusion/exclusion being documented using the EPPI-reviewer V.4.2 software. Any discrepancies were resolved through discussion within the author team. Further details on the selection process are provided in the two flow charts reported in Figure 1.

Studies were categorised as follows:

- *qualitative studies*: using qualitative methods (e.g. focus group discussion, semi-structured or in-depth interviews, participant observation);
- *quantitative studies*: using quantitative methods (e.g. randomised controlled trials, before and after studies, cross-sectional surveys);

[1] http://data.worldbank.org/about/country-classifications/country-and-lending-groups#Low_income
[2] The issue of whether these stove technologies are in fact improved with respect to emissions and other aspects of performance is important, and is discussed further in section 3.3.

- *case/policy studies*: often based on more than one source of information of an empirical nature about a project/programme or technology and providing in-depth insights on factors influencing success/failure.

Table 22 and consist of (i) cooking fuel and technology intervention options, and (ii) terms related to the framework domains; the two sets of terms were combined using the Boolean operator "AND".

Initial selection was based on titles and abstracts, and conducted by one author, with 10% independent random checks of included abstracts and 10% of excluded abstracts. All selected studies were then independently screened for relevance by two or more authors, with all decisions for inclusion/exclusion being documented using the EPPI-reviewer V.4.2 software[3]. Any discrepancies were resolved through discussion within the author team. Further details on the selection process are provided in the two flow charts reported in Figure 1.

Studies were categorised as follows:

- *qualitative studies*: using qualitative methods (e.g. focus group discussion, semi-structured or in-depth interviews, participant observation);
- *quantitative studies*: using quantitative methods (e.g. randomised controlled trials, before and after studies, cross-sectional surveys);
- *case/policy studies*: often based on more than one source of information of an empirical nature about a project/programme or technology and providing in-depth insights on factors influencing success/failure.

Table 2: Search terms

Intervention AND	**Uptake**
***Search 1*:**	
*stove/*stoves	adopt*
cook* AND technol*	accept*
cook* AND fuel*	deliver*
LPG	dissemin*
"LP gas"	implement*
"liquid petroleum gas"	scale
"liquefied petroleum gas"	"scal* up"
"liquified petroleum gas"	"roll* out"
chulha/chulhas	"tak* up"
chulla/chullas	uptake
chullah/chullahs	
chulas	
Search 2:	

[3] http://eppi.ioe.ac.uk/cms/Default.aspx?alias=eppi.ioe.ac.uk/cms/er4

Biogas Bio-gas Biodigester *Bio-digester* *Ethanol* *Solar* *"clean fuel"* *"modern fuel"*	

2.4 Data analysis and quality assessment

Data from different types of studies were extracted onto standardised forms (2). The quality of each study was appraised using appropriate quality appraisal tools.

For qualitative studies, established criteria were adapted from Harden et al. 2009, which reflect quality of reporting, use of strategies to increase reliability and validity, and the extent to which findings reflect user's perspectives and experiences. Each study was independently coded and appraised by two researchers (3).

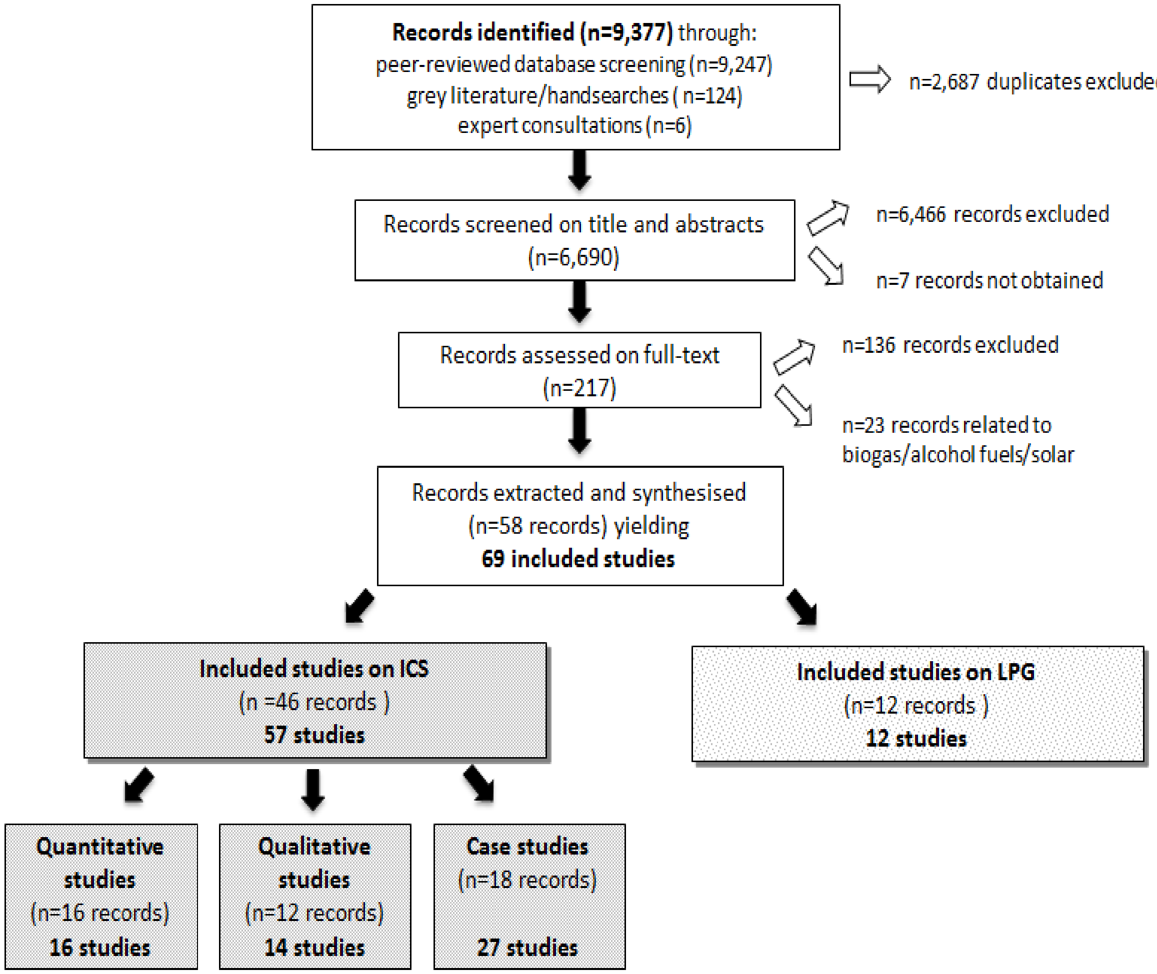
For quantitative studies, quality was appraised using the Liverpool University Quality Assessment Tool developed for and tested in a number of systematic reviews *(4-5)*. The tool has been independently appraised against other quality assessment instruments (6). The tool focuses on the following five domains: sampling, baseline exposure/intervention, outcome, analysis and impact.

Case/policy studies were examined by adapting published criteria by Atkins and Sampson (2002) (7) for case studies, with a particular emphasis on distinguishing between empirical analysis and subjective author interpretation. Quality appraisal was independently conducted by two authors and any discrepancies resolved through discussion.

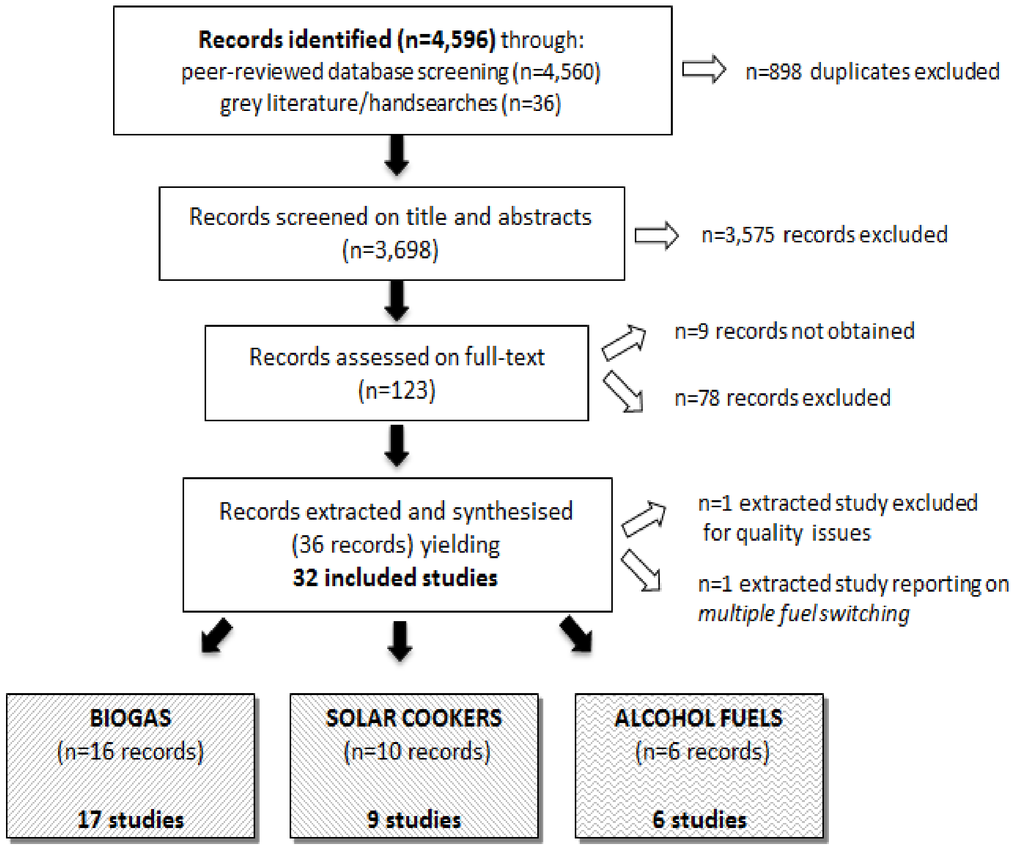
Studies of each study type were categorised as strong, moderate or weak quality; however, it is important to note that the appraisal score is not directly comparable across study designs and this should be taken into account in interpreting the findings.

Figure 1. Flow chart of factors influencing the uptake of clean household energy

SEARCH 1: **Improved solid fuel stoves and LPG**



***SEARCH 2*: Clean fuels (i.e. biogas, solar cookers, alcohol fuels)**



2.5 Evidence synthesis

The synthesis of evidence on factors affecting adoption and sustained use was organised under seven pre-specified domains (see Box 1), adapted from recent reviews of household energy and health *(8-9)*.

Box 1: Domain headings used for synthesis of study findings

1. Fuel and technology characteristics;
2. Households and setting characteristics;
3. Knowledge and perceptions;
4. Financial, tax and subsidy aspects;
5. Regulation and legislation;
6. Market development;
7. Programmatic and policy mechanisms

The first domain relates to the technology disseminated, including technical aspects and associated savings. Domains 1 to 3 primarily operate at household and community levels, whereas Domains 4 to 7 operate mainly at programmatic and societal levels (2). Equity was assessed based on poverty, urban/rural location and gender.

Due to a number of distinct issues that arise in respect of adoption and use of improved solid fuel stoves as compared to clean fuels, syntheses were carried out separately (following the approach described below), generating two set of findings described in sections 4 and 5.

The synthesis process consisted of two phases. In the initial phase, study findings on what enabled or limited adoption were extracted and recorded separately according to type of study design, (i.e. qualitative, quantitative and case studies/policy analysis) by one or two authors working together. In order to retain fidelity to the nature of the data and findings, these were recorded separately under headings of ‘barriers’ and ‘enablers’ respectively according to how these were reported in each study. Tables retaining this information are available as Appendices in the report (2). Qualitative studies were synthesised using thematic synthesis, as developed and applied by Thomas and Harden (2008)(10), where full-text studies are initially coded line-by-line in order to generate themes in individual studies, and are then used to synthesise across studies. The coding framework used was developed by two members of the research team, following independent coding of each study. Quantitative and case/policy studies were initially synthesised by compiling key findings under a tabular format. In order to retain fidelity to the nature of the data and findings, these were recorded separately under headings of ‘barriers’ and ‘enablers’ respectively according to how these were reported in each study. This process generated ‘synthesis tables’ which retained this information and which are also available as Appendices in the report (2).

In the second phase, findings across different study designs, countries and settings were then combined into a set of relatively distinct “factors”, which were identified for each of the seven domains. Preserving a distinction between barriers and enablers in the final stage of synthesis was not considered meaningful as it emerged from the findings that each factor typically operates along a spectrum, enabling if the characteristic was present or satisfactory in some respect, and acting as a barrier if absent or unsatisfactory. This concept is further discussed in section 3.4.

3. Extent and quality of evidence

3.1 Overview of available evidence

The search on improved solid fuel stoves (ICS) identified 57 eligible studies which were extracted on full text. For clean fuels, 44 eligible studies were extracted, covering LPG (12 studies), biogas (17 studies), solar cookers (9 studies) and alcohol fuels (5 studies on ethanol, one study on methanol). For ICS, all types of study designs were well represented, whereas evidence on clean fuels was dominated by case studies/ policy analysis.**Table 3** and Figure 2 illustrate the countries represented in this review, with the number of studies conducted in each country indicated by the colour key.

Figure 2. Countries with one or more studies included in review

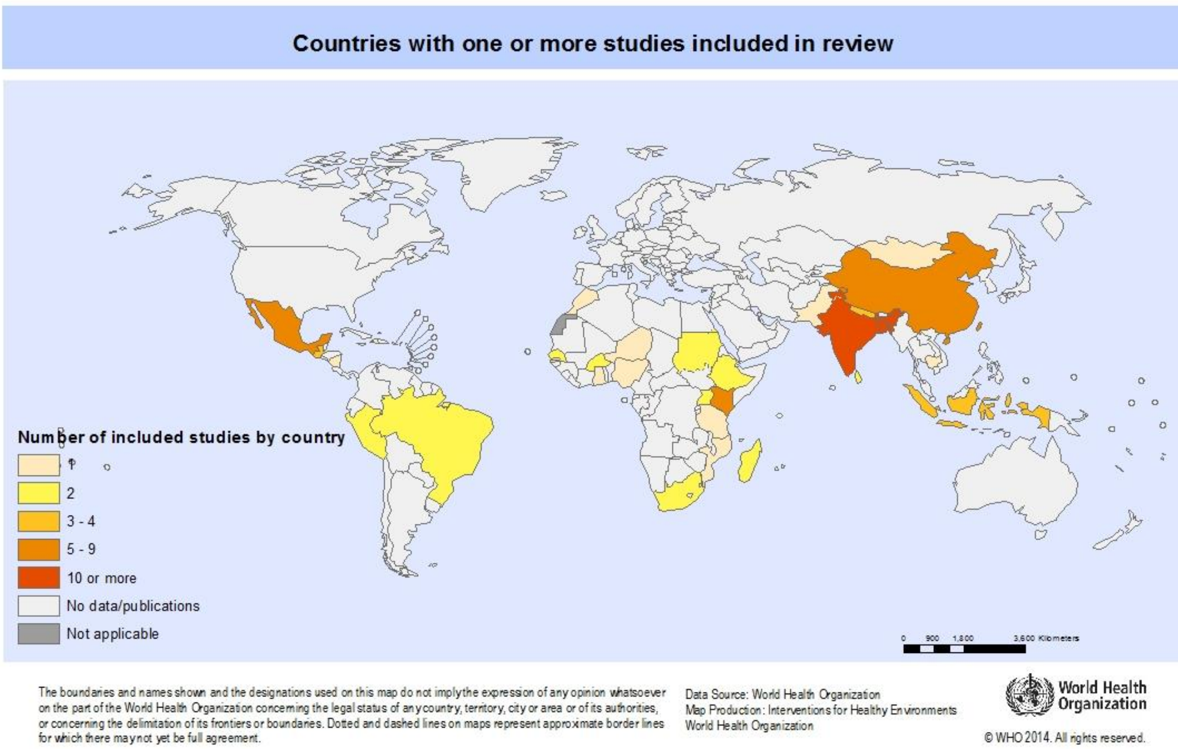


Table 3: Geographical source of studies by fuel and technology category

Fuel and technology category	**WHO region**[4]				
	Africa	**Americas**	**Eastern Mediterranean**	**South-East Asia**	**Western Pacific**
ICS	Burkina Faso Ethiopia Ghana Kenya Niger Senegal Uganda	Guatemala Mexico Peru	Pakistan Sudan	Bangladesh India Indonesia Nepal Sri Lanka	Cambodia China Mongolia Indonesia
LPG	Mozambique	Brazil Haiti Nicaragua	Morocco Sudan	India	Indonesia

4 See www.who.int/about/regions/en/index.html

Fuel and technology category	WHO region[4]				
	Africa	Americas	Eastern Mediterranean	South-East Asia	Western Pacific
Biogas	-	-	-	Bangladesh India Nepal Sri Lanka	China
Solar cookers	Burkina Faso Kenya Senegal South Africa Tanzania	Mexico	-	India	-
Alcohol fuels	Ethiopia Madagascar Nigeria	Brazil	-	-	Indonesia

3.2 Quality of individual studies

An overview of the quality of individual studies, assessed as described in section 2.5 is provided below. Although a three-level scale (i.e. strong, moderate and weak) has been used for all study types, it is important to note that the quality appraisal processes for qualitative, quantitative and case studies are not equivalent, and direct comparisons should only be made between studies of the same type.

3.2.1 Qualitative studies

A total of 19 qualitative studies were included, 14 of which related to improved solid fuel stoves exclusively and 2 were in combination with clean fuels (which were treated and counted as separate studies). The remaining studies addressed either biogas or solar cookers exclusively. No qualitative studies investigating a switch to LPG or alcohol fuels were identified. Studies ranged from 1989 and 2012 and included ethnographies (whose intent is to provide a detailed and in-depth description of cultural phenomena such as everyday life and practice), focus group discussions, as well as semi-structured or in-depth interviews (with users, stove builders, stove promoters or key informants/stakeholders).

Quality appraisal of individual studies resulted in 6, 9 and 2 studies being classified as strong, moderate and weak respectively. The variable quality assessments reflected the finding that some studies lacked a detailed description of the methods used (in particular in relation to data analysis and interpretation) and limited descriptions of how themes were derived or data presented to support findings. This caused difficulties in assessing whether the author(s)' interpretation was appropriate.

3.2.2 Quantitative studies

The review identified a total of 22 quantitative studies, of which 16 related to ICS, and 6 to fuel switching. With regards to the latter, 3 studies on LPG, 2 on biogas and 1 study on solar cooking were included. Studies were conducted between 1992 and 2012 and varied considerably in design and methodology. Some of the included studies reported a single quantitative component of data collection, such as one or a set of community-based surveys. Several were economic analyses based either on national survey data or local surveys. One study used scenario modelling based on a large national survey.

The quality assessment of individual studies classified 7, 10 and 5 studies as strong, moderate and weak respectively. A robust sampling approach (i.e. use of stratified random sampling with large sample sizes and judged to be representative of the study population) was identified in 50% of the studies, and about 45% provided adjusted estimates of predictors of enablers/barriers using multivariable regression analysis.

3.2.3 Policy and case studies

A total of 60 case/policy studies were identified covering the period 1989 to 2012, of which 27 related to ICS and 33 to fuel switching. Only about one fifth were published in peer-reviewed journals, with the rest being conference proceedings, reports or book chapters mainly identified through grey literature searches and expert consultation. These studies were very different in nature. Some presented a range of information about a specific small-scale project, programme or intervention, with others being evaluations of national programmes. All studies variously incorporated empirical data based on either cross-sectional surveys, mixed-method approaches or data obtained from other sources such as government or industry.

Individual study quality appraisal classified 11, 34 and 16 studies as strong, moderate and weak respectively. Main quality concerns were: (i) inadequate reporting and description of methods used (e.g. sampling and representativeness of data sources), (ii) poor data analysis (i.e. most used a largely descriptive approach to analysis), and (iii) reports written by the implementing agency. However, most of the studies were based on mixed-method approaches, with use of large sample sizes and representation of a range of stakeholders in addition to users, and they often provided relevant information across all seven domains.

3.3 Effectiveness of the interventions studied

Improvements to household energy technology and fuels can bring many benefits, including reductions in pollution emissions and exposure, greater fuel efficiency with associated cost and time savings, improved safety, and a set of social and related benefits that follow from having a cleaner and less polluted home environment. Although assessing the effectiveness of interventions was not among the objectives of this systematic review, very little information on effectiveness was provided or even referred to in the included studies. From a health perspective, it is the impact on emissions and exposure that is of most concern, along with safety through the prevention of burns, scalds and poisoning (e.g. from kerosene use).

Review 2 reviews laboratory-based emissions performance of a range of stoves and fuels, while Reviews 5 and 6 provide a detailed assessment of current knowledge regarding the effectiveness of different improved solid fuel stove and clean fuel interventions in everyday use. From this it can be concluded that, while most interventions available over the period of this review can deliver quite large reductions in HAP (and exposure where assessed) of between 30 and 70% of the levels experienced using traditional solid fuels and stoves, post-intervention $PM_{2.5}$ levels are still high relative to the WHO annual $PM_{2.5}$ IT-1 of 35 μg/m^3, and substantially above the annual AQG value of 10 μg/m^3. Review 10 addresses burns and poisoning, and finds relatively little evidence evaluating the safety of ICS and clean fuels, while most poisoning was associated with kerosene use (which was not included as a clean fuel intervention in this systematic review).

A key question, therefore, in drawing conclusions from this review is whether the findings on factors influencing adoption and use of interventions of uncertain effectiveness will be relevant to the adoption of the much more effective stoves and clean fuels which governments and programmes will promote in the future in order to meet air-quality guideline limits. For clean fuels, the issue is more the degree to which households (and their neighbours) can make a complete transition from solid fuels. The extent that it is possible to answer this question from the review, is considered further in section 6.

In light of these considerations, it is important therefore to ensure clarity about terminology used to describe the 'improved' solid fuel stoves reviewed here. The term *improved cookstove*, shortened to ICS, has been used throughout, as all were promoted for a variety of reasons, but with the intention of improving people's lives, protecting the environment, etc. and not necessarily improving human health. The reader should keep in mind, however, that whether or not each stove really is improved, and whether it is improved enough, can only be judged when adequately, evaluated which includes a certified emission reduction.

3.4 Factors on a spectrum from enabling to limiting adoption

In section 2.5, it was explained that the initial stage of data extraction included recording separately whether a factor was found to be an enabler or a barrier. For example, some studies identified a factor such as poverty as a barrier to adoption, while other studies reported that higher income was enabling. As the analysis progressed, it emerged that, rather than there being some discrete characteristics that were enablers and others that were barriers, the data were more consistent with findings representing data points on a spectrum of effect for each factor. These factors would generally enable adoption and use if present or satisfactory in some respect, and act as barriers if absent or unsatisfactory. This concept is illustrated by the examples given in Table 4

Thus, while it may appear attractive to seek a list of enablers (which should be incorporated into policy) and barriers (which should be avoided or explicitly overcome), it would seem more useful to identify a set of factors capable of acting for or against adoption and sustained use, the status of which can be assessed for any given project or programme. These factors are presented within the seven domains for ICS in section 4 and for clean fuels in section 5.

Table 4: Examples of factors influencing uptake on a spectrum from enabling to limiting.

Factor	How factor operates as an enabler or barrier
Household income level	Higher household income favours adoption, while lower (and low absolute) income acts as a barrier (although this may be modified by financing options).
Perceived and/or measured fuel savings	Fuel saving is highly appreciated and therefore enabling (especially in areas where it is paid for), while households report disappointment with stoves that do not save fuel.
Post-acquisition support	The provision of after-sales or post-acquisition support makes repairs and maintenance easier, and is appreciated by users. The lack of this service means that stoves requiring maintenance or repair may fall into disuse.
Number of animals for biogas users	More cattle can help a larger family generate enough gas for its use and possibly also to sell some locally. A minimum number of cattle or other animals (e.g. pigs) is required, usually at least two, and where these cannot be kept, this (along with other key requirements including water supply) is a barrier to production.

3.5 Relative importance of factors

One critical issue, especially for those responsible for policy and planning, is whether it is possible to identify some factors which are more important than others, or indeed whether there is a shortlist of essential factors. Furthermore, prioritisation requires both a suitable method and an evidence base that supports such assessment, and it is not clear that either of these is currently available. As will be shown, this review finds that all factors can matter, but some are undoubtedly critical for successful adoption and/or use. For example, a stove that does not meet the majority of needs for a family's cooking will not be adopted and used for this purpose. However, meeting those needs does not guarantee adoption or sustained use, if – for example – the stove is not reasonably durable, creates safety concerns, or cannot easily be replaced or repaired when worn out. Thus, meeting users' needs can be thought of as one of a number of **necessary but not sufficient** factors.

Factors which are considered especially important in this way are identified and discussed in the in the results commentary of sections 4 and 5, although it must be emphasised that the nature of the evidence available and the critical influence of context does not easily allow a clear separation of essential factors from other influential factors. A key message is that all factors need to be considered, almost all are interdependent and the relative importance of many is context-specific.

3.6 Differentiation of factors impacting on initial adoption and sustained use

Factors affecting short-term adoption and use may differ from those affecting longer-term sustained use. For the purposes of this review, drawing on and further developing concepts advanced in the literature *(11-12)*, adoption is defined to include both acquisition (stoves are purchased or installed without any reference to their use) and initial adoption (use is assessed less than one year from acquisition). Sustained use comprises both medium-term (assessed one or two years from acquisition) and long-term sustained use (reflecting longer time periods). Factors linked to one or both of these 'phases' of use are identified in the results.

4. Findings on adoption and use of improved solid fuel stoves (ICS)

This section presents the findings from the 57 included studies on ICS (14 qualitative, 16 quantitative and 27 case studies). Studies were conducted in Asia, Africa and Latin America; 31 studies in rural settings, 11 in urban areas, and 15 in both settings. The countries most represented were India and Bangladesh, followed by Mexico and Kenya. Biomass was the principal fuel used, but two studies assessed coal. A total of 36 studies were concerned with adoption, 13 with sustained use and 8 with elements of both adoption and sustained use. Improved stove technologies included a variety of stove models, with one or more potholes and also including some with a chimney or smoke hoods. The majority of studies were concerned with locally produced stoves. No studies were found on adoption of more recently developed advanced combustion stoves (e.g. forced draft or semi-gasifier stoves). More detailed information on study characteristics and the ICS technology involved is presented in Annex 1.

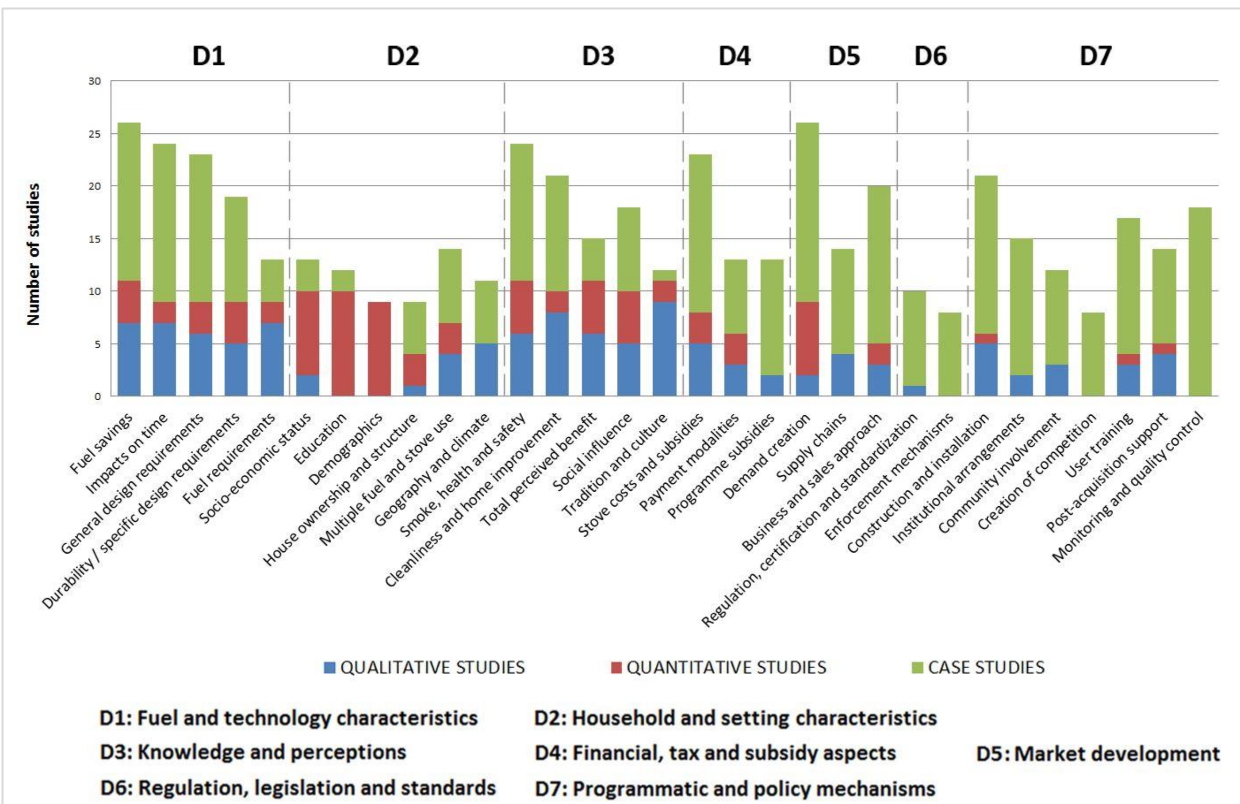
4.1 Factors influencing adoption of ICS by domain

A total of 31 factors influencing uptake of ICS were identified across the seven framework domains, summarised by contributing study designs (i.e. qualitative, quantitative and case studies) in Figure **3.** A narrative describing the findings within each domain is given below.

Some of the identified factors were drawn from a more extensive evidence base (i.e. larger numbers of studies across different study design) than others (Figure **3),** potentially suggesting that these factors were more important than those supported by less information. Scarcity of evidence, however, does not necessarily mean that a given factor should be given less consideration. Often, limited findings in support of a given factor are a consequence of donor preferences or of the particular issues that researchers have elected to investigate and how suitable a certain study design is addressing these. For example, Domain 6 '*Regulation, legislation and standards*' is supported by only a few case studies; however there is no doubt that standards and regulation are needed for meeting efficiency requirements, reducing health and safety hazards and increasing user satisfaction. The lack of evidence is therefore more a reflection of historical lack of policy attention in this field. Indeed, much effort is currently being put into developing stove standards with the International Standarization Association (ISO) along with regional testing centres *(13)*.

Quantitative evidence is available across most domains, but most frequent for household and setting characteristics (Domain 2), and particularly limited for Domains 6 and 7. The qualitative findings largely relate to '*Fuel and technology characteristics*' and '*Knowledge and perceptions*' of users (Domains 1 and 3 respectively). Case studies generally offer a broader perspective and are represented in all domains, although relatively few provide evidence on household characteristics and settings.

Figure 3. Factors influencing uptake of ICS across seven domains (D1-D7), by study type and number of studies



Source Puzzolo et al. 2013 (2) Reproduced with permission

In terms of individual study quality, 19 out of 57 studies were appraised as strong, 29 as moderate and 9 as weak. As noted in section 3.2, the quality score for individual studies should not be considered equivalent across the three study methodology groups as it is design-specific. The potential impact of study quality was examined through a sensitivity analysis which examined the domains and factors were affected following exclusion of the weak studies. The results of this analysis did not result in any substantive impact on the level of evidence available for the 31 factors, and the remaining studies provided evidence on all of the factors identified in Figure 3.

4.1.1 Domain 1: Fuel and technology characteristics

Fuel saving: Fuel and time savings were widely cited and assessed mainly through self-reports from users and in some cases direct measurement. Fuel saving was an incentive highly valued by users *(14-30)* as it impacted on household expenditure (where fuel is purchased) and the amount of time women spent collecting fuel (and in some studies associated injuries and threats) where fuel is gathered *(22-23, 31-36)*. Conversely, increases in fuel use/consumption with no associated savings in fuel expenditure discouraged use *(16-18, 20, 37)*, especially when stoves required additional time for fuel processing and/or stove or chimney cleaning *(38-41)*.

Impacts on time: Stoves which reduced cooking time due to better heat transfer efficiency and/or parallel cooking on multiple potholes were highly valued by women *(15-17, 19-23, 27, 29-31, 34, 40-44)*. Time savings from faster cooking and/or reduced collection time have been reported to be used for other household work *(22-23, 44)* or income generation *(22)*, but the attached value varied between settings *(32, 39)*. Poor performance and longer cooking times were reported as a barrier *(17-18, 20, 38-39, 45)*.

General design requirements: A number of design features were found to be of fundamental importance in relation to adoption and sustained use with multiple studies reporting that culturally and/or locally inappropriate stove designs hampered use, often leading to stove modifications by users *(14, 16, 18-21, 31, 39, 41, 44, 46)* or reversion to traditional stoves *(14, 16-21, 31, 39, 41, 44, 46-47)*. It is therefore clear that households will not adopt of their own volition, or continue using, stoves which do not meet their needs *(18, 22, 45, 48-51)*, especially for cooking most of their daily meals at least as quickly as the traditional stove, achieving favoured taste, and using available fuels and familiar pots *(14, 29-30, 45, 51)*. These factors are thus very important for appropriate stove design *(18, 48-50)* and successful adoption *(11, 52)*.

Durability and specific design requirements: Positive features of stoves reported to facilitate adoption included convenience, safety, durability, and the ability to provide warmth and portability in cold and rainy settings respectively *(14-15, 22-26, 29-30, 44, 53)*. Aesthetic features (as further discussed under Domain 3) were also valued *(25, 30, 39, 41, 43, 54)*. The involvement of women in the design of stoves was found to be important in a variety of settings *(14, 17, 20, 48, 54)*, and failure to do so has led to several examples of women subsequently modifying the stove *(16, 18-21, 46)*, for example enlarging the entrance to the combustion chamber to allow use of larger pieces of wood *(39, 41)* and removal of grates *(31, 44)* which had been included to improve combustion.

Fuel requirements: Stoves which were more restrictive in terms of type *(29-30, 33, 45, 47, 55)*, reliance on dry fuel *(31, 39)* and size of fuel *(31, 39, 41, 48, 52)* could add work for users (e.g. cutting wood into smaller/straighter pieces) *(21)* and studies reported this could act as a barrier to sustained stove use *(21, 31, 39-41, 48, 55-56)*.

4.1.2 Domain 2: Household and setting characteristics

The household and settings domain includes socio-economic status (SES), education, demographics, home ownership and geography, factors which are often highly interrelated and linked in a variety of ways to most of the other domains affecting adoption and sustained use of improved cooking technologies.

Socio-economic status: Having a higher SES was widely reported across different study designs as a key enabler to uptake of ICS *(26, 45, 57-62)*. This was measured differently across studies in terms of income, household expenditure, land ownership or household assets. Initial adoption, especially when stoves were sold on the open market and purchased at full price by users, was more frequent among better-off families with greater financial liquidity.

Education: Education is closely related to SES, and was found to be associated with increased uptake in a number of studies *(11, 15, 28, 45, 57, 63-65)*, but not all *(60, 66-67)*.

Demographics: No clear conclusions can be drawn in terms of demographics, although there was evidence that larger families were less likely to adopt *(11, 53, 60, 63, 66).* This is probably related to the number of adults working in the household as well as the number of women and children available for fuel gathering *(11, 59, 66-67)*, resulting in low opportunity costs being attributed to time spent in traditional fuel collection and cooking *(19, 22-23)*.

House ownership and structure: Additional factors such as home ownership and having a permanent house and enough space inside/around the house for positioning a permanent stove were reported to increase willingness to adopt *(11, 18-19, 30, 54, 57, 62, 68)*.

Multiple fuel and stove use: The majority of studies reported existing fuel use and/or stove ‘stacking’ - the continued use of the old fuel and stove as the new one is adopted. This appeared to facilitate uptake of an additional cooking technology (and/or fuel) (11) - as there was already familiarity with using more than one type of stove/fuel *(22, 35, 39, 43, 45, 58)*, but clearly also acted as a barrier to exclusive use of the improved stove *(15, 18, 22, 38, 45, 54)*. A variety of combinations was described, but most frequently households employed a mix of traditional stoves *(15, 19, 22, 35, 45)* and LPG (with the latter used to a lesser extent mainly due to the costs of refilling the bottle) *(39, 43, 48, 58)*. Households that purchased rather than collected solid fuels were more likely to adopt an improved stove *(58)*, as monetary savings were valued more than time savings where wood is collected *(39, 41)*. This issue of opportunity cost *(19, 63)* and valuation of time was reported to be very important and is a recurrent theme across several other domains.

Geography and climate: Not surprisingly, geographical settings were reported to greatly impact on initial uptake and sustained use of improved stoves, as cold and rainy conditions require stoves to be able to meet heating and drying needs *(17, 36, 39, 51)* and, (where outdoor cooking is practiced), to be portable so as to be able to cook indoors or under shelter during the rainy season *(17, 24, 34)*. Also, urban households appeared to be more willing to adopt – a finding that appeared to be at least partly independent of SES *(22-23, 58)*. Households located in disaster-prone areas *(40)* or affected by drought and famine *(34)* were reported to be less likely to adopt.

4.1.3 Domain 3: Knowledge and perceptions

Smoke, health and safety: When new stoves were perceived to reduce emissions *(14, 16-19, 21, 27, 45)*, women typically reported (for themselves and for their children) fewer negative health effects *(11, 16-21, 31, 36, 39-44)*, although these tended to be related to more acute symptoms, rather than more chronic and longer-term health effects. Where the stove was perceived to be safer, women also reported fewer burns and injuries *(22, 25, 30, 35, 39, 41, 44)*. In most studies, it was not clear whether an expectation of health benefits could be considered an enabler of uptake *(30-31, 36)*; however, less smoke and fewer symptoms certainly formed part of the users' satisfaction with the new technology. Moreover, these benefits were often a subject of conversation with neighbours and friends and were therefore likely to influence adoption patterns in the community *(62)*. In a study exploring gender dynamics in household decision-making, economic benefits from improved stove uptake such as fuel savings and associated costs were more valued by men, who tended not to acknowledge the importance of health benefits in the same way that the women did *(28)*.

Cleanliness and home improvement: A cleaner home/kitchen *(14, 16-21, 30, 32, 36, 39, 41-42, 51, 54)* and cleaner cooking vessels *(16-21)* due to smoke reduction *(25)* were appreciated by users of improved stoves *(34, 62)*. Conversely, some technologies require more cleaning, in particular of the chimney, which could be a barrier to sustained use *(17, 36, 41, 55-56)*. Additional benefits, such as warmth provided by the stove, the family being able to eat together in the kitchen *(51, 54)* or children being able to study/play indoors as a result of less smoke *(20-21)* were also valued.

Total perceived benefit: Where the overall advantages of improved stoves were thought to outweigh those associated with traditional practices, households perceived the investment in ICS purchase to be a good value for money *(29, 44, 65-66)*. However, improved stoves were not always found to meet users' expectations *(20, 24, 31, 55)*. This and competing household priorities *(18)*, in particular the need to secure food prior to investing in the purchase of an improved stove, *(62)* could impact negatively on willingness to pay for a new stove.

Social influence: Beyond individual household knowledge and perceptions, social factors and community interactions were reported to influence adoption *(11, 30, 41, 60)*. The decision whether or not to purchase was significantly influenced by both positive and negative experiences of neighbours or relatives who had adopted the stove *(18, 24-25, 34, 41, 45, 55)*. The influence of opinion leaders within a community was likewise important in this regard *(11, 28)*. The aesthetic appeal and subsequent social status gain associated with the new technology were also reported to be among motivating factors for both adoption and sustained use, *(25, 39, 41, 43)*, including for example where users in some settings (e.g. in Latin America) were reported to be planning improvements to their houses as a consequence of acquiring a built-in ICS *(39, 54, 68)*.

Tradition and culture: The suitability for preparing traditional dishes with the normal taste (using the pots that users own and are familiar with) was also reported to be an enabling factor for adoption and sustained use of a new cooking technology *(32, 41)*. Several studies reported that users found it possible to cook only some of their usual meals on the improved stoves, with the rest being prepared on the traditional stove, for practical reasons such as use of larger pots *(34, 39, 41, 55)*, or to achieve the preferred smoky taste of the prepared food *(19, 29-32, 40-41)*. The lack of any perceived need for a new stove and change in cooking habits was also quite frequently reported as being associated with a lower likelihood of adoption *(31, 39-40, 48)*.

4.1.4 Domain 4: Financial, tax and subsidy aspects

Stove costs and stove subsidies: In the case of market-based approaches in which the full costs of stoves had to be paid by users, the key barrier to purchasing or repurchasing tended to be cost *(18, 24-25, 28, 30-31, 34, 36, 45, 53, 62)*. Flexible stove pricing policies were reported to encourage adoption of a wider variety of stoves according to customers' ability to pay *(21, 46, 69)*. Economies of scale through bulk orders of stoves *(16-17, 47)* or fixed costs for raw materials also favoured adoption *(37, 51)*.

Many government-led and NGO-led approaches have employed stove subsidies; in the majority of cases these were reported to facilitate adoption *(14, 16, 21, 35, 56, 70-71)* but not necessarily sustained use of the ICS *(17, 19-20)*. For example, two studies conducted in India reported that subsidies were perceived to devalue the improved stove, with evidence that households receiving the greatest subsidies had the poorest maintenance record *(16-17)*. On the other hand, evidence suggested that without subsidies the poorest families tended to be excluded from access to improved stoves *(14, 72)*.

Payments modalities: Payments in instalments *(23, 53, 69, 73)* and consumer finance through microcredit *(50, 69)*, community lending schemes *(34)* or loan schemes *(68)* were reported to facilitate adoption of ICS *(28, 32, 42, 44, 58)* but long-term success varied across settings. However these financing arrangements for individual households were not without problems including difficulties related to high interest charges *(69)*, excessively short payback periods for microcredit *(69)*, lack of credit for the poorest *(14)* and users' inability to complete their payments for the stove *(50, 53)*.

Programme subsidies: Direct or indirect financial support by the government for improved stove programmes was reported to have facilitated ICS uptake in China *(49)*. In other programmes, adequate upfront capital for entrepreneurs to develop their stove businesses and carry out staff training was reported as potentially critical *(23, 37, 49-50, 58, 74)*, and programmes that did not receive or provide financial support for longer-term stove maintenance, user support and awareness-raising, were found to be less successful *(19-20, 23, 46)*. Dependence on external financial support (national or international) should, however, be carefully evaluated with a view to implications for programme sustainability *(14, 48, 51, 56, 62)*.

4.1.5 Domain 5: Market development

Demand creation: The last decade has seen an increased trend towards market-based dissemination of improved stoves and as a consequence demand creation is becoming a higher priority resulting in more attention being paid to designing and promoting stoves with attributes that are more attractive to potential customers. A wide range of marketing strategies has been used across countries to generate demand *(14, 24, 26-27, 46-47, 50, 54, 58)*. Stove promoters making contact with individual users and live demonstrations of the new technology were cited among the most successful strategies *(14, 25, 30, 34-35, 37, 45-46, 50-51, 53-54, 58-59, 68-69)*. On the other hand, coercion, false promises or misinformation were reported to lead to rapid rejection of new cooking technologies even if initial purchase/ adoption occurred *(17, 20, 23, 33, 45)*.

'Word of mouth' was also reported to be a powerful influence within communities *(11, 34, 41, 55, 67)* acting for or against adoption depending on the perceptions and experiences communicated (see Domain 3, social influence). A number of studies recommended that more should be done to specifically target men (in addition to women) during stove promotion, as they tended to be the main household decision-makers *(28, 34, 65)*. One study indicated that this could be achieved through promotion of additional products or attributes which directly attract the interest of men *(28)*.

Supply chains: Functional and efficient supply chains for stoves or stove components were reported as essential for meeting demand and keeping costs as low as possible *(14-15, 24, 31, 35, 40, 46, 58)*, with the extent and condition of road infrastructure impacting on price and market diffusion *(14, 34, 50)*. Another important aspect of supply was related to ensuring availability of replacement parts and services *(14, 20, 45, 51, 74)*, which are essential for market sustainability. Short-term projects, which usually focus on rapid initial stove uptake, have frequently omitted this aspect of planning and implementation.

Business and sales approach: A number of studies explored the perspectives of stove builders, stove entrepreneurs *(16-23, 35, 40, 48, 58)* and sales approaches *(34-35, 53)*. The stove market is characterised by numerous challenges for generating and maintaining adequate income *(19, 27)*, including the development of an effective business plan, ensuring sufficient upfront capital *(19, 23)*, and coping with relatively low demand *(17-18, 20, 35)*. Business development and demand creation therefore need to go hand-in-hand *(22, 27)*. Approaches that have been used to help ensure sustained income among both small- and larger-scale producers included: (i) combining sales through a government programme with sales on the open market *(16)*, (ii) cross-subsidising sales to households through business with commercial/institutional customers (e.g. restaurants) *(58)*, (iii) specialising in the production of stove parts *(14, 51, 54, 74)*, (iv) identifying appropriate distribution channels via indirect (through sales outlets)*(50)* or direct sales (from manufacturers)*(45)*, (v) exploring opportunities for marketing multiple products *(67)* and (vi) ensuring an independent second source of income *(50)*.

4.1.6 Domain 6: Regulation, legislation and standards

Relatively few studies reported on the role of regulation and certification of ICS, but those that did concluded that standards and their enforcement were fundamental for achieving successful large-scale use, by increasing the likelihood of efficient functioning of ICS in everyday use and over time.

Regulation, certification and standardisation: Certification of stoves or stove components by a standards agency or a network of producers was reported as a means of ensuring adherence to design specifications for fuel efficiency and emissions *(22, 34, 49, 58)*. The use of prefabricated moulds *(18)* or stove labels to guarantee construction standards *(22, 58)* were successfully used in a few settings. Indeed, in some reviewed programmes/projects, poorer-quality stoves or stove parts or chimneys were purchased from uncertified manufacturers *(14, 20, 25, 51)*, leading to stove modification and limited ICS use over time *(16, 21)*. Lack of regulation was also reported to be problematic where there was no state control of the financial speculation on raw materials *(24)*.

Enforcement mechanisms: In order to be effective, certification must be enforced through mechanisms such as the procurement of materials from designated suppliers, the exclusive use of accredited manufacturers and penalties to revoke accreditation in case of non-compliance with standards *(17, 22, 27, 47, 49)*. Dissemination of stoves and stove parts purchased from non-approved vendors and dealers was documented in a number of studies, resulting in users often having problems with the stoves and experiencing considerable variation in procurement rates *(16, 19, 21)*.

4.1.7 Domain 7: Programmatic and policy mechanisms

Construction and installation: Successful programmes involved careful planning and implementation at all stages from choice of raw materials for stove construction to post-acquisition support *(14, 22, 64)*. Stove builders should be adequately trained *(15-20, 22-23, 39,* *49)*, as professionalism is needed for achieving good-quality stoves and for an effective start-up of the stove businesses. Lack of proper construction or installation of stoves and chimneys was widely reported as a barrier to sustained use *(16-20, 22-23, 33, 49, 51, 56, 68-69)*.

Institutional arrangements: Lack of coordination and regular interaction among key stakeholders and programme actors at local, regional and national levels was widely reported as a barrier for successful adoption and use because of poor planning, management and lack of effective monitoring *(15-18, 21, 46, 51)*. Synergies through integration with other stove programmes in the same geographical area *(51, 56)* and with rural development programmes (involved in energy, housing or other related areas of policy) were reported to exist but were rarely utilised to maximise uptake *(19, 49, 58)*. Careful programme management *(18, 21, 40)* with good feedback systems were recommended to respond to and correct problems at an early stage *(40, 46)*.

Independent of the ideological approach pursued in promoting improved technologies (i.e. the respective roles of the state vs the market), the government role should include policy co-ordination, support for research and development, education and awareness-raising as well as financial planning and investment to make improved stoves programmes successful *(46-47, 58)*. By contrast, short-term and target-driven programmes (frequently related to strict funding schemes) were generally found not to achieve sustainability *(20-21, 40, 48, 62)*.

Community involvement: Involving the community throughout the process from the identification of an appropriate stove design to stove distribution was found to create a greater sense of ownership *(14, 18-19, 35, 48)*. Fostering women's engagement was particularly important *(14, 17, 20, 50, 62, 73)*(see also '*Durability and specific design requirements*' under Domain 1).

Creation of competition: Some programmes have successfully employed competition and reward schemes – between households, implementing companies or networks, villages or counties – to encourage uptake and sustained use of stoves *(16-19, 21-22, 35, 49, 68)*, and also to identify promising stove designs for local adoption *(49)*.

User training: Insufficient user training on stove (and chimney) use, cleaning and maintenance negatively affect functionality and sustained use, leading to frustration and rejection of the improved technology *(16-21, 39, 41, 45, 69)*. Hands-on-training of users *(27, 39, 46, 64, 73)* was reported to be more effective than the provision of an instruction manual *(23)*.

Post-acquisition support: A lack of, or inadequate, follow-up or after-sales services for improved stoves and chimneys was reported to result in stove malfunctioning and users experiencing difficulties with the stove *(16, 18, 21, 23, 35, 40-41, 46, 49, 69)*. The absence of a pre-arranged agreement to pay for after-sales service, and the lack of warranties, can result in users subsequently being reluctant to pay for repairs *(21, 46, 69)*. Conversely, mandatory or upon request after-sales/post-construction visits for minor repairs and stove maintenance were reported to promote sustainability *(17, 27, 46, 48, 64)*.

Monitoring and quality control: Many of the included studies reported a lack of appropriate monitoring and quality control mechanisms in relation to stove production, installation and post-installation support *(14, 16, 18-21, 23, 40, 50-51, 54)*. Ensuring the allocation of adequate financial resources for monitoring the different stages of a dissemination campaign *(17-18, 20, 22)* - including immediate verification of stove installation *(20, 37, 46)* follow-up checks *(14, 20,* *22, 46)* and post-installation surveys *(20, 22)* - is important for successful adoption and use of ICS *(24, 45)*.

4.2 Equity considerations on ICS uptake

Equity is critical in efforts to scale up improved stove interventions because it is generally those with the lowest incomes, those living in rural and more remote areas, and women who experience the greatest health risks, yet these groups are also the least able to access or afford improved stoves. The evidence from this review suggests that an explicit focus on equity as part of a programme's objective can facilitate the targeting of disadvantaged households.

With regard to poverty, some programmes have adopted mechanisms to reach families on lower incomes, including (i) a tiered approach offering different stove models and prices for higher- vs lower-income households *(17, 69)*, (ii) subsidies *(16, 19, 23, 35)*, (iii) payments in instalments *(23, 69)* and (iv) access to credit *(74)*. The risk of exclusion of more disadvantaged families with market-based dissemination programmes *(47)* was reported in several settings *(25, 32, 35, 40, 58)*, especially in rural areas *(22, 39, 49, 58)*. This is because very disadvantaged groups with limited education *(15, 22)* tend to favour spending limited resources on what are seen as more pressing household priorities (including paying for food and clothes) *(34, 62)* and hence generate little or no demand for improved stoves *(22, 56)*.

In terms of rural/urban location, perceptions about the opportunity costs of fuel collection *(39, 41)* and fuel availability *(19)* both appear to play a part in determining uptake. Poor rural communities – who usually collect firewood and pay for little or nothing for their fuel – can be a difficult group to target. Two factors may contribute to this: first, they have little direct financial incentive for saving fuel; second, the availability of labour (and especially that of poorly educated women) results in a low perception of the opportunity costs of time spent collecting fuel and using inefficient stoves. As a consequence, commercial businesses tend to target more urban and other higher population density and income areas *(16, 25)*, where the business is more feasible and profitable *(40)*, as users often pay for fuelwood or other solid fuels and are more willing to pay for an improved stove *(15)*.

A gendered approach is critical for adoption and sustained use of improved stoves, and the key message is that while better understanding of women's needs and involvement in technology development and implementation are vitally important *(14, 25, 37, 46, 50)*, so too is greater involvement of men *(28, 33, 39, 62)*. This is because men usually exercise more control over the household budget, and have more decision-making authority when it comes to changing the structure of the kitchen, or installing/buying an improved cookstove *(33, 39, 62)*. However, although women's decision-making power were often limited *(31, 39)*, there are examples where women are able to pay for the ICS using their savings which had been intended for purchasing clothes or additional food *(34)*. Studies also reported that women could significantly influence their husbands in favour of ICS adoption through negotiations with other family members (e.g. mothers-in-law, co-wives) *(34, 39, 62, 65)*. Further, the role of women in some projects was defined much more broadly than simply being the beneficiaries of improved stoves. There are examples of women being properly trained in stove manufacture, stove installation or as retail entrepreneurs *(25, 37, 50)*. One way of specifically encouraging women to take on these roles is micro-loans for opening stove businesses to be offered only to women *(37, 50)*.

While we are also aware of programmes that have supported acquisition of ICS in low income communities through conditional cash-transfer schemes, for example the Juntos programmes in Peru *(75)*, no studies evaluating the impacts of these on equitable adoption were available for this review.

4.3 Summary of findings in relation to ICS

This review has included a total of 57 qualitative, quantitative and case studies, from a wide variety of settings. These studies have provided evidence of the influence on adoption and sustained use of ICS of some 31 factors, spread across all seven domains. All domains were well populated, with the possible exception of Domain-6 '*Regulation, legislation and standards'*. Sensitivity analysis excluding weak studies led to little substantive change in the levels of evidence support across the domains. No evidence was found on the adoption and use of advanced combustion stoves (i.e. models using forced draught and gasification), reflecting the fact that these have only recently been introduced and so far lack evaluation of factors influencing their adoption and sustained use.

The nature of the available evidence does not support formal prioritisation of these factors or domains; all of the factors can be influential, most are inter-related, and many context specific. Nevertheless, some appear to be critical to the extent that if these are not met, adoption and sustained use are unlikely. Accordingly, these are described as 'necessary but not sufficient'. Examples of some of these (note this is not an exhaustive list) include:

- Meeting users' needs, particularly for cooking main dishes and being able to use large enough pots;
- Providing valued savings on fuel;
- Offering products of a quality that meet user expectations and ensure durability;
- Having success with early adopters, in particular opinion formers;
- Guaranteeing support (e.g. loans) for businesses producing and promoting ICS;
- Ensuring support to users in initial use, and for maintenance, repair and replacement;
- Developing an efficient and reliable network of suppliers/retailers;
- Providing financial assistance for equitable access and/or for more expensive ICS.

Furthermore, some of the factors that are poorly supported by the available studies are still likely to be of importance. For example, the lack of evidence on standards, testing and certification is mainly a reflection of the lack of these instruments being available and implemented in practice, and a concomitant lack of attention in research studies.

Subsidy remains a complex area of policy, and can work for and against adoption and sustained use, depending on how these are applied and managed. Subsidies are likely to be important for equity of access, especially to higher performing and more expensive ICS, but must be managed carefully to avoid adverse effects on markets and the perceived value of the technology. Conditional cash transfer schemes and other forms of 'smart' targeted subsidy – for which evidence was not available for this review – may well be important instruments and should be given attention in future research.

Based on these findings, the assessment of all factors as relevant to the setting would seem to be important for ensuring the best prospects for success in adoption and sustained use of ICS.

5. Findings on adoption and use of clean fuels

This section presents findings from the 44 studies investigating fuel switching from biomass (firewood, charcoal and other biomass fuels), coal and kerosene to cleaner fuels, namely LPG, biogas, solar cookers and alcohol fuels. Although there are some general characteristics influencing uptake which are common to all clean fuels (see sections 5.5), there are sufficient distinct features regarding their production, supply, adoption and use to warrant separate reporting of the findings for each of these fuels in section 5.1 to 5.4. For each of the clean fuels, results are reported under the seven domains plus equity.

To facilitate the comparison across different fuels, graphical representations illustrating factors affecting uptake are presented at the beginning of each sub-section, similar to the approach used for ICS (section 4). The graphics display a full list of factors, some of which were found to be common across ICS and clean fuels, while others were found to be fuel-specific. This approach aims to facilitate the visual identification of those factors for which limited or no evidence is reported in relation to the different fuel categories.

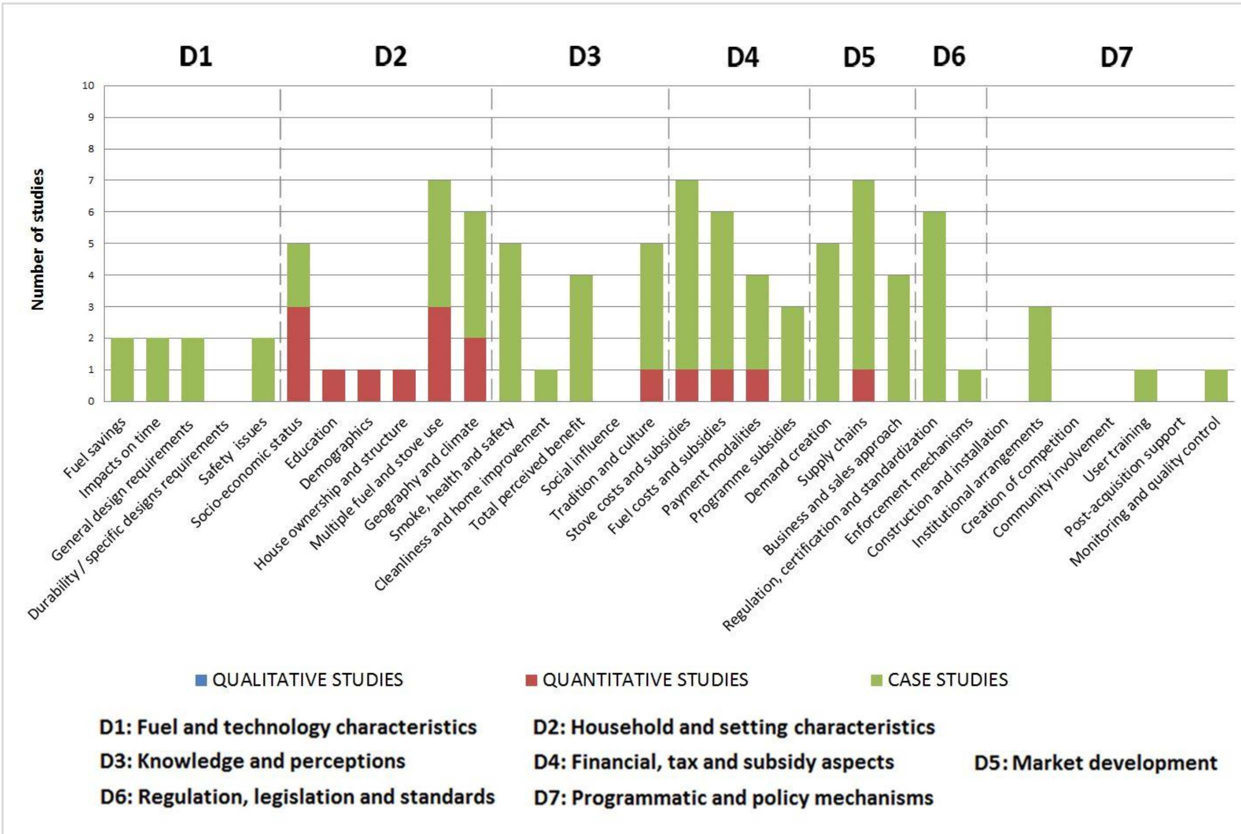
Absence of evidence for some of the listed factors – in particular relating to LPG, solar cooking and alcohol fuels – should, however, be treated with caution as the overall number of included studies for clean fuels is rather limited. Indeed, the gaps in the evidence need to be recognised but should not be interpreted to mean that these factors or domains are of less or no importance. Among the reasons for the limited evidence are the topics chosen for investigation by those conducting research and the limited availability of certain study approaches, in particular qualitative studies, in the field of clean fuels.

5.1 Liquefied petroleum gas (LPG)

A total of 12 studies were found reporting on the adoption and use of LPG and gas stoves. Studies were classified as quantitative (n=3) and, policy and case studies (n=9); no qualitative studies were identified. There was a mix of small-scale studies and larger studies of sub-national or national scope, with studies conducted in South Asia (n=3), Africa (n=3), Western Pacific (n=1) and Latin America/Caribbean (n=5). Nine of the studies assessed factors influencing adoption of LPG (initial switch up to one year); two studies assessed sustained use over time (as part of national campaigns) and one study assessed elements of both adoption and sustained use. In terms of methodological quality, studies were found to be variable, with 2, 5 and 5 studies scoring as strong, moderate and weak respectively.

The majority of studies focused on switching from biomass to LPG, while one reported on the large-scale Indonesian conversion from kerosene to LPG for cooking, which had (at the time of reporting) involved more than 40 million households *(76)*. Another study described the impact of market liberalisation of LPG in Brazil *(77)*. The policy studies focused mainly on the long-term assessment of national policy affecting level of subsidies and LPG usage patterns *(55, 78)*. Detailed study characteristics are summarised in Annex 2.

Figure 4. Factors influencing the uptake of LPG across seven domains (D1-D7), by study type and number of studies



Source Puzzolo et al. 2013 (2) Reproduced with permission

As illustrated in **Figure 4**, 26 factors were identified as influencing the uptake of LPG across all framework domains. Evidence from quantitative studies is limited to Domains 2 and 4, whereas evidence from case and policy studies is spread across all domains (albeit very thinly for Domains 1 and 7). Evidence for most of the factors under Domains 4 and 5 are drawn from a more extensive evidence base, whereas Domains 1, 3 and 7 are supported by limited evidence.

The gaps in the evidence need to be recognised but should not be interpreted to mean that these domains are less important for LPG uptake. For example, if we consider the factor "durability and specific design characteristics" under Domain 1 – where no evidence is reported, this is likely to reflect the lack of studies focusing on this aspect through exploring users' perspectives, rather than this factor being unimportant in adoption and sustained use of LPG.

Following exclusion of the five weak studies through sensitivity analysis, evidence was available for 23 out of the 26 factors, with some representation across all the seven domains, although this was very limited for Domains 3, 6 and 7. The factors lost (as these had been reported only within weak studies) included '*Programme subsidies*' under Domain 4 and *'User training*' and *'Monitoring and evaluation*' under Domain 7, further emphasising the need to strengthen research on adoption and use of LPG as a clean fuel.

5.1.1 Domain 1: Fuel and technology characteristics

Fuel savings: Although LPG is generally considered to be an expensive fuel, when costs for biomass fuels are relatively high; LPG uptake can be favoured *(79)*. In Indonesia, users reported monthly savings associated with LPG use instead of kerosene use, which was considered an important enabler for successful fuel switching *(76)*.

Impacts on time: Users appreciate faster cooking with LPG stoves *(76)*. The expectation that cooking with LPG is quicker than wood was also documented and was reported as a reason for switching among firewood users *(79)*.

General design requirements: A large majority of the recipients of LPG conversion packages given in Indonesia reported overall satisfaction with the LPG stoves and 3 kg LPG refills *(76)*. Stoves and bottles were received in good condition and stoves were reported to be easy to use and maintain, and were largely preferred over kerosene stoves *(76)*. A suggestion made in a market survey conducted in Haiti was for LPG stoves to be designed to accommodate larger pots *(80)*, in order to facilitate cooking in households with a larger family size, especially in rural areas *(80)*.

Safety issues: Very few studies report on this aspect, but it merits special attention, as safety concerns are frequently reported. Safety issues arise primarily from leaks and bottle failures caused by inadequate manufacture and safety checks on bottles and valves, which can result in explosions *(76, 81)*. This issue is discussed further under Domain 3.

5.1.2 Domain 2: Household and setting characteristics

Socio-economic status: Measures of income and/or household expenditure are important features of LPG uptake *(78, 82-84)* and one study reported that achieving a complete switch requires reaching a certain threshold of income or household expenditure *(85)*. Having an electricity connection seems to promote fuel switching *(84)*, probably in part due to higher SES, but electricity access may also be enabling in other ways. The studies reporting this, however, did not provide data or insights to help with further explanation of the finding.

House ownership and structure: The number of rooms in the house was reported to be positively associated with LPG switching in urban areas, and this was thought to be most likely due to the association with wealth *(84)*.

Education: In an analysis of nationally representative survey data from Guatemala, a higher level of education was associated with adoption *(84)*. This same study provided insights into a number of other social, economic and cultural factors: for example, indigenous ethnicity was a barrier to uptake *(84)*, and this was presumed to be due to cultural preferences (e.g. food preparation) in addition to associated socio-economic factors.

Demographics: In terms of household size, uptake was found to be greater in households with fewer members in one national study from Guatemala *(84)*. In that study, a higher proportion of females in the home (availability of female labour) *(84)* and of those with a lower level of education (availability of labour with low economic value) *(84)*, acted as barriers to adoption; these findings were interpreted as being the result of the low perceived opportunity cost of the additional time spent using traditional (solid) fuels and stoves.

Multiple fuel and stove use: Where data on multiple fuel use in developing countries were available, LPG was almost always accompanied by use of more traditional fuels, generally biomass *(52, 77, 82-83, 85)*. Although existing widespread use of LPG was enabling (including use by the commercial sector as this enhances demand in and supply to a given location) *(77, 86)*, the perception of lower fuel costs associated with traditional practices acted as a barrier to change. For example, living on a farm (i.e. greater availability of biomass) *(84)* or being able to buy small amounts of wood on a daily basis (which avoids large periodic outlays required for gas refills) *(79)* were found to discourage LPG adoption.

Geography and settings: Adoption and use was also greater in urban settings *(52, 79, 84-85)* due to higher income and, fuel availability and because time savings tend to be more highly valued by urban dwellers *(84)*. This finding was supported by an additional study conducted in Sri Lanka and not formally included in the review, as it considered transition to multiple clean fuels including LPG, biogas and electricity *(87)*. According to this study, women in the labour market valued time savings much more than women who did not engage in paid work, and this served as an incentive to switch from traditional to modern fuel. Rural areas also face relatively higher prices of LPG (due to supply issues as further discussed under Domain 5) *(85)* and less access to credit *(83)*, which act as barriers to uptake.

5.1.3 Domain 3: Knowledge and perceptions

Smoke, health and safety: Negative perceptions and fear of LPG explosions, due to leaks and poor quality equipment *(76, 79)* or lack of knowledge on the safe use LPG *(81)*, were reported as barriers to LPG adoption *(76, 79-81, 85)*. Some users considered it a toxic fuel *(85)*. Safety fears could also adversely affect traders' willingness to stock LPG *(85)*, which in turn impacts on fuel availability (as further discussed in Domain 5). No direct health benefits associated with LPG use and reduced emissions were reported in the identified studies, but perceptions that wood was a dirtier fuel and could negatively impact on health were expressed *(79)*.

Cleanliness and home improvement: Having a cleaner kitchen was listed by users among the LPG benefits *(76)*.

Total perceived benefits: Prior knowledge of LPG use was usually accompanied by a greater level of awareness of its benefits and increasing willingness to adopt *(81, 85-86)*. Users considered the LPG equipment (i.e. LPG stove and LPG refill bottles) easy to use *(76)*.

Tradition and culture: Cultural aspects such as cooking habits and food taste, as found in relation to uptake of ICS, are also important in relation to uptake of LPG *(79-80, 84-85)*. Preference for food tasting of smoke and the habit of cooking outside can reduce the likelihood of LPG adoption and use, especially in rural areas *(84-85)*. On the other hand, the widespread and growing use of LPG in many developing countries suggests that such preferences only operate as a barrier in some circumstances, and can change over time and with increasing familiarity with LPG *(77)*.

5.1.4 Domain 4: Financial, tax and subsidy aspects

Stove costs and stove subsidies: The initial purchase price of the LPG stove and gas bottles were among the most frequently reported factors limiting uptake *(52, 79, 81, 83, 86)*. Direct subsidies on stoves and bottles were used to promote adoption *(76, 78, 83)*. For example, such subsidies supported the large-scale conversion of kerosene to LPG in Indonesia, where LPG stoves and bottles were initially provided for free, with users responsible for paying for subsequent refills; the LPG price, however, remained subject to a general subsidy *(76)*.

Fuel costs and subsidies: The price of the LPG fuel itself (as opposed to the initial costs of stove, regulator and gas bottle) is an important issue in relation to resistance to fuel switching *(83)*, especially for poorer and rural households *(52, 78, 85)*. For these, low-price availability of traditional fuels and poor road infrastructure (which increases fuel price due to transportation costs) negatively influence uptake *(81, 85)*. Fuel subsidy may therefore be an issue of critical importance *(77-78)*. Fuel subsidies are argued to have been one of the main reasons for widespread uptake of LPG in Brazil prior to market liberalisation, and withdrawal of these subsidies led to poorer families reducing the amount of cooking and/or reverting to solid fuel *(77)*. This in turn, led to the introduction of a targeted benefit for low-income families in what appears to have been an effective means of promoting and maintaining LPG use among the poorer segments of society. In India, LPG subsidies have been available for over twenty years and different LPG consumption patterns have been observed across Indian states, with the northern region and some of the more prosperous states reporting higher number of LPG connections and LPG use *(52, 78)*. Misuses of such general fuel subsidies were also reported (e.g. LPG subsidies used for fuelling air conditioning devices or vehicles, rather than for cooking purposes) *(52, 77)*.

Payments modalities: Methods of payment for LPG stoves and bottles include loans, credit and payments in instalments *(81, 83, 85)*. Since users struggle with the recurrent high cost of LPG refills, the use of smaller 3 kg bottles to reduce these costs was found to be beneficial *(76)*.

Programme subsidies: Aspects such as the provision of financing facilities for retailers *(80)*, financial incentives to rural entrepreneurs to set up an LPG business *(86)* and programmes/initiatives covering the costs of user training on safe LPG use *(81)* were all reported as positive factors in setting up sustainable LPG markets.

5.1.5 Domain 5: Market development

Demand creation: In Indonesia, demand for LPG was fostered by widespread media promotion *(76)*. Targeting potential customers in local dialects *(86)* and safe cooking events were used in other countries, such as Sudan, as part of participatory projects with low-income communities *(81)*. Consumer profiling for effective marketing was also recommended *(80, 85)*.

Supply chains: Distribution and supply play a key role in LPG uptake. Supply is strongly influenced by oil prices, and the extent to which a country is a producer or importer of oil. In addition, policies on internal supply and distribution planning for LPG and LPG appliances were found to be important *(76-77, 80-81, 84)*. In Indonesia, for example, calculations were made on the amount of LPG required based on the respective energy content of kerosene and LPG, to ensure that supply of the latter would meet household energy needs, and local distributors of kerosene were encouraged to change to supplying LPG *(76)*. Conversely, limited LPG availability and distributional problems were reported to limit the continuous use of LPG *(79, 85)*.

Business and sales approaches: Approaches to favour market growth and to reduce LPG costs include market expansion (for example extending demand through LPG use in schools and businesses) *(77)*, bulk transportation *(85)*, and credit mechanisms to increase commercial use *(85-86)*. This can particularly help price stability in rural areas *(86)*. In Indonesia, extensive opportunities for the private sector to invest in building private bottle refilling stations across much of the country favoured the acceleration of the programme *(76)*.

5.1.6 Domain 6: Regulation, legislation and standards

Regulation legislation and standardisation: Policy and legislation are fundamental to controlling LPG price volatility *(52)*, including importation issues *(80)* and regional price variations *(85)*. Price volatility *(79)* and lack of control over large regional price differentials *(85)* adversely affect adoption and sustained use of this fuel. As noted above for Domain 4, legislation to allow low-income households to continue buying LPG emerged as necessary in

Brazil subsequent to market liberalisation *(77)*. In Indonesia, the establishment of the legal basis and parliamentary approval for the conversion programme were important in obtaining budgetary support *(76)*.

Enforcement mechanisms: Enforcement of standards is required to ensure LPG safety *(76)*; lack of oversight mechanisms and insufficiently regulated expansion of the LPG market contribute to the release into the market of unsafe products, which may further reinforce general fears concerning the use of LPG *(76)*.

5.1.7 Domain 7: Programmatic and policy mechanisms

Institutional arrangements: Strong institutional arrangements to prepare for large-scale implementation and the presence of an implementing agency with overall responsibility were argued to be an essential component for the success of the LPG conversion programme in Indonesia *(76)*. Government support at the highest level was also found to be important in this programme. In particular, having one ministry to co-ordinate other ministries and stakeholders, facilitated programme implementation *(76)*. In general, various institutional arrangements are needed to address key issues of price volatility *(52)* and ensuring adequate LPG imports *(80)*.

User training: Small-scale initiatives to support user training for safe use of LPG are valuable and were found to positively affect demand *(81)*. Provision of user training is an aspect which should not be overlooked as a means of reducing fear of explosions *(81)*.

Monitoring and quality control: There is little documentation on the role monitoring and evaluation can and should play in large-scale conversion initiatives, with only one study describing the importance of this in a small-scale intervention *(81)*.

5.1.8 Equity considerations in relation to LPG uptake

Only a few studies addressed issues of poverty and urban/rural location, with no studies specifically looking into gender issues.

The aspect that most clearly emerges in relation to LPG adoption and use is the problem of disadvantaged families being unable to afford the cost of a new LPG stove and bottle, and the cost of refilling bottles. Both were found to be prohibitive among poorer communities when no form of subsidy or financial support was applied *(81, 85-86)*. However, the extent to which subsidies for the initial costs (stove and bottle) and the ongoing fuel costs can overcome inequalities in access was debated *(52)*. Two Indian studies reported that subsidies were primarily directed at the middle-income groups*(52, 78)* who were likely to be able to buy and use LPG independent of subsidies *(52)*, lending support to the concept of graded subsidies such as those used in Brazil *(77)*. Microfinance schemes, however, can be successful in supporting disadvantaged families in acquiring LPG equipment *(81, 85-86)*, but refilling costs may continue to be a barrier.

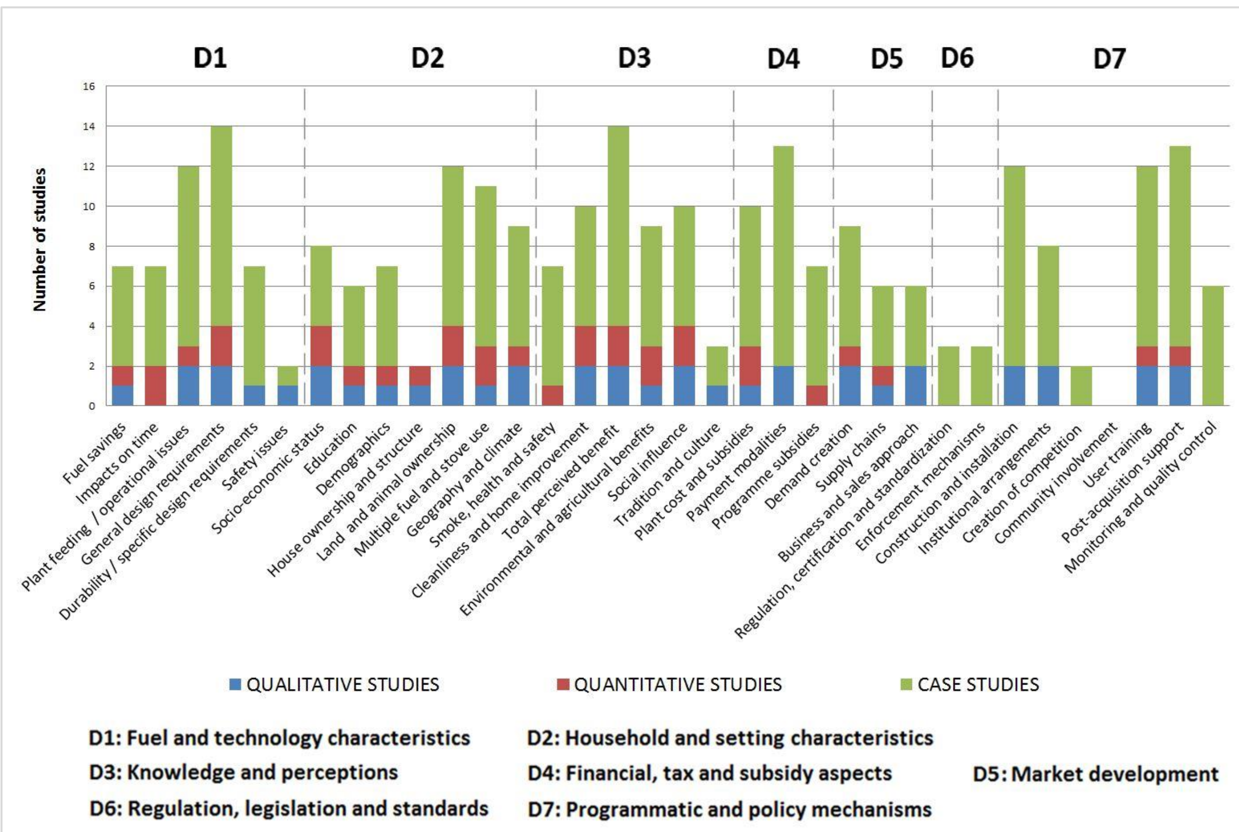
LPG adoption and sustained use in rural areas encounters similar problems. The high price of LPG in rural areas, which may be as much as three times higher than in urban areas *(85)*, is related to the higher cost of distribution *(78)* and exacerbated by poor road infrastructure *(81, 85-86)*. Such high costs discourage LPG use in rural areas, with less access to credit for the initial purchase of the LPG stove and bottle being additional limiting factors *(83)*.

5.2 Biogas

A total of 17 studies were identified on the adoption and sustained use of household biogas systems (2 qualitative, 2 quantitative and 13 case studies). Studies ranged from 1990 to 2012 and were conducted in Bangladesh (n=6), China (n=4), India (n=4), Kenya (n=1), Nepal (n=2) and Sri Lanka (n=1). Two of the studies assessed factors influencing adoption of biogas (defined as up to one year since installation of biogas plant); 11 studies explored the status of biogas plants (i.e. to check functionality) and their sustained use; and 4 studies assessed elements of both adoption and sustained use. In terms of methodological quality, this can be considered robust, with 2, 12 and 3 studies scoring strong, moderate and weak respectively. Detailed study characteristics are summarised in Annex 3.

A total of 33 factors influencing uptake of biogas were identified across all framework domains, summarised with contributing study designs (i.e. qualitative, quantitative and case studies) in **Figure 5** Some of the factors are clearly biogas-specific and include: (i) land and animal ownership, (ii) plant feeding and operational issues and (iii) environmental and agricultural benefits. All domains are supported by evidence from all three study designs, except for Domain 6, which is supported by case studies only. Sensitivity analysis excluding the three weak studies made very little difference to the evidence available for each of these factors.

Figure 5. Factors influencing the uptake of biogas across seven domains (D1-D7), by study type and number of studies



Source Puzzolo et al. 2013 (2) Reproduced with permission

5.2.1 Domain 1: Fuel and technology characteristics

Plant feeding and operational issues: Biogas places labour demands on users, as regular maintenance and daily management of the plant are essential and labour-intensive.

For effective biogas production, adequate amounts of feed and water are required *(88-89)*. Cattle dung is the main feed, but while use of human waste, straw and poultry droppings increase available feed *(90-93)*, these are not always available. Underfeeding due to (i) lack of available manure *(88, 91-92, 94-96)*, (ii) the use of unsuitable feeding materials which can block the digester *(88, 95, 97)*, (iii) lack of knowledge about the correct water-dung ratio *(40, 88-89, 92, 98)*, (iv) labour shortage *(88, 95-96)* and (v) inadequate management *(89, 95, 98)* were all reported in multiple studies. These aspects can reduce energy output and/or cause malfunctioning of the digester and need to be better addressed through user training (see Domain 7).

Fuel savings: A range of savings are attributed to biogas and are likely to enable adoption and use, with no corresponding barriers identified in the studies. Studies reported cost savings due to greater energy efficiency *(98-99)* and less money spent on purchased fuels such as firewood *(89-90, 92, 100)* and kerosene *(40, 90)*.

Impacts on time: Using biogas saves cooking time as a result of faster cooking due to greater energy efficiency *(98-99)* and the use of multi-pot stoves *(40, 92, 96, 98, 100)*, which is highly valued by users. Time savings from reduced or no wood collection was also reported to be a positive consequence of biogas use *(90, 92, 94)*.

General design requirements: There are multiple types of digesters (e.g. floating and fixed dome) and considerable variations in the type and standards of materials and construction methods *(40, 89, 96, 100-101)*. Functionality depends on plant type and plant size *(40, 96, 101)* and is affected by animal holding and daily operation *(88, 90-91, 94-95, 98-99)* (see Domain 2). Specific features of the design and construction need to be taken into account in assessing whether these act as enablers or barriers for adoption and use in any given setting. In Bangladesh, for example, greater rates of adoption and sustained use were reported when service providers *(92)* or trained engineers *(102)* correctly advised households on the type and size of biogas system suitable to their specific circumstances.

Durability and specific design requirements: Durability relating to design and construction has been found to be variable *(89, 101)*, but high-quality biogas units can operate for several decades if properly maintained *(101)*. Poor design and quality (e.g. leaks, absence of moisture traps in pipes) are commonly reported and impact on sustained use *(88, 92, 98)*. Having a plant with the capacity to produce sufficient gas output to meet household needs favours use over time *(101)*. Specific design enhancements are needed in cold settings *(95)* and add to cost *(90, 99)*; without these low temperatures slow down and ultimately stop digestion (See Domain 2).

Safety issues: Regular inspection of the digester and pipes is important to ensure functionality (technical reliability) and safety of the digester *(92, 95)*. While the studies did not specify the key areas of safety concern, these are expected to relate to gas leakages.

5.2.2 Domain 2: Household and setting characteristics

Socio-economic status: Biogas is more frequently adopted, maintained and used over time among higher socio-economic groups as measured by income *(40, 92, 94-96, 100)*, caste *(103)*, type of profession *(93, 103)* and broader measures of household wealth, such as access to electricity or ownership of a toilet *(103)*, as well as in settings where there is a high market value for cattle *(100)*.

Education: Higher education and/or literacy level facilitates adoption *(92-93, 95, 101, 103)*, primarily through greater awareness of benefits but also through greater awareness of credit options *(103)*.

Demographics: Larger households are more likely to adopt, mainly because more labour is available to look after the biogas plant *(92-93, 103)*. Reduction in family size over time *(96)*, including through rural to urban migration by the younger generation in the face of economic stresses, was reported as an important factor in several studies (especially China), which affects the functionality of existing digesters and limits interest in future installations *(88, 94-95, 97)*.

House ownership and structure: Having tenure of the home *(40)* and title deeds *(100)* can favour uptake, as once constructed, biogas plants cannot be moved. Consequently, adopting biogas requires an investment in long-term infrastructure.

Land and livestock availability: Having sufficient land and space close to the house to construct the biogas system is crucial for adoption *(92, 96, 100, 103)* and management of the bio-slurry *(93)*; indeed lack of space was reported as one of the main reasons for not building a plant *(93-95)*. Having enough livestock to produce sufficient gas to cover family needs is also crucial *(88-89, 92-97, 100-101, 103)*, and greater functionality of plants was found among those working with animal husbandry *(96)*. A larger number of cattle (i.e. at least four) and the practice of zero grazing (keeping and feeding cattle in pens) is enabling, as this facilitates collection of dung and feeding the digester *(100)*. The availability of dung in general, including collection from neighbours *(91-92)*, also favours uptake of biogas plants. In China, pig dung and straw stalks are used as primary feeding material *(94-95, 97, 99)*.

Multiple fuel and stove use: Limitations in access to other fuels *(93)*, including shortage of fuel wood *(89)* and shortage or high costs of LPG *(88, 101)* are all factors that can favour the adoption and the use of biogas *(88-89, 92)*. Conversely, easily available wood and coal, and access to other inexpensive fuels and cooking technologies, are reported to be barriers *(94-96)*. Some households that have already invested in other 'modern' energy sources were reluctant to invest further in biogas *(100)*.

Geography and climate: Biogas production is reduced at low temperatures and/or higher altitude *(90, 92, 94, 96, 99)* and ceases below 10°C *(99)*. In these settings production is not reliable across seasons without costly adaptations including insulation and a warm-water feed *(99)*. The rainy season is a favourable time for production of good-quality bio-slurry to be used as fertiliser *(93)*. Seasonal drought and other factors may lead to selling animals hence reducing or stopping gas production *(89, 95)*. Similarly, flooding disrupts digester function unless digesters are sited or built to withstand it *(40, 91)*.

5.2.3 Domain 3: Knowledge and perceptions

Smoke, health and safety: Acknowledgement of health benefits including fewer episodes of eye and respiratory diseases from not using traditional solid fuel stoves *(90, 92-93, 98)*, and less backache from reduced firewood collection *(100)* were widely described, in particular among women *(96)*. Some concerns about infectious diseases spreading through handling of manure *(88)* and increased breeding of insects after plant installation *(88, 90)* were also reported.

Cleanliness and home improvement: Perceived benefits from improved sanitation (in particular through the inclusion of latrines during the installation) *(90, 94-95)*, reduced smoke *(100)*, a cleaner home environment *(93, 96)* and cleaner cooking vessels *(92, 96)* were reported. Biogas is also used for lighting purposes in some settings, but the evidence does not allow any conclusions to be drawn as to whether or not this is considered an incentive for biogas uptake *(90, 98, 100)*.

Total perceived benefits: Other perceived benefits from biogas use included improved quality of life *(92, 95)*, convenience for cooking *(93, 95, 100)* and the possibility of meeting all cooking needs *(96, 101)*. Additional economic benefits associated with biogas include cost savings made from purchasing less fuel *(40, 93)* and from the production of bio-slurry; the latter is a substitute for chemical fertiliser *(92, 94)*, but can also be used as an insecticide *(94)* or fish feed *(93)*. Moreover, if sold to other households, it can provide a source of income generation *(40, 92, 94, 96, 98, 102)*, as can excess biogas *(93)*.

Satisfaction with the system is mainly related to the status of functioning *(93, 95)*. Poor system functionality *(95)*, insufficient gas production (especially in certain climatic conditions) *(88-89, 91, 94, 96, 98-99)*, and inadequate knowledge about biogas benefits, significantly impact on continued use of biogas for cooking *(95-96, 100)*. Biogas production requires labour-intensive daily operations and some users suggested that the perceived monetary value of overall benefits are lower than they felt had been 'advertised' *(88, 95)*. This perception was, however, strongly related to lack of awareness about the potential economic benefits from bio-slurry use *(88-89, 95)*.

Environmental and agricultural aspects: Forest conservation and other environmental benefits from the use of biogas *(40)* were acknowledged by some users *(92, 100-101)*, including increase in crop yield due to seeds being soaked in bio-slurry before planting *(94, 98, 101)*. Two studies reported a potential concern that slurry not converted into fertiliser could pollute close-by water sources, although these studies did not provide data on how these influenced behaviour *(40, 93)*.

Social influence: The influence of social networks in the decision to adopt can reinforce the positive experience of users (enabling wider adoption) *(90, 93-94)* or act as a barrier where there have been negative experiences *(88)*. The perception of enhanced social status *(98, 100)* and a greater number of years over which the technology has been available in a given community *(94)* favour adoption. However, social and cultural taboos with the use of human waste can reduce connection to latrines which would otherwise increase the amount of available feed and consequent gas production *(40, 88, 90, 92, 98, 103)*. Also, the smell of dung and animals in close proximity of the dwelling can be a matter of concern for some users *(88, 95)*.

Tradition and culture: Familiarity with cooking on traditional stoves *(89)*, food taste *(89, 96)* and a family preference to sit around an open fire during the winter *(95)* were all reported to play a part in discouraging uptake.

5.2.4 Domain 4: Financial, tax and subsidy aspects

Biogas plant cost and subsidies: Initial plant installation is very expensive (US$180–500 among the included studies) *(88, 91, 94, 96, 98)*. Therefore almost all biogas programmes offered some form of subsidy ranging from 25 percent to 80 percent of initial costs, which constituted an important motivating factor for installation *(90, 92, 95-96, 100-101)*. Subsidy could be constant or vary according to plant type and size *(90, 96, 100-101).* The subsidy amount covered only part of the total installation costs, and the building of a latrine or an animal house associated with the digester was usually an extra cost to be incurred by users themselves *(95, 98)*.

Payment modalities: Multiple forms of credit were available to complete installation costs *(88-90, 92-93, 101)* but provision of grants or loans was not always appropriately managed; for example, some users experienced pressure from creditors to repay loans in less time than the agreed monthly instalments *(93)*. In addition, some households stopped paying monthly instalments due to a lack of adequate after-sales support *(91)*. Bureaucracy and delays in receiving subsidies *(98)* as well as difficulty in obtaining loans for securing livestock *(91, 102)* were also reported as barriers. Attempts to manipulate personal data in order to become eligible for subsidies and other types of assistance were reported *(40).* Lack of personal investment by the household in the biogas system was associated with less commitment to continue its use and high rates of non-functionality in some settings *(88, 96)*.

Programme subsidies: In addition to subsidies on plant construction and installation, some governments/programmes offered additional subsidies for toilet attachment *(96)* and construction of an improved kitchen *(94)* by households.

Programme subsidies were also made available towards the development of the biogas market with financing of trained staff and post-acquisition support *(90, 96)*. However, additional financial support for purchasing of livestock, user training in use and maintenance of the biogas plant or awareness campaigns on bio-slurry benefits and correct use were not usually provided *(91, 95-96, 102)*.

5.2.5 Domain 5: Market development

Demand creation: The importance of demand creation is well recognised, and programmes employ a range of marketing strategies, such as local companies employing local masons/rural energy technicians *(40, 90, 92, 96)*, local government representatives *(102)* or local NGOs and village-level motivators *(89, 91-92, 100)*. Companies investing more in personal contact and demonstration activities show better achievements *(103)*; seeing functional plants of neighbours and relatives also increases willingness to adopt *(92, 95, 102-103)*.

Supply chains: In terms of supply, existing road infrastructure favoured plant construction *(92, 94)*, while lack of roads and construction in rugged terrain increased installation costs *(90, 95)*. The lack of availability of construction materials, equipment and labour were also found to be important factors impacting on plant construction and completion *(93, 96)*.

Business and sales approaches: Income generated through biogas plant construction can be sufficient for ensuring livelihoods *(101)*, although repair work has been reported to be less profitable in remote areas (129). Promotion of small-sized digesters able to operate with a limited number of animals (usually two) *(90)* and avoidance of creating false expectations among clients *(40)* were reported to increase biogas uptake *(92, 102)*. Shops which offer the possibility of purchasing livestock were also valued by users, as reported in studies from Bangladesh *(40, 91)*.

5.2.6 Domain 6: Regulation, legislation and standards

Regulation, certification and standardisation: Standards for design, materials and construction of biogas systems are crucial for proper system functioning and this aspect was acknowledged in a number of programmes *(90, 97, 102)*. Incentives for high-quality construction and maintenance (including certification, signed agreements and linkage to a subsidy mechanism) *(90)* and the obligation to provide after-sales services were considered to favour adoption and sustained use.

Enforcement mechanisms: Enforcement through inspection visits *(92, 102)*, verification of quality standards and penalties for non-compliance with standards *(90)* are important for longer-term plant functionality. Indeed, lack of verification of technical standards set by the service provider can negatively impact on the quality of construction materials and construction methods *(92)*.

5.2.7 Domain 7: Programmatic and policy mechanisms

Construction and installation: The success of biogas adoption and use is increased through construction and installation by skilled masons or service centres, use of good quality appliances and the appropriate placement of plants, e.g. on higher ground to avoid flooding where this is a risk *(90, 92, 97)*. Construction is expensive, so poor-quality construction by inadequately trained builders, and use of poor-quality materials, which were reported to be used in a range of different settings *(40, 89, 91-93, 95-96, 98)*, adversely affected adoption and use because of negative experiences and poor plant functioning. Also, there are a number of specific design and construction issues that may need attention, for example the underground placement of pipes which can make detection of leaks difficult *(88, 102)*.

Creation of competition: Competition among builders favours good quality construction and regular follow-up of plants *(90, 101)*, resulting in an increase in client satisfaction with subsequent promotion of the technology within the community. Entrepreneurs able to assist prospective users in obtaining financial support (i.e. subsidies) were favoured *(101)*.

Institutional arrangements: Success appeared to be more frequent when built on well-functioning dissemination networks (involving multiple agencies, local government and collaboration with the private sector) *(40, 90, 93, 101)*, and on national targets (such as overall numbers of installed plants) *(90, 95-96)*. However, failure to achieve national targets was not infrequent and was reported to be mainly due to poor coordination between agencies involved *(96)*, lack of interaction with other rural development programmes *(96)* and insufficient programme staff *(88, 96)*.

User training: User training in the operation and maintenance of biogas systems was reported as a crucial factor in ensuring system functionality *(40, 90, 95-96)*. In several settings, lack of proper training is a recognised barrier to proper functioning of biogas systems, impacting on daily production of biogas to meet cooking needs and the adequacy of system maintenance *(88, 91-92, 95, 99, 103)*. Training in relation to correct use and benefits from bio-slurry production was also generally insufficient *(90, 93-94)*.

Post-acquisition support: After-sales service is another aspect associated with maintenance and long-term functionality of biogas systems *(89-90, 101)*. In some countries, programmes offered a combination of free repair services during warranty periods with subsequent services against payment, which ensured performance *(40, 90, 96, 101).* Lack of a warranty period or some form of insurance for plant installation *(91, 95)*, high repair costs *(94-96)*, long distances from repair stations *(95, 103)* or service unavailability *(88, 96)* usually led to lack of maintenance and a digester with insufficient gas production.

Monitoring and quality control: Quality control procedures are critical in ensuring the functionality and continued use of biogas systems *(90, 102)*. As described under Domain 6, household inspection visits were found to be a key element of successful monitoring schemes *(90-91, 102)*, sometimes embedded in a multilevel monitoring system, such as for the National Domestic Biogas and Manure Programme in Bangladesh, which combined overall programme monitoring by the steering committee and day-to-day monitoring by the partner organisations *(102).* Users may be empowered by involvement in quality control, for example, by paying building charges directly to masons upon satisfactory completion of construction and installation *(89)*, or by only paying monthly instalments to microfinance agencies, if the plant is operating properly *(91)*. Poor or no follow-up services provided by installers have a negative impact on quality *(88)*. Also, while some programmes formulated obligations to inspect plants and issue certificates for subsidy release, these obligations were often not met due to shortage of staff and excessively low fixed inspection fees *(96)*.

5.2.8 Equity considerations in relation to biogas uptake

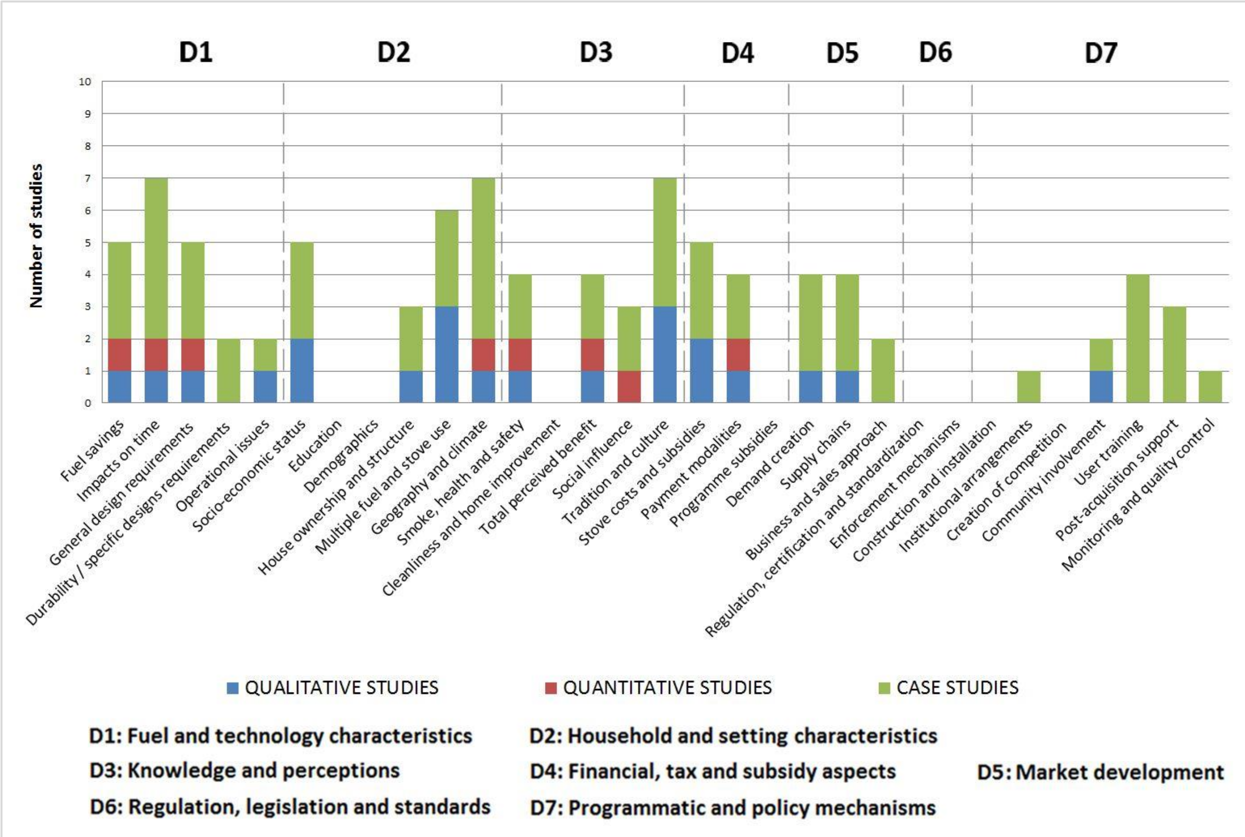
Biogas is a clean fuel primarily acquired and used by upper- and middle-income (mainly rural) households in possession of sufficient livestock and land. In view of this and based on the studies reviewed, uptake currently seems unlikely to be scaled up for poorer households with smallholdings (i.e. small-scale farms usually supporting a single family with a mixture of cash crops and subsistence farming) *(40, 94-95).*

In general, loan and subsidy mechanisms are widespread, and the provision of higher subsidies for the construction of smaller-sized digesters among small-and medium-scale farmers was one possible means to overcome inequalities in access to the technology *(90, 96)*. However, in addition to the initial high costs for construction of the biogas system, poor families may also require financial support to purchase and maintain livestock, and to maintain and repair the biogas system in appropriate ways *(95-96)*. Results show remote settings to be particularly disadvantaged in terms of obtaining technical post-acquisition support *(88, 95, 103)* as the repair business is not considered profitable in these areas and users may need to travel long distances to reach a repair station *(95)*.

5.3 Solar cooking

A total of 9 studies were identified on adoption and use of solar cookers (3 qualitative, 1 quantitative and 5 case studies). Studies ranged from 1998 to 2012 and were conducted in South Africa (n=2), Kenya (n=2), Senegal (n=1), Burkina Faso (n=1), Tanzania (n=1), India (n=1) and Mexico (n=1). Six studies assessed adoption of cookers, and three described aspects related to sustained use of cookers or a mix of adoption and sustained use over time. Cookers included mainly panel cookers ('Hotpot' and 'Cookit'), as well as parabolic and box cookers. In terms of quality, two studies were scored as strong, five as moderate, and two as weak. Detailed information on study characteristics, type of solar cooker and quality appraisal are reported in Annex 4.

Figure 6. Factors influencing the uptake of solar cookers across seven domains (D1-D7), by study type and number of studies



Source Puzzolo et al. 2013 (2) Reproduced with permission

Twenty three factors were identified as influencing the uptake of solar stoves as illustrated in **Figure 6**. Most of the evidence pertains to the first three domains, and no study reported on Domain 6. The only quantitative study contributed evidence to four domains; qualitative studies supported factors across the first five domains, and case studies supported all domains apart from Domain 6. Traditional and cultural aspects, followed by impact on time and opportunity cost issues, along with geographical and climatic considerations, are among the principal factors guiding household choice about adoption and use of solar cookers.

As further discussed below, the fact that solar cookers cannot meet all cooking tasks, in particular not those required early in the morning or later in the afternoon/evening, greatly impacts on who adopts solar cookers and on how these cookers are used. Following sensitivity analysis excluding the two weak studies, 21 out of 23 factors were retained with at least some supporting evidence, although the factors '*Institutional arrangements*' and '*Monitoring and quality control*' were lost.

5.3.1 Domain 1: Fuel and technology characteristics

Fuel savings: Solar cooker users were found to benefit from cost savings due to reduced need to purchase fuels, provided the stove was frequently used *(104-107)*. However, when the cookers were used infrequently (i.e. 10 percent of days over a six month time period in one study) there may have been no significant difference in fuel used and time spent gathering *(72)*.

Impacts on time: Solar cooking requires forward planning to be time-efficient. Time savings arose from less time spent collecting wood *(104, 106-108)* and less need for regular attention to be paid to the food *(105-109)*. Loss of time occurred mainly due to slower cooking *(105, 108-110)*.

General design requirements: In terms of design requirements, a common issue reported was that most solar cookers did not have sufficient capacity to cook for large households (e.g. more than 5-6 family members) *(72, 107-108)*; one study suggested that using two solar cookers could offer a solution to this problem *(108)*. Another design issue was that most cookers were heavy and bulky and therefore difficult for women to handle and move; this issue was particularly important in urban settings where space for cooking with or storing the solar cooker was a concern *(105, 110)*.

Durability and specific design requirements: In terms of thermal performance, variability across cookers was reported *(104)* and the lack of control for regulating heat negatively impacted uptake *(110)*.

Operational issues: New users of solar cookers were not familiar with the technology, and needed to master the basic technical requirements for cooking, in particular correct orientation of the reflective surface and how often to change this orientation. Lack of these skills led to difficulties in initial use of the technology *(62, 108)*.

5.3.2 Domain 2: Household and setting characteristics

Socio-economic status: Households with higher incomes were more likely to adopt solar cookers, as high-quality cookers were usually costly *(107)*, and lower-income families were unable to afford them *(62, 105, 109-110)*.

House ownership and structure: Use of a solar cooker requires a sunny area by definition, and in practice this needs to be a protected area located close to the home, ideally within the yard. Lack of a convenient, well-insolated area such as this discouraged adoption *(105, 107)*. In some settings where no yard is available, a roof can be used (particularly in urban settings), but daily cooker transfer to the roof and back to the house was reported to be a major source of inconvenience *(110)*. In one study conducted in an urban area, adoption was more likely among those living in detached houses or on top floors of buildings, as the cooker could more easily be moved between places of cooking and storage *(110)*.

Multiple fuel and stove use: The prevailing fuel use and availability affected solar cooker adoption, as accessibility of alternative cheaper fuels *(109)* and use of more familiar stoves *(62)* was a disincentive to switch to solar cooking. Conversely, scarcity of gathered fuelwood, situations where women face personal risks in fuel collection *(43, 107)* or high prices of commercial fuels (e.g. kerosene or LPG) among more affluent households habitually using these *(104-107)* favoured adoption.

Geography and climate: Climatic conditions and seasonality play critical roles in daily use, as solar cookers require reliably high levels of solar irradiance *(104, 106, 110)*; their use is usually not possible or practical when conditions are cloudy, windy or very dusty *(72, 105, 107-108)*. Also, cookers cannot be used at all during the early morning or late afternoon/evening *(104, 106, 109)* which impacts on continuity of stove use, and highlights the need for forward planning of cooking activity, including fitting this in with other commitments (see Domain 3).

5.3.3 Domain 3: Knowledge and perceptions

Smoke, health and safety: From a health perspective, female users found a number of advantages in using solar cookers, including better health conditions *(105)*, less backache with no need to stand for long periods *(110)* and less risk of burn-related injuries *(106)*. However, results from a recent randomised controlled trial conducted in Senegal identified no statistical difference on self-reported health data between users in intervention groups using solar cookers and non-users. This, and the lack of exposure reduction to carbon monoxide (CO) among the intervention group, can be explained as a result of intervention households using open fires and/or other traditional stoves as well as with solar cookers to meet cooking needs *(72)*.

Total perceived benefit: Solar cookers are particularly suitable for preparing dishes which require slow cooking *(43, 106, 109)*, but cannot be used for preparing all meals. This means that users are generally unable to rely on solar cookers alone *(43)*. Although some users reported satisfaction with technology *(72, 106)*, others were found not to appreciate the benefit of using a cooker when they were already able to meet all their cooking needs with just one device *(109)*.

Social influence: The use of solar cookers can offer other benefits, including in relation to social networks *(106)*. In one study, for example, it was found that the cooker could easily be lent to relatives and neighbours, and this was a positive attribute *(106)*. However, the inability to prepare large quantities of food or the need for special food size requirements (such as meat being chopped into smaller pieces) was seen as a sign of inhospitality in some settings, and hence discouraged use of the device *(72, 109)*.

Tradition and culture: In relation to food preferences, results were mixed; some users reported satisfaction in terms of taste, colour and texture of the food *(105-106, 108, 110)* whereas others did not *(43, 108-110)*. The use of solar cookers also requires behavioural change, including alteration to daily routine, planning ahead and adaptation to technology requirements, which can discourage use *(108-110)*. Adapting to these changes was reported to be more difficult for older women *(62)*.

5.3.4 Domain 4: Financial, tax and subsidy aspects

Stove cost and subsidies: High-quality solar cookers were generally considered to be expensive, especially when imported *(105, 108)*. Although cost depend on cooker design, stove cost was reported as a major barrier to adoption in several studies *(62, 105, 108-109)*. Availability of subsidies for initial purchase and cooker replacement favoured adoption and use over time *(110)*, but even with large subsidies in place, solar cookers may still be beyond the reach of medium- and low-income households as reported in other studies *(72, 105, 109)*.

Payment modalities: Access to credit schemes (e.g. microcredit through local co-operation) *(109)* or payment in instalments *(72, 104-105)* facilitated stove purchase, as did the promotion of locally manufactured cookers which were more affordable than imported stoves *(105)*.

5.3.5 Domain 5: Market development

Demand creation: Strategies to promote solar cookers included media advertisements *(105, 110)* and cooking demonstrations *(105)*. Word-of-mouth within small communities was also found to be effective *(105)*. Special attention to design features was recommended, as poor appearance and packaging discourage users from purchasing products which are perceived as low quality *(107)*.

Supply chains: Local production of cookers contributes to sustainability *(105, 110)*, while lack of supply of parts is a barrier *(109)*. Importation costs, taxes and shipping costs for the cookers were reported as additional barriers to adoption *(107, 109)*.

Business and sales approaches: Some donor and NGO programmes have had restricted population or geographical reach and consequently may fail to build up a broader, self-sustaining market *(107)*. Low demand for cookers indirectly impacts on prices but also on availability and stocking of cookers by shops and other commercial outlets, as doing so is perceived as a high risk investment *(109)*.

5.3.6 Domain 6: Regulation, legislation and standards

No evidence has been identified under this domain.

5.3.7 Domain 7: Programmatic and policy mechanisms

Institutional arrangements: A consortium of organisations working together to promote market development, focusing on areas such as reducing production costs and developing financial incentives for production, distribution and training, was reported to have facilitated uptake use in one study *(109)*. However, lack of government support was considered a reason for limited dissemination in the same study *(109)*.

Community involvement: Inclusion of users in the development of projects to promote solar cookers was recommended in two studies as a means to increase popularity and usability of cookers *(105, 110)*.

User training: Adequate training to adjust to the practicalities of solar cooking was reported to be very important for successful adoption and longer-term use of solar cookers *(107-110)*, although training could be costly, especially if this involved individual or small-group demonstrations and support *(109)*.

Post-acquisition support: After-sales service in person or by telephone was reported to be promoted in one study, but it is not clear whether this favoured sustained use of the cookers *(110)*. In small-sized community projects selected individuals have been appointed as mentors to offer technical support to their peers *(104)*. It was argued that follow-up which offers more than just technical assistance is needed to encourage users to continue use of the cookers *(109)*.

Monitoring and quality control: As for several other interventions, systematic monitoring has been stated to be a crucial element for effective promotion of solar cookers in one study *(109)*, but was an issue that has been neglected by most studies.

5.3.8 Equity consideration in relation to solar cookers

In relation to urban/rural location, increased adoption was reported in places where wood was scarce and savings from reduced purchasing of wood could have a positive impact *(107)*. Solar cookers were, however, usually unaffordable for poorer households *(62, 105, 110)*. Instead, it was noted that better-off families appreciated the savings that could be made on more expensive modern fuels *(107)*.

With respect to gender, time savings from less wood collection and less need to watch over food closely, may have a positive impact on women, as free time was reported to be used for income-generating activities *(105)* and, domestic work *(105)*, and for time spent within the community *(106)*. On the other hand, the time that women spent on fuel collection was not always valued (low opportunity cost) *(109)*, and neither were other social and economic benefits from solar cooking *(109)*. Also, delays in serving meals as a consequence of solar cooker use (i.e. not having a hot dinner ready to be served) were reported to have triggered domestic abuse in some families *(109)*.

5.4 Alcohol fuels

5.4.1 Introduction

Promotion of alcohol-based fuels for household cooking (such as ethanol and methanol, available usually as liquids but also in gel form) is a relatively recent development. Bio-ethanol is a liquid that can be produced by sugar fermentation from various types of biomass feedstock including sugar-based materials (e.g. sugar cane, sorghum), starches (e.g. cassava, maize) and cellulose-based products (e.g. wood, grasses and agricultural residues) *(111)*. The ideal feedstock depends on climate and soil conditions, as well as the available technology *(112)*. The ethanol-water mixture produced after fermentation needs to be further purified by distillation. The higher-quality ethanol stoves require hydrous ethanol (95%), with a maximum water content of 4-10% *(113)*. Denaturating agents (e.g. bitter tasting substances) and colorants are usually added to ethanol to discourage users from drinking it as an alcoholic beverage. Methanol is mainly produced from fossil fuels such as natural gas or oil products and its production cost is less than for ethanol *(114)*. Its potential for the household cooking market may therefore be greater in countries with natural gas supplies *(115)*. Gelfuel is a much higher viscosity fuel produced when denatured liquid ethanol is mixed with a gelling agent (e.g. calcium acetate or cellulose) and water, resulting in a combustible gel *(116)*. However, limited gelfuel stove programmes seem to be in operation today as gelfuel has the disadvantage of not providing sufficient heat (and hence energy to the pots) and the initial gelfuel stoves which were promoted during the 'Millennium Gelfuel Initiative' had serious performance limitations, which resulted in very low adoption rates by consumers *(113)*.

5.4.2 Studies meeting inclusion criteria

A total of 6 case studies were identified providing empirical evidence on factors influencing the uptake of alcohol-fuelled stoves. Three of the studies were reports of small-scale projects to assess the feasibility of larger-scale promotion of alcohol fuels carried out in Ethiopia *(117)*, Brazil *(118)* and Nigeria *(119)*. Studies focused on testing users' satisfaction with imported stove technology, willingness to pay for the fuel, after an initial free fuel supply of one to three months. The Madagascar study, (available online as two reports separately included in this reviews [i.e. components A and B]) *(113, 120)* was a comprehensive mixed-methods assessment to investigate socio-economic factors and user perceptions of ethanol fuel and ethanol stove preferences in two communities (Ambositra and Vatomandry). The study focused on substituting ethanol for charcoal in one and charcoal and wood in the other. The last included study was a case study describing the activity of a small company producing ethanol in Indonesia *(121)*.

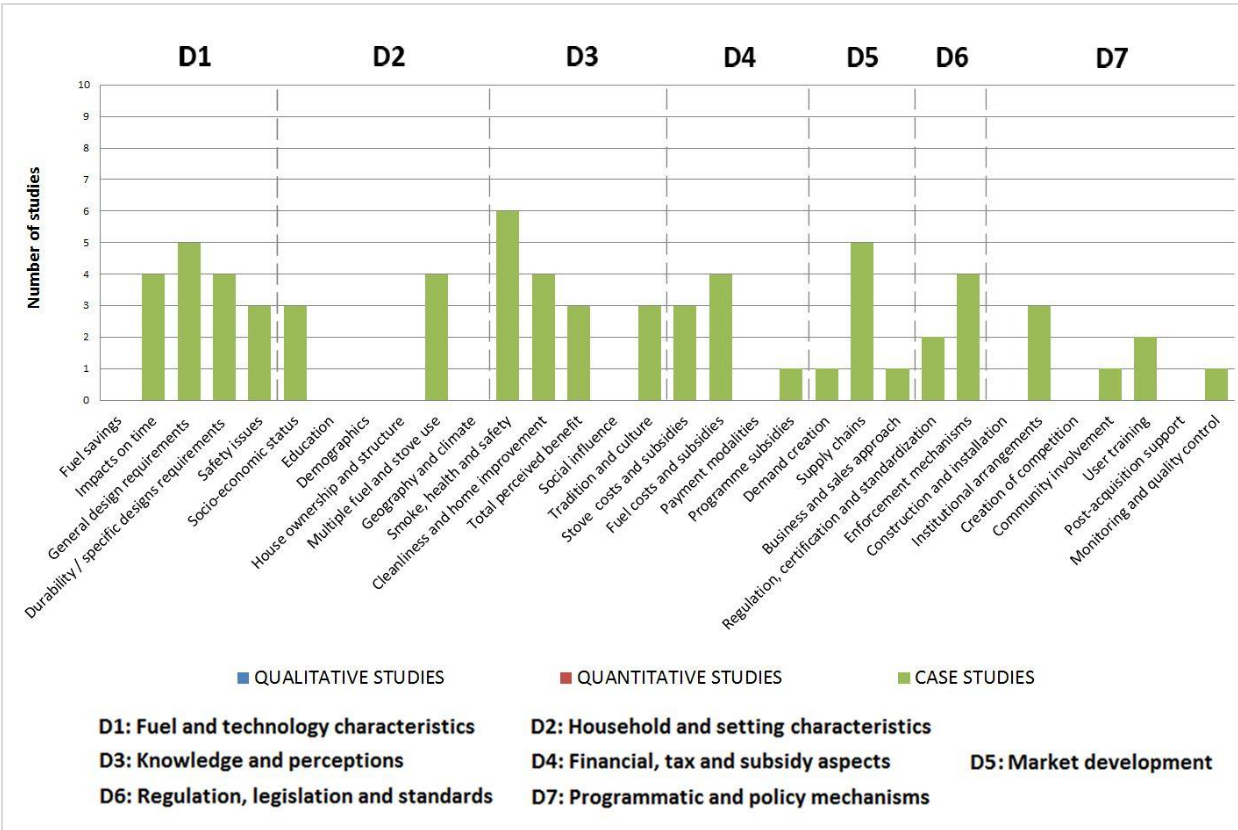
Five of the included studies report on the use of locally-produced and denatured ethanol and one study is based on denatured methanol *(119)*, (both fuels in the form of liquid preparations, available as refillable plastic bottles or canisters). In terms of quality, one study was scored as strong, four as moderate, and one as weak. Detailed study characteristics, summarised in Annex 5, illustrate the 22 factors identified across the seven domains for alcohol fuel adoption and use. Despite the fact that all domains were represented, with only six studies, this evidence base is quite limited. As the majority of the studies were small-scale feasibility studies, special attention was given to users' perceptions of stove design, the advantages and disadvantages of stove use during tests and willingness to pay for the alcohol fuel. This is particularly reflected in Domains 1 and 3, although supply chains within Domain 5 were also investigated in most of the studies. Following sensitivity analysis excluding the one weak study, the number of factors with supporting evidence was reduced to 17, with loss of this information from Domains 4, 5 and 7. Given the paucity of studies, the findings for alcohol fuels should be seen as tentative, with results pertaining to an early stage in the process of implementation. One other issue relating to the lack of breadth of evidence is that the majority of experience with alcohol fuels related to a single type of stove, the Dometic 'CleanCook', (with single or double burners). This reflects the widely acknowledged quality and safety of this stove and fuel canisters, but also the lack – to date – of suitable alternatives and specifically local production in the countries where use has been studied.

5.4.3 Domain 1: Fuel and technology characteristics

Time savings: One of the main reported advantages of cooking with alcohol-fuelled stoves was time saving as a result of both faster cooking and being able to carry out other tasks while cooking *(113, 117, 120)*. One litre of ethanol used on the 'CleanCook' normally provides 4 to 4.5 hours of cooking at full power (that is at ~1.5 kW), or up to 8 hours of cooking at lower power settings.

Based on results from the feasibility studies, one litre of fuel is generally sufficient for one day of cooking (based on three meals for a family of five), which translates to 7 litres per week *(119)*. Five litres per week were usually considered insufficient to meet family needs *(117-118)*.

Figure 7. Factors influencing the uptake of alcohol fuels across seven domains (D1-D7), by study type and number of studies



Source Puzzolo et al. 2013 (2) Reproduced with permission

General design requirements: In terms of design requirements imported stove models were considered of high quality, efficiency and speed *(113, 117, 119-120)*, with substantial reduction in household pollutant concentrations. Measured reductions were available from several studies, including for example large reductions in 24-hour average kitchen concentrations of CO and $PM_{2.5}$, and personal CO for women and children, among groups of households using ethanol with the CleanCook stoves, in comparison with traditional charcoal and wood stoves in the study from Madagascar which used a quasi-experimental design *(120)*. Adjustable cooking speed was valued *(117)* and promotion of stove models with a second burner to allow cooking with more than one pot was recommended by users *(118, 120)*.

Durability and specific designs requirements: Suggested design improvements include secure pot supports *(119)* for either smaller *(118)* or larger pots *(120)* and larger capacity canisters (the standard fuel canister in the CleanCook stove was 1.2 litres) *(119)*. In one study, the main complaints reported were wastage of fuel during refilling of the canister *(113)* and some difficulties in lighting the stove *(113)*.

Safety issues: A low risk of fuel leakage and no risk of explosion were described by users using imported alcohol-fuelled stoves (i.e. the CleanCook) *(118-119)*, since the fuel is not pressurised and it is fully retained by a densely packed refractory ceramic fibre contained inside the canisters, so no leakage occurs even if the cooker tips over. Also, in the Madagascar study, a lower risk of burns was reported in comparison to traditional stoves *(113, 118-119)* (see Domain 3).

5.4.4 Domain 2: Household and setting characteristics

Socio-economic status: To date, the ethanol market and the small-scale feasibility studies have been mostly targeted at middle-income households already using purchased fuels such as charcoal *(113)*, kerosene *(117)* and LPG (to a limited extent) *(118)*, against which ethanol fuel can compete on price *(113)*.

Multiple fuel and stove use: The included studies presented limited information on characteristics of households and settings that might influence adoption of fuel switching to alcohol fuels. Households selected to take part in pilot-studies, reported high use of the new stoves, but also simultaneous use of kerosene *(117)*, LPG *(118)* and/or other traditional fuels *(120)*. This seems to have been in part due to insufficient ethanol being available during the feasibility study periods to meet cooking needs for the entire family *(117)*.

5.4.5 Domain 3: Knowledge and perceptions

Smoke, health and safety: The quantitative component of the Madagascar intervention study (upon which the adoption case study was based) *(120)* reported a statistically significant reduction in headaches and eye irritation among women due to smoke reduction, as well as a significantly reduced occurrence of burns in both women and children using ethanol fuel/ stoves compared to traditional fuel/stoves *(120)*. Alcohol fuels were also perceived by users to be safer than kerosene and LPG, especially in relation to the risk of explosions *(117-119)*. However, use of poor-quality stoves (during the initial option appraisal stage – not used in evaluation study) *(113)* or unpatented/ not standardised models disseminated in Indonesia *(121)* raised safety concerns and fears about fire. In addition, despite the inclusion of denaturants which have a bitter taste, the issue of ingestion of fuel by children was not fully documented in the included studies and should not be overlooked until this has been more carefully evaluated, as the fuel may be purchased and stored in soft drink bottles *(120)*. The issue of adults obtaining ethanol fuel to augment or substitute alcoholic beverages is also reported, but to date little information is available on the potential or actual health risks *(120)*.

Cleanliness and home improvement: Increased home and kitchen cleanliness (from reduced smoke and soot) and improvement of indoor air quality were also reported as positive factors that can favour adoption *(113, 119-120)*.

Total perceived benefits: Alcohol fuels are considered high-quality fuels *(117)*, and convenience for cooking is valued by users *(118-120)*.

Tradition and culture: Some users complained about lack of smoky taste *(118)*, and in Madagascar there were some difficulties in cooking the full range of traditional foods during cooking tests *(113)*.

5.4.6 Domain 4: Financial, tax and subsidy aspects

Stove cost and subsidies: Both the upfront costs for stove purchase and the costs of fuel are considered to be high by users participating in these early-stage field studies *(113, 118)*. Although stoves were given free in these studies, the cost of imported stoves may be a barrier for many potential low- and middle-income users. However, locally manufactured stoves should help to reduce ethanol stove prices and facilitate initial adoption *(113, 121)*.

Fuel costs and subsidies: Among the key barriers to ethanol use were inadequate fuel availability on the local market, and a relatively high price. That said, one study found that full market-based pricing could still complete with traditional purchased fuels, notably charcoal in Madagascar *(113)*. Following a period of fuel being available free during feasibility studies, use of ethanol/methanol and willingness to continue paying for the fuel was variable and mostly influenced by household income *(118-119)*. Fuel cost was certainly a barrier for low-income households *(118)*, but an increase in demand irrespective of price rise over time was also reported for middle-income households in one study *(119)*. In addition, distance from fuel supply affected uptake *(118)*, which needs to be carefully considered when fuel is not produced in local distilleries and therefore needs to be imported or transported over relatively long distances *(113)*.

Programme subsidies: The included studies did not provide any direct empirical evidence on this aspect, as stoves were provided free during the small-scale feasibility studies. Similarly, fuel was donated to study participants. In Indonesia, abolition of national subsidies on existing fuels (e.g. on kerosene) could facilitate the switching to ethanol, as the fuel could be sold at a competitive price; local production also offers opportunities for local business development and jobs creation *(121)*.

5.4.7 Domain 5: Market development

Demand creation: Empirical evidence on effective mechanisms to enhance demand for alcohol fuels among prospective users is unfortunately very limited in the few available studies. The Indonesian study, however, suggested that marketing strategies for local communities and partnerships with local distributors could assist with market penetration *(121)*.

Supply chains: In terms of supply, investment in in-country production of ethanol and distribution was considered more important than issues of fuel importation *(120-121)*. Access to raw materials and local processing facilities are key to sustained ethanol production *(113, 121)*. Lack of a low-cost ethanol supply and the geographical distance between suppliers and users, limiting availability of fuel, were both reported to be barriers to uptake *(117-119)*. With regard to promoting local manufacturing of stoves, quality and safety issues must be carefully addressed before a successful local market can be set up *(113, 121)*.

Business and sales approaches: Selling ethanol stoves at a comparable price to kerosene/LPG stoves and increasing the availability of basic infrastructure (including feedstock processing and stove production facilities) could facilitate sales *(121)*. Aspirational LPG users may also provide a potential market for ethanol, as the possibility of buying ethanol in small quantities (i.e. by the litre rather than in bulk quantities needed for LPG refilling) was reported to be an incentive for prospective ethanol users taking part in the study *(118)*.

5.4.8 Domain 6: Regulation, legislation and standards

Regulation, certification and standardisation: National/regional legislation was found necessary to support fuel production, for example in providing market incentives for local ethanol micro-distilleries *(118)* and also for fuel transportation as regulations restricting transportation and distribution of alcohol-based liquids can create serious barriers to wider dissemination of this fuel *(121)*. Appropriate tax legislation for the use of ethanol as a household fuel (as opposed to use in alcoholic beverages) is very important if this fuel is to be affordable *(118)*.

Enforcement mechanisms: A few studies have emphasised the importance of appropriate enforcement of taxation strategy and standards for stoves and fuel storage, in order to ensure quality, functionality and safety of stoves and fuels *(113, 119, 121).* Lack of patented stove designs has resulted in imitated, poor quality stove copies being sold to customers, with consequent users' complaints as a result of having purchased defective and potentially risky devices *(121)*.

5.4.9 Domain 7: Programmatic and policy mechanisms

Institutional arrangements: Evidence of factors governing the success of ethanol introduction on a national market suggested that fuel availability, sustained production and price are important *(113, 118, 121)*. Findings showed that, if alcohol is to find a place as a household fuel, strategic large-scale investment and supportive polices are required to address local production (or importation), taxation, transport and sales *(118, 121)*. The 'overlap' with the legal and illegal alcohol beverage markets also needs to be institutionally regulated *(113)*.

Community involvement: Training in ethanol production (e.g. from local crops) and empowering local communities through business activities for wider dissemination were highlighted as a means of increasing production and promoting uptake *(121)*. It is important however that this be properly managed so agriculture for fuel production does not adversely impact on food crops and land use (see also equity considerations, below) *(120)*.

User training: The feasibility studies reported here paid special attention to training in stove use, fuel refilling and stove cleaning through frequent follow-up visits *(113, 119)*, and concluded that training in fuel refilling was particularly important to ensure safe use of fuel and stoves *(113, 119)*.

Monitoring and quality control: The role and importance of monitoring was not discussed among the included studies; however, it was acknowledged that quality control measures should be taken into account and these should include aspects such as feedstock processing *(121)*.

5.4.10 Equity considerations in relation to alcohol fuels uptake

The six studies included in this review offer limited evidence on the prospects for alcohol fuels (and in particular for ethanol) to reach poorer households, although some benefits of this are acknowledged and apply especially in rural settings. The development of local micro-distilleries for example, has the potential to help alleviate poverty among rural populations with access to the necessary feedstock crops, etc. *(118, 120)*. It was suggested in one study that an increase in family income might also help in discouraging farmers from moving to cities in search of job opportunities, thereby reducing rural-to-urban migration *(118)*. The studies in Madagascar recommended that use of land for sugar cane, cassava or other types of feedstock to produce bio-ethanol needs effective management and strategic, large-scale investment to ensure that high yields can be achieved sustainably, and non-interference with food crops *(120)*. The reports also suggested that this could be achieved through creation of medium- and small-scale biofuels enterprises, which should involve farmers and local communities to target poverty reduction *(120)*.

Gender and regional (urban/rural) issues in relation to adoption of alcohol-based fuels are not directly explored in the included studies, but similar considerations and benefits to those reported for other clean fuels can be envisaged in relation to alcohol fuel adoption.

5.5 Summary of findings in relation to Clean Fuels

5.5.1 Overview of main issues for uptake

A summary of the main issues for adoption and sustained use of the four clean fuels considered in this review is provided below.

- **LPG**: This is an aspirational fuel for many (if not most) households currently using solid or other liquid fuels (e.g. kerosene), but both the start-up costs and ongoing fuel costs are relatively high. Exclusive use for cooking is limited to higher income and mainly urban households, with lower income and rural populations using a mix of LPG and traditional (solid) fuels and stoves appropriate to their needs and financial circumstances. Issues of safety (and associated regulation), production vs. importation, oil price volatility, subsidy, demand and distribution/availability are critical determinants of the use of LPG that require a strong policy and management response.

- **Biogas**: Production and use of this fuel is constrained by a set of necessary conditions, including adequate numbers of livestock and suitable farming practices, water supply, climate (the technology does not function in low temperatures without costly enhancements) and labour to manage the digester. As a consequence, it is most suitable for rural households, although urban users are by no means excluded. Biogas systems are expensive to install (costs range from approximately US$180-500 depending on type, etc.), and substantial financial support was the norm for all programmes reviewed. Maintenance and repair services are also needed if the biogas plant is to function well over many years. When functioning well and appropriately maintained, the fuel is popular in everyday use and it saves on wood collection and/or purchase, provides fertiliser slurry, can be used for lighting and can be linked to a latrine which both improves sanitation and provides additional feed.

- **Solar**: This method of cooking can be very effective, but has restricted potential as experience shows that even among users familiar with solar cookers it generally only meets around 25-33% of cooking needs. It relies on high levels of sunshine and appropriate placement, and training of users to plan ahead for their cooking requirements, in particular given the need to use the cooker during the middle part of the day. It may, however, have more potential than realised so far as an option complementing other fuels and technologies, not least as it can save on fuel collection and costs, particularly of expensive clean fuels. To date production and marketing of low-cost, high-quality cookers has been constrained by what would appear to be piecemeal and poorly coordinated strategy.

- **Alcohols**: Ethanol is a relatively new household fuel for which there is less evidence than is the case for the other fuels reviewed here. As a consequence, firm conclusions cannot currently be drawn as to the situations and circumstances where it is most likely to succeed, but as a renewable, safe, clean and relatively cheap fuel (compared to LPG) it would appear to have considerable potential certainly for urban settings and possibly also for rural areas. Although it can be produced from a wide range of feedstock, land competition with agricultural production and excise (pricing) issues arising from the need to separate its use as a fuel from the legal and illegal alcoholic beverage markets present challenges, and should be priorities for strong and consistent policy.

5.5.2 Costs associated with uptake of clean fuels

The costs of switching to and continuing to purchase clean fuels are among the more important factors determining adoption, the extent to which these fuels are used (that is, the proportion of cooking done with clean compared to traditional fuels), and sustained use. Broadly, there are three components to these costs: (i) the initial outlay for the technology, (ii) the ongoing purchase of fuel (when applicable), and (iii) system maintenance; these vary significantly between the fuel types and are summarised in **Table 5.** Furthermore, as a consequence of the high costs of one or more of these components, factors impacting on affordability including subsidy, credit arrangements and loans have been found to be very important for adoption and sustained use. These are complex and – particularly in the case of subsidy – controversial areas of policy.

Table 5: Costs associated with clean fuel adoption and use

Fuel	Initial costs	Ongoing costs
LPG	High cost of stove, pipe, regulator and gas bottle, although small bottles with a single burner can be more affordable.	Refill of LPG bottles is costly, and linked to fluctuating oil prices. For most systems, the bottles are exchanged, requiring payment for the full contents of the bottle. Generally low maintenance costs.
Biogas	Very high cost of construction of biogas plant, piping and stove; substantial capital financial support for installation has been the norm, however.	With sufficient livestock or other suitable feed, fuel costs are zero, but labour is required to manage and maintain the plant. Repairs may be (very) costly.
Solar	Moderately high cost for high-quality stoves, particularly those imported.	No fuel cost, and if good quality the stove should be maintenance-free.
Ethanol/ Methanol	High cost of stove, especially of the high-quality imported models, but in contrast to LPG the fuel storage bottle can be relatively cheap.	Fuel costs are lower than for LPG and can compete with charcoal. Low maintenance cost.

6. Discussion

This review has described the evidence on factors affecting the uptake of improved solid fuels stoves and clean fuels, assessed through a mixed-method systematic review based on 101 studies from 29 countries in all developing and middle-income countries. In this section, we consider the extent to which the relative importance of the identified factors can be ascertained, the degree of commonality in factors across solid fuel stoves and the four types of clean fuels, and how the nature and quality of evidence available affects reliability and generalisability of the findings.

6.1 Relative importance of enabling and limiting factors

The range of factors identified across domains for ICS and each of the four clean fuels is summarised in **Table 6**. This may present a challenge for efficient policy-making, and as a consequence the question of which of these factors is most important is critical.

As noted in section 3.5, prioritisation requires both a suitable method and an evidence base that supports such assessment, and it is not clear that either of these is available. Specifically, the heterogeneity inherent in this set of studies makes comparative assessment difficult, and only the quantitative studies using multivariable regression provide any formal analysis of independently associated factors. Yet, even then, outcomes vary considerably across studies, so combining this evidence to rank factors would not be reliable. Consistency of findings offers some guide to importance, but many factors fulfil this criterion, and lack of evidence does not mean a factor is unimportant. An example of this last point is that relatively few studies report on standards and regulation, but this is more a reflection of the historical lack of policy attention in this field, which is quite counter to the effort now being put into developing stove standards with ISO along with regional testing centres and the national regulation governing certification which can be expected to follow[5]. Consequently, attempts to identify the most important factors are bound to rely mainly on judgement at this stage.

Against this background of methodological constraint on prioritisation, the assessment of the evidence as reported in sections 4 and 5, suggests that **all domains** and **all the identified factors** within them can influence adoption and/or sustained use of improved solid fuel stoves and clean fuels, although the extent of that influence is often dependent on the setting and specific stove/fuel combination. While some of these factors would appear critical, such as affordability and the ability of the technology to cook traditional meals, meeting these criteria does not guarantee that a stove or fuel will be adopted, or that it will be used in a sustainable way. Such factors can therefore be considered **necessary** but **not sufficient**, and indeed many other factors play a part in ensuring adoption and continuity of use over time.

For example, even if a woman is initially encouraged to purchase an improved stove and is able to pay for it, if the stove does not suit her family's needs and the more common foods cannot be prepared, the stove will not be used on a regular basis. Even if it meets all these requirements and she begins to use it, if the stove breaks after a year of use and she cannot afford to repair it, or has no access to parts and the necessary assistance, it will fall into disuse. Therefore, while affordability (whether as a result of price, household income, availability of finance, or a combination of these) and meeting users' needs are prerequisites for success, many other factors from across the domains will ultimately determine whether households adopt, use, maintain and replace improved stoves and clean fuels over time, and the extent to which these interventions displace traditional stoves and fuels. Which is the necessary combination of factors depends on the settings (e.g. households and community targeted, local/national policies), circumstances (e.g. programme and support frameworks) and, of course, fuels and technologies used.

This suggests that, rather than attempting to identify a small number of critical factors, a systematic and systemic assessment of the domains and corresponding factors should be carried out in order to identify those factors that are most relevant to the setting/programme under consideration. Additionally, some factors operate primarily at household and community level while others operate primarily at programme and societal level, indicating that both levels need to be taken into account during planning and implementation.

6.2 Common and distinct factors for solid fuel stoves and clean fuels

As shown in **Table 6**, the vast majority of factors are common to all or most of the interventions. Indeed, it is surprising that uptake and sustained use of such different technologies are largely determined by the same factors operating across the seven domains. Yet there are also a few

[5] See www.cleancookstoves.org/blog/standards-and-testing-2012-highlight-and-2013-outlook.html and www.iso.org/iso/catalogue_detail?csnumber=61975

important differences, which usually reflect specific requirements for one or more of the clean fuels. For example, for all technologies stove and fuel costs play an important role in influencing uptake. Indeed, characteristics of the fuel and cooking technology itself have the potential to act as enablers or serious barriers to adoption and use. High-quality design and construction, in particular, is critical for meeting users' needs and, ultimately, for significantly reducing emissions and improving safety across ICS, LPG gas stoves, and ethanol, biogas and solar cookers. On the other hand, safety aspects associated with risk of burns and fires are more relevant for solid fuel stoves, while explosions are more relevant to LPG (and to some extent alcohol stove use), and less relevant to biogas and solar cookers). The availability of livestock and land to build a digester is a critical determinant of biogas adoption, and is a factor specific to that fuel.

Absence of evidence for some of the listed factors, especially for LPG, solar cookers and alcohol fuels, must be treated with caution, as this may be a result of the more limited number of included studies. Specifically, very few quantitative and qualitative studies were identified for these fuels.

Table 6: Common and distinct factors influencing uptake of ICS and clean fuels

Domains	Factors influencing uptake	ICS	Clean fuels			
			LPG	Biogas	Solar cookers	Alcohol fuels
Fuel and technology characteristics	Fuel savings	✓	✓	✓	✓	-
	Impacts on time	✓	✓	✓	✓	✓
	General design requirements	✓	✓	✓	✓	✓
	Durability/specific design requirements	✓	-	✓	✓	✓
	Fuel requirements	✓	-	-	-	-
	Operational issues	-	-	✓	✓	-
	Safety issues	-	✓	✓	-	✓
Household and setting characteristics	Socio-economic status	✓	✓	✓	✓	✓
	Education	✓	✓	✓	-	-
	Demographics	✓	✓	✓	-	-
	House ownership and structure	✓	✓	✓	✓	-
	Land and animal ownership	-	-	✓	-	-
	Multiple fuel and stove use	✓	✓	✓	□	✓
	Geography and climate	✓	✓	✓	□	-
Knowledge and perceptions	Smoke, health and safety	✓	✓	✓	✓	✓
	Cleanliness and home improvement	✓	✓	✓	-	✓
	Total perceived benefit	✓	✓	✓	✓	✓
	Social influence	✓	-	✓	✓	-
	Tradition and culture	✓	✓	✓	✓	✓
	Environmental and agricultural benefits	-	-	✓	-	-
Financial, tax and subsidy aspects	Stove costs and subsidies	✓	✓	✓	✓	✓
	Fuel costs and subsidies	-	✓	-	-	✓
	Payment modalities	✓	✓	✓	✓	-
	Programme subsidies	✓	✓	✓	✓	✓
Market development	Demand creation	✓	✓	✓	✓	✓
	Supply chains	✓	✓	✓	✓	✓
	Business and sales approach	✓	✓	✓	✓	✓
Regulation, legislation and standards	Regulation, certification and standardisation	✓	✓	✓	-	✓
	Enforcement mechanisms	✓	✓	✓	-	✓

Domains	Factors influencing uptake	ICS	Clean fuels			
			LPG	Biogas	Solar cookers	Alcohol fuels
Programmatic and policy mechanisms	Construction and installation	✓	-	✓	-	✓
	Institutional arrangements	✓	✓	✓	✓	□
	Community involvement	✓	-	-	□	□
	Creation of competition	✓	-	✓	-	-
	User training	✓	✓	✓	✓	✓
	Post-acquisition support	✓	✓	✓	✓	-
	Monitoring and quality control	✓	✓	✓	✓	✓

6.3 Impact of perceived opportunity cost of time

A theme found to be particularly important across all five interventions is the influence of perceptions about opportunity cost (particularly in relation to time savings) on adoption of interventions, and the implications of this for policy.

Improved stoves and clean fuels can save time in two main ways, first by reducing fuel collection time and second through more efficient cooking processes. The latter can arise from the ability to cook faster with controllable power and/or through use of multiple pots simultaneously. This aspect is usually highly valued by women and it is a direct benefit that users recognise in almost all the circumstances studied. Moreover, the ability to leave food unattended while cooking with an improved fuel and/or technology enables them to perform additional tasks in the house. With respect to time savings from biomass collection the evidence is mixed but there were multiple examples where the greater availability of labour – and in particular where this involved women and those with less education (i.e. often not in paid employment) – was associated with a low 'value' assigned to the potential time savings. Consequently, the time and other savings from more efficient stoves or modern fuels such as LPG provided less incentive for switching than might have been anticipated. Conversely, there was evidence that where women were engaging in paid employment, the time saving from use of modern fuels was a positive incentive to adoption.

This suggests that programme planning should include assessment of how time savings are valued, followed up by engagement with prospective users to see whether and how, appreciation of the opportunity costs of inefficient fuel collection and cooking can be increased. By contrast, households that purchase rather than collect wood or other commercial fuels are more likely to adopt an improved stove with demonstrably better fuel efficiency, as monetary savings are directly experienced and more highly valued by those already paying for the fuel.

It should be acknowledged that this issue does not appear to have been extensively studied, and a first step would be to review existing research in related areas of development (with a focus on rural communities and women's time), in order to assess the need for further research on the importance and policy implications of directly addressing opportunity cost valuation as a means to stimulate demand for more time-efficient households energy technologies and fuels.

6.4 Relevance of findings to more advanced technologies and products

This section is concerned with the question of whether findings regarding the uptake of improved solid fuel stoves derived for stoves of uncertain effectiveness provides a valid basis for determining the factors influencing adoption and sustained use of more effective technologies, for example low-emission forced draught stoves. It is likely that despite the absence of recent empirical evidence specific to more modern technologies, the findings reported in section 4 (ICS) are relevant for the following reasons, although some caution is needed. Effectiveness (especially fuel and cost savings and cleanliness), quality, modernity and similar attributes are highly valued by users. As these are (or can be) characteristics of the more modern stove types, it can be expected that this will reinforce demand and continued use. On the other hand, if more advanced solid fuel stoves and clean fuel systems do not meet user needs and are not accompanied by the necessary services and support, they can be expected to fail.

The other critical factor is price, which could easily exclude low income homes from these improved technologies. This is, however, a complex issue as large-scale production should reduce price (and improve quality), while innovations in financing for both suppliers and potential consumers can clearly be effective in extending access and will need to play a role in future efforts. These points support the view that assessment of the same set of factors should be relevant to currently available modern ICS types and also for clean fuels (and accompanying stoves, storage methods, etc.), as well as to those which will emerge over the coming months and years.

Similar arguments apply to specific types of ICS that are presented in the evidence reviewed. Although it is conceivable that specific findings or recommendations could be made for particular stove types, it must be borne in mind that in any given setting the actual model, cooking and other needs from the stove, fuel availability, delivery mechanism and support, together with the household and community circumstances, will all vary and any one of these may influence success or otherwise. Again, the most practical and effective approach would appear to be to assess the range of factors across all domains, as relevant to the settings and technology, and to plan accordingly.

6.5 Causal linkage or association?

Given the predominant study designs identified in this review, the majority of the findings obtained through individual studies should be seen as associations, rather than as causal linkages. It is principally through the combination of studies, in terms of their multiplicity across settings and different study types (qualitative, quantitative, policy and case studies), that we can draw some conclusions about likely causal effects.

Factors which are identified consistently in different countries and regions, in different types of study, and as enabling (when present/satisfactory) and limiting (when absent/unsatisfactory) are more likely to be causal. Furthermore, qualitative findings will often provide a different perspective, giving explanations for why factors influence adoption and use, which further strengthens the understanding of and therefore the case for causality.

Also, the specificity of some findings, for example the need for training and demonstrations to enhance adoption and use of solar cooking or the need for adequate finance, land and cattle for expensive biogas plants, makes it hard to advance any explanation other than that these factors are having a causal effect on adoption and/or sustained use.

There are, of course, many inter-relationships between the factors identified, and it is impossible to reliably disentangle which are most important. In some of the quantitative studies, multivariable regression methods were used to identify independent associations, but not all quantitative studies employed these methods. Qualitative studies use different perspectives for understanding causation, and few of the case or policy studies presented such detail in analysis. Furthermore, it is through an understanding of these inter-relationships that meaningful and ultimately effective policy can be developed.

6.6 Factors impacting on adoption and sustained use

It is now widely recognised that, while many stove (and some clean fuel) projects and programmes have achieved a degree of adoption across the communities in which they have worked, sustained use, maintenance and replacement have been much less successful. The majority of identified studies provided information on short-term adoption among relatively small-scale projects and programmes, although some studies also provided information on longer-term use. Nevertheless, there are examples where large-scale adoption (such as in China, India and Indonesia) and sustained use (for example in Nepal and Bangladesh for biogas, Brazil for LPG) have taken place. These examples provide important evidence on aspects of scale and sustainability.

Among the clean fuels, studies on biogas offered useful information about biogas production and use over time, collected during inspection of biogas plants and assessment of their functionality several years after installation, some extending for as long as ten years. Another issue that influences which factors emerge as important for longer-term use is that adopters become a selected group – if those adopting a new technology are predominantly homes with higher incomes, then income may not be identified as influential in determining sustained use and other factors that differ across the 'adopter' group may come into play. The process of adoption and sustained use is dynamic, and takes place at different rates and at different times across the various socio-economically and culturally defined segments of society. Assessment of the status of adoption and change over time within a community, region or country should form part of the planning process outlined in section 7.

Several identified factors clearly impact on initial acquisition of improved household energy options, such as initial cost, access to credit, availability of space or land to build a built-in improved stove or a biogas digester, and user training for correct and safe use of technology. Some of these, notably those concerning price and availability, will also impact on replacement. Other factors, such as the quality of material used for construction/installation, daily operation and maintenance, fuels savings over time, post-acquisition support and costs associated with repairs, mainly impact on sustained use, although experience of these among existing users will also influence prospective new adopters through social networks – sometimes strongly so.

There are a number of factors which influence the initial decision for acquisition as well as longer-term use. In the case of biogas, for example, availability of feedstock is a motivating factor for plant installation, but it is also an important determinant of security of gas production over time to meet family needs. In addition, supply chains and infrastructure make improved technologies initially accessible to users, but also favour re-purchasing of stoves or stove-parts, availability of spare parts for repairs and follow-up visits by technicians.

6.7 Overall quality and strength of evidence

The methods used to assess quality of individual studies according to study design based on established criteria are described in section 2.4. The quality for this body of evidence was variable and the methodological limitations acknowledged. However, with 17 out of 19 qualitative studies, 17 out of 22 quantitative studies and 47 out of 60 case/policy studies scoring moderate to strong quality respectively, many of these studies provided useful and reliable information.

This section focuses on providing an assessment of the strength of the overall body of available evidence as a basis for making recommendations. The nature of the evidence available does not lend itself to assessment with the GEPHI scoring system, however, the GRADE domains were useful as a guide to assess quality.

***Study designs*:** The available evidence is drawn from a wide range of study designs, namely randomised trials, before-and-after studies, cross-sectional surveys, economic and survival analysis, in depth and semi-structured interviews, focus group discussions and several mixed-methods studies. While the studies were not always designed primarily to answer questions about adoption (e.g. some of the health studies) the majority were, and the designs used were generally appropriate for the purpose with the caveat of a lack of longer-term prospective studies of sustained adoption. The extent to which findings from these varies study designs are consistent is considered below.

Risk of bias*:* Quality assessments were conducted according to established criteria for each study design. A proportion of quantitative studies used sampling that may not have been representative, and some used only simple descriptive (unadjusted) analysis, but are expected to be of high internal validity. It was not possible to perform a formal assessment of risk of bias for the qualitative or case studies, but there was reasonable coherence of findings across study designs, discussed further below. The sensitivity analyses carried out with and without the studies assessed to be weak in terms of quality, found no major change to the findings; this assessment also supports the conclusion that there is no serious risk of bias.

Inconsistency: Quantitative assessments of inconsistency (i.e. by measures of statistical heterogeneity) were not possible across this body of evidence, but an indirect assessment was made, based on evidence reported during the data extraction and synthesis process. Studies which were 'out of line' with the majority of studies were noted in the initial synthesis stage. An assessment of the records and the overall synthesis based on combined study designs show that inconsistency among studies of similar interventions in comparable settings was uncommon, and it is concluded that inconsistency is not a major issue.

Imprecision: This relates to the power of the combined studies. For quantitative studies, the individual sample sizes and their representativeness were summarised, with 19 out 22 studies having a sample size of 200 or more individuals (including surveys conducted with a sample of over 1000 individuals); assessment of an overall pooled effect is not feasible or appropriate due to the different interventions and outcomes. For qualitative evidence, sample size is not relevant as meaningful information can be obtained from a small number of study participants identified through a purposive or snowball approach. For case and policy studies, it was possible to assess precision of some elements of the data used (e.g. quantitative components of studies) when this information was reported. Some of the case studies made use of cross-sectional or longitudinal surveys, with 17 studies based on a sample size of 200 or more individuals). For ICS, all domains and most factors were well supported by evidence. For the clean fuels, the situation was more variable: LPG and biogas each had a fairly strong evidence base across domains, but for solar cooking and especially alcohol fuels, rather less so.

Publication bias: This cannot be assessed in the formal way used for quantitative systematic review using funnel plots and statistical tests, but publication bias may nevertheless be present. While it was therefore not possible to determine whether there is a bias towards not publishing unsuccessful programmes, but there were multiple examples of projects and programmes with mixed experience of adoption and sustained use. A related form of publication bias may arise from non-peer reviewed (and at a less extent also from peer-reviewed) reports published by authors who have managed or were otherwise very close to the implementation process. Only one fifth of the included studies were peer-reviewed, with the rest being research reports, dissertations, conference proceedings and book chapters. About 12 out of the 101 included studies seem likely to have been written and/or published by authors closely associated with the implementing programme/agency. It was reassuring to find no marked differences in findings between these two groups of publications, other than case studies (which were less likely to be peer-reviewed) usually focusing on a wider spectrum of factors influencing uptake and including the domains concerned with regulation, certification and institutional arrangements.

6.7.1 Consistency of evidence

One of the additional criteria proposed with GEPHI was recognition of similar findings among studies conducted using different designs, and across multiple settings. This appears to be a feature of this set of studies:

- *Consistency of evidence from multiple study designs*: findings supported by more than one study type are likely to be more valid or of greater relevance than findings supported by a single study type. This is one of the strengths of this evidence base as reported in the discussion, although in terms of consistency it is weaker for some of the clean fuels (in particular alcohol fuels) due to the limited available evidence.

- *Consistency of evidence from multiple settings*: findings supported by studies carried out with very distinct interventions, settings, socio-economic and cultural contexts are likely to be more valid or of greater relevance than findings supported by a single study type. Studies were identified across Africa, Asia and Latin-America which is an additional point of strength of this evidence base.

6.7.2 Analogous evidence

A second criterion proposed in GEPHI was taking account of the contribution of analogous evidence. Although there may be some useful ‘analogous’ evidence from interventions in the household environment requiring similar combinations of technology enhancement and behavioural change, e.g. from the water and sanitation field, the relevance of this to adoption and sustained use of household energy interventions has not been formally assessed in this review (or elsewhere to our knowledge) and is not drawn upon in this assessment of evidence. It would be useful to conduct such a review in future.

6.7.3 Other GRADE domains for assessing quality

There are other GRADE domains for assessing quality of evidence which could not be considered in the assessment of this set of studies. While a large effect can lead to upgrading, this was not relevant as too few (quantitative) studies have provided comparable effect estimates and no attempt to pool such effects was made. Plausible confounding can weaken observed effects and if present, potentially lead to upgrading, but this was not consistently assessed across studies and could not be evaluated. Finally, investigation of an exposure-response relationship was not supported by data, and could not be considered.

6.7.4 Summary

This assessment suggests that the overall set of evidence does provide a consistent and moderately strong basis for drawing conclusions about the design and delivery of programmes to ensure more effective adoption and use of improved solid fuel stoves and cleaner fuels. Among clean fuels, the evidence for alcohol fuels and to a lesser degree for solar cooking, is weaker. It is also notable that no studies of adoption of newer ICS technology (i.e. advanced combustion fan-stoves) were available, but as discussed in section 6.4 above, the same domains and factors can be expected to apply.

7. Conclusions and Recommendations

7.1 Translating findings into a policy implementation and evaluation tool

This review has reported on the enabling and limiting roles of a wide range of factors under seven domains, and found that, although some are critical for success, none guarantee this. It is therefore important to consider all factors that are likely to be relevant in a given setting, and with respect to a specific technology or fuel. Interactions are noted as important, and may operate at the level of individual factors (within and between domains), but also between domains and sets of domains. It is important to recognise that some factors primarily act at the household or community level (e.g. 'Household and settings characteristics'; 'Knowledge and perceptions') whereas other factors primarily act at the regional, national and international level (e.g. 'Financial, tax and subsidy aspects'; 'Regulation, legislation and standards'). Since all domains impact in a significant way on whether programmes reach their intended populations and whether they achieve sustained adoption and use, this suggests that the connection between local and national levels is important, if programmes are to be successful at scale and over extended periods of time.

The findings from this review provide the basis for the development of a policy planning tool to assess all domains and constituent factors at household and community level as well as regional, national or international level. The tool would consist of domains and key factors being organised in a framework conforming to the main stages in the development and implementation of policies and programmes for increasing access to ICS and clean fuels.

A proposal for the content of this tool is presented on the online publication (2), covering seven key components. Such a tool would be applicable to both programme planning and in the evaluation of programmes that have already been implemented. The tool would need to developed and subsequently tested and could employ a software interface to ensure that unnecessary data collection is avoided.

7.2 Needs for extending the evidence base

A number of issues have been identified with regards to limitations in the available evidence, and recommendations are made here to address the most important among these. Two general recommendations emerge. First, intervention programmes or initiatives should establish the effectiveness of the stoves and fuels, in particular in relation to reducing emissions and exposure to household air pollution in absolute terms/concentrations, but also in relation to fuel efficiency and safety, prior to embarking on large-scale dissemination. Second, such programmes should be accompanied by robust monitoring and evaluation efforts, which should also include a component of assessing emissions and concentrations in situ, and in selected cases, by studies designed specifically to investigate factors that enable or limit uptake. More specifically, key recommendations for future research are:

- There is a need for an upfront, comprehensive research agenda to accompany large-scale regional, national or global initiatives, addressing (i) research and development (R&D) for technology (where applicable), (ii) effectiveness and (iii) uptake. This should increase the range of perspectives, involving all major stakeholders (which may include beneficiaries, civil society, government and industry).
- Studies investigating uptake should clearly distinguish between adoption, initial use and longer-term sustained use. There is a need for longitudinal studies to investigate sustained use and, where applicable, reacquisition of technology rather than short-term adoption. For ICS, there is a particular need for studies of sustained use. For clean fuels, we have identified numerous studies on sustained use of biogas (although almost exclusively in Asian countries), whereas for the remaining clean fuels most of the evidence relates to the initial switch and short-term use.
- Due to the timing of the review, no studies were available on the adoption and use of advanced combustion biomass stoves (e.g. forced draft or semi-gasifier models), technologies which hold promise of delivering much lower levels of emissions. It is important to include this group of technologies in the next round of adoption studies for ICS.
- While there is a reasonable amount of evidence on ICS and biogas (although more in some settings than others), there is still very limited empirical evidence on adoption and use of other clean fuels. One critical aspect requiring increased attention is the fuel-stacking phenomenon and the factors that may influence a more rapid and complete transition to exclusive or near-exclusive use of clean fuels.
- Some of the described domains are much more densely populated with evidence than others. Future intervention programmes and initiatives should strive towards a more comprehensive approach, looking at all domains that are relevant to the setting and interventions concerned. Given the findings of this review, it is recommended that all seven domains be included, as well as incorporating an equity perspective.

ANNEX 1: Characteristics of included studies on ICS, by study category

Author (year) ***(reference no.)***	**Country/ setting**	**Study design and sampling**	**Data collection**	**Data analysis***	**Quality appraisal#**	**Improved stove technology**			**Adoption (A) vs sustained use (S)**
						Stove type	**Potholes**	**Stove ventilation**	
				QUALITATIVE STUDIES (QL)					
Anderson (2007) *(31)*	India (rural)	Ethnographic case study: FGDs, 3 SSIs, 2 KIIs, PO	Interviews and FGDs with women users and non-users	Editing analysis	Strong	Bhagyalaxmi stoves (cement)	2	×	S
Chowdhury et al. (2011) *(33)*	Bangladesh (rural)	70 SSIs, 1 FGD, PO	Face-to-face survey and FGD with women users and non-users	Method not stated; descriptive narrative and tables	Weak	Mud stoves	2	✓	A/S
Christoff (2010) *(41)*	Mexico (rural)	4 FGDs	FGDs with women users	Thematic analysis	Strong	Patsari stoves Onil stoves	Multiple 1	✓ ✓	A
Gordon et al. (2007) *(36)*	Mongolia (urban)	3 FGDs, 6 SSIs	Mixed-gender FGDs with users and non-users	Editing analysis	Strong	Coal stoves	Not specified	✓	A
Jagoe et al. (2006a) *Qualitative findings (32)*	India (rural)	FGDs at baseline and follow-up	Separate FGDs with men and women users	Framework analysis	Moderate	Anandi stoves Sukhad stoves	1 2	✓ ✓	A
Jagoe et al. (2007a) *Qualitative findings (44)*	India (rural)	FGDs at baseline and follow-up	FGDs with women users and non-users	Framework analysis	Moderate	Bhagyalaxmi stoves Laxmi stoves	2 2	× ✓	A
Pandey (1989) *(55)*	Nepal (rural)	25 SSIs, PO	Interviews with women users and non-users	Method not stated; descriptive narrative	Moderate	Bikase stoves	2	×	A/S
Person et al. (2012) *(34)*	Kenya (rural)	40 SSIs	Interviews with women purchasers and stove promoters	Thematic analysis	Strong	Upesi Jiko charcoal stoves	1	×	A
Sesan (2012). *Findings on ICS (62)*	Kenya (urban**)	15 SSIs, 9 KIIs, PO	Interviews with women users	Method not stated; descriptive narrative	Moderate	Mainly Upesi Jiko charcoal stoves with/without eaves space	1	×/✓	A
Simon (2007) *(35)*	India (rural)	55 SSIs, 11 KIIs, PO	Interviews with women users, stove builders and stakeholders	Method not stated; descriptive narrative	Strong	Bhagylaxmi and Laxmi stoves and other models	1, 2	×/✓	A/S
Sovacool and Drupady (2011) *Findings on ICS (40)*	Bangladesh (rural/urban)	Case study based on 48 SSIs/KIIs	Interviews with users and stakeholders	Narrative analysis	Moderate	Clay stoves	1–3	✓	A/S
Troncoso et al. (2007) *(39)*	Mexico (rural)	67 SSIs, 18 KIIs	Interviews with women users and non-users	Method not stated; descriptive narrative and tables	Moderate	Patsari stoves	Multiple	✓	A

Author (year) ***(reference no.)***	**Country/ setting**	**Study design and sampling**	**Data collection**	**Data analysis***	**Quality appraisal#**	**Improved stove technology**			**Adoption (A) vs sustained use (S)**
						Stove type	**Potholes**	**Stove ventilation**	
Troncoso et al. (2011) *(48)*	Mexico (rural)	24 KIIs	Interviews with stakeholders, including stove builders	Method not stated; descriptive narrative	Moderate	Patsari stoves	Multiple	✓	A
Velasco (2008) *Findings on ICS (43)*	Mexico (rural)	24 SSIs, PO	Interviews with women users	Method not stated; descriptive narrative	Moderate	Patsari stoves	Multiple	✓	A
QUANTITATIVE STUDIES (QN)									
Agurto-Adrianzen (2009) *(60)*	Peru (rural)	Cross-sectional survey (n=816); stove monitoring survey (n=82% of beneficiaries)	Interviews with heads of household (users/non-users)	Multivariable approach adjusting for confounders	Strong	Mud brick and metal frame/plate stove	Multiple	✓	A
Bensch and Peters (2011) *(61)*	Senegal (urban)	Cross-sectional survey (n=624) and KII	Interviews with users/non-users	Analytical approach without adjustment	Moderate	Portable Jambar charcoal stoves	Not specified	×	A
Damte and Koch (2011) *(57)*	Ethiopia (urban)	Cross-sectional survey (n=1577)	Interviews with users/non-users	Multivariable approach adjusting for confounders	Strong	Mirt Injera stoves Portable Lakech charcoal stoves	1 Not specified	× Not specified	S
George and Yadla (1995) *(64)*	India (rural)	Cross-sectional survey (n=390)	Interviews with main cooks	Descriptive comparison and analytical approach without adjustment	Weak	Mamta stoves	2	✓	A
Inayatullah (2011) *(63)*	Pakistan (rural)	Cross-sectional survey (n=100)	Interviews with male respondents	Multivariable logistic regression	Moderate	Biomass metal stoves	1	×	A
Jagoe et al. (2006b)*Quantitative findings (38)*	India (rural)	Before-and-after study (12 months) without control group (n=150)	Structured questionnaires at baseline, follow-up at 3 and 12 months	Analytical approach without adjustment	Weak	Anandi stoves Sukhad stoves	1 2	✓ ✓	A
Jagoe et al. (2007b)*Quantitative findings (42)*	India (rural)	Before-and-after study (12 months) with interventions and controls (n=156 + n=98)	Structured questionnaires at baseline, follow-up at 6 and 12 months	Multivariable approach adjusting for confounders	Moderate	Bhagyalaxmi stoves Laxmi stoves	2 2	× ✓	A
Levine and Cotterman (2012) *(53)*	Uganda (urban)	Randomised trial of multiple sale offers (n=1690)	Interviews with households during marketing visits	Multivariable approach adjusting for confounders	Moderate	Ugastove charcoal stoves	1	×	A
Miller and Mobarak (2011) *(28)*	Bangladesh (rural)	Randomised controlled trial (n=3079)	Interviews during marketing visits	Multivariable approach adjusting for confounders	Strong	Mud stoves Clay stoves	1 2	× ✓	A
Muneer and Mohamed (2003) *(65)*	Sudan (rural/urban)	Cross-sectional survey (n=300)	Interviews with wife and husband in household	Multivariable approach adjusting for	Strong	Firewood/charcoal stoves	Not specified	Not specified	A

Author (year) *(reference no.)*	Country/ setting	Study design and sampling	Data collection	Data analysis*	Quality appraisal#	Improved stove technology			Adoption (A) vs sustained use (S)
						Stove type	Potholes	Stove ventilation	
				confounders					
Mwangi (1992) *(59)*	Kenya (rural)	Cross-sectional survey (n=306)	Interviews with heads of household	Multivariable approach adjusting for confounders	Moderate	Kenya Ceramic Jiko charcoal stoves Portable Kuni Mbili stoves	1 1	✗ ✗	A
Pandey and Yadama (1992) *(29)*	Nepal (rural)	Cross-sectional survey (n=100)	Interviews with women users	Analytical approach without adjustment	Weak	Bikase stoves	2	✗	A
Pine et al. (2011) *(11)*	Mexico (rural)	Longitudinal study with baseline and monthly follow-up surveys (n=233)	Interviews with users over 10 months	Univariate multinomial logistic regression	Moderate	Patsari stoves	3	✓	A
Pushpa (2011) *(66)*	India (rural)	Cross-sectional survey (n=492)	Interviews with users/non-users	Analytical approach without adjustment	Weak	Several stove models	Not specified	✓	A
Silk et al. (2012) *(67)*	Kenya (rural)	Cross-sectional surveys (n=1,250) and follow-up (n=293)	Interviews with women; follow-up with purchasers	Analytical approach without adjustment	Moderate	Upesi Jiko biomass and charcoal stoves	1	✗	A
Wallmo and Jacobson (1998) *(30)*	Uganda (rural)	Cross-sectional survey (n=165)	Interviews with users/non-users	Descriptive comparison and analytical approach without adjustment	Weak	Lorena stoves	3	✓	A
CASE/POLICY STUDIES (CS)									
Amarasekera 1989 *(15)*	Sri Lanka (rural/urban)	Surveys (n=not stated)	Not described	Descriptive narrative	Weak	Several mud stove models	1, 2	✗	A
Barnes et al. (2012a). *Case study I (16)*	India, western Maharashtra (rural/urban)	Mixed-method approach: household survey (n=73) and FGDs, SSIs, KIIs	Interviews and FGDs with users and non-users, stove builders and other stakeholders	Descriptive narrative and statistics	Strong	Laxmi, Grihalaxmi, Parvati and Bhagyalaxmi stoves Portable Priagni stoves	1, 2 1	✓/✗ ✗	S
Barnes et al. (2012b). *Case study II (17)*	India, Haryana (rural/urban)	Mixed-method approach: household survey (n=94) and FGDs, SSIs, KIIs	Interviews and FGDs with users and non-users, stove builders and other stakeholders	Descriptive narrative and statistics	Strong	Mud and cement stoves	1, 2	✓	S
Barnes et al. (2012c). *Case study III (18)*	India, Karnataka (rural/urban)	Mixed-method approach: household survey (n=190) and FGDs, SSIs, KIIs	Interviews and FGDs with users and non-users, stove builders and other stakeholders	Descriptive narrative and statistics	Strong	Astra Ole and Sarale Ole stoves (mud) Portable Priagni, Swosthee and Chara Ole stoves	1, 2 Not specified	✓/✗ ✗	S
Barnes et al.	India, Gujarat	Mixed-method	Interviews and FGDs	Descriptive	Strong	Mamta, Supriya,	1, 2	✓/✗	S

Author (year) *(reference no.)*	**Country/ setting**	**Study design and sampling**	**Data collection**	**Data analysis***	**Quality appraisal#**	**Improved stove technology**			**Adoption (A) vs sustained use (S)**
						Stove type	**Potholes**	**Stove ventilation**	
(2012d). *Case study IV (19)*	(rural/urban)	approach: household survey (n=79) and FGDs, SSIs, KIIs	with users and non-users, stove builders and other stakeholders	narrative and statistics		Priya, Kiran, Sneha, Grihalaxmi and Kamdhenu stoves			
Barnes et al. (2012e). *Case study V (20)*	India, Andhra Pradesh (rural/urban)	Mixed-method approach: household survey (n=134) and FGDs, SSIs, KIIs	Interviews and FGDs with users and non-users, stove builders and other stakeholders	Descriptive narrative and statistics	Strong	Sukhad, Gayathri and Gramalakshmi stoves Portable stoves	2 Not specified	✓/✗ ✗	S
Barnes et al. (2012f). *Case study VI (21)*	India, West Bengal (rural/urban)	Mixed-method approach:househol d survey (n=100) and FGDs, SSIs, KIIs	Interviews and FGDs with users and non-users, stove builders and other stakeholders	Descriptive narrative and statistics	Strong	Mud/cement biomass and coal stoves; Portable stoves	1–3 Not specified	✓/✗ ✗	S
GERES (2009) *(22)*	Cambodia (urban)	Mixed-method approach: cross-sectional survey (n=1,600) and SSIs (n=51)	Interviews with users and stove builders	Descriptive narrative and statistics	Strong	New Lao charcoal stoves	1	✗	A/S
Kürschner et al. (2009) *(23)*	Bangladesh (rural/urban)	Mixed-method approach: surveys, interviews, FGD (n=450 overall)	Interviews with users, non-users and stove builders	Descriptive narrative	Moderate	Mud/clay stoves	1, 2	✓	A/S
Masera et al. (2005) *(54)*	Mexico (rural)	Cross-sectional survey (n=42)	Interviews with users	Descriptive narrative	Moderate	Patsari stoves	Multiple	✓	A
Mounkaila (1989) *(24)*	Niger (urban)	Survey and KIIs (n=unknown)	Not described	Descriptive narrative and statistics	Moderate	Mai Sauki metal stoves	1	✗	A
Namuye (1989) *(25)*	Kenya (urban)	Survey (n=unknown)	Interviews with users, stove producers and stove promoters	Descriptive narrative	Weak	Kenya Ceramic Jiko charcoal stoves	1	✗	A
Osei (2010) *(74)*	Ghana (rural/urban)	Business model case study (3 KIIs)	Not described	Descriptive narrative	Weak	Toyola charcoal stoves	1	✗	A
Sawadogo (1989) *(26)*	Burkina Faso (urban)	Mixed-method approach: survey, interviews and PO	Not described	Descriptive narrative and statistics	Moderate	Ouaga stoves; Mixte wood or charcoal stoves	1	✗	A
Shastri et al. (2002) *(27)*	India (rural)	Cross-sectional surveys (n=155 in 1994 and n=132 in 2001)	Interviews with housewives	Descriptive narrative and statistics	Strong	Astra stoves	2, 3	✓	S
Shrimali et al. (2011) *(58)*	India (rural/urban)	12 KIIs	Interviews with company representatives	Descriptive narrative and statistics	Strong	Several stove models	Not specified	Not specified	S
Simon (2010) *(47)*	India (rural)	55 SSIs, surveys, 11 KII, PO	Interviews with women users, stove builders and NGO	Descriptive narrative	Moderate	Laxmi, Bhagyalaxmi stoves and other	1, 2	✓/✗	A/S

Author (year) *(reference no.)*	**Country/ setting**	**Study design and sampling**	**Data collection**	**Data analysis***	**Quality appraisal[#]**	**Improved stove technology**			**Adoption (A) vs sustained use (S)**
						Stove type	**Potholes**	**Stove ventilation**	
			employees			models			
Sinton et al. (2004) *(49)*	China (rural/urban)	Mixed-method approach: household survey (n=3,476) and stakeholders survey (n=108)	Open-ended interviews with structured questionnaire	Descriptive narrative and statistics	Strong	Biomass and coal stoves	Multiple	✓	S
Sudjarwo et al. (1989) *(45)*	Indonesia (rural)	Surveys of users and non-users (n=1,000) and PO	Interviews with households, stove producers and stove traders	Descriptive narrative and statistics	Moderate	SAE pottery stoves	2	×	A/S
USAID/Winrock (2008) *(68)*	Peru (rural)	Mixed-method approach: survey (n=169) and FGDs (n=unknown)	Not described	Descriptive narrative and statistics	Moderate	Inkawasina rocket stoves	2	✓	S
USAID/Winrock (2009) *(50)*	Bangladesh (urban)	Survey (n=625)	Interviews with main cooks	Descriptive narrative	Moderate	Portable and fixed BCSIR stoves Grihalaxmi stoves	1, 2 1	✓ ×	A
World Bank (2004a). *Case study I (14)*	Guatemala (rural)	24 SSIs, 2 FGDs	Interviews and discussions with users	Descriptive narrative and statistics	Moderate	Tezulutlan plancha stoves	3	✓	A
World Bank (2004b). *Case study II (51)*	Guatemala (rural)	31 SSIs and 2 FGDs	Interviews and discussions with users	Descriptive narrative and statistics	Moderate	Plancha stoves	1–4	✓	A
World Bank (2004c). *Case study III (56)*	Guatemala (rural)	32 SSIs and 2 FGDs	Interviews and discussions with users	Descriptive narrative and statistics	Moderate	Plancha stoves	3	✓	A
World Bank (2010a). *Case study I (46)*	Bangladesh (rural/urban)	Literature review supported by surveys with users (n=142)[§] and FGDs and KIIs	Survey with women users (n=70)[#], interviews with technicians and other stakeholders (n=41)[§]	Descriptive narrative	Moderate	Portable or semi-submerged mud stoves Fixed mud stoves	1 1, 2	× ✓	S
World Bank (2010b). *Case study II (105)*	Bangladesh (rural/urban)	Literature review supported by surveys with users (n=142)[§] and FGDs and KIIs	Survey with women users (n=70)[§], interviews with technicians and other stakeholders (n=41)[§]	Descriptive narrative	Moderate	Mud or mud/brick stoves	1, 3	✓	S
World Bank (2010c). *Case study III (37)*	Bangladesh (urban)	Literature review supported by surveys with users (n=142)[§] and FGDs and KIIs	Survey with women users (n=70)[#], interviews with technicians and other stakeholders (n=41)[§]	Descriptive narrative	Moderate	Portable and fixed BCSIR stoves Grihalaxmi stoves	1, 2 1	✓ ×	A

✓=Yes, ×=No.
BCSIR=Bangladesh Council of Scientific and Industrial Research; FDG=focus group discussion; KII=key informants interview; PO=participant observation; SSI=semi-structured interview.
*Data analysis for quantitative studies: (i) *descriptive comparison*=summary of attributes of adopters; (ii) *analytical approach*=comparison of adopters with non-adopters univariately; (iii) *multivariable approach*=summary of factors associated with adoption after adjustment for potential confounders/covariates.

[#]Quality appraisal of studies was conducted using separate quality assessment tools for each type of evidence resulting in an overall score of strong, moderate or weak. Please note that quality appraisal across evidence types is not directly comparable.
[§]These figures are cumulative for all the World Bank 2010 (a–e) case studies; a breakdown for each case study is not available

ANNEX 2: Characteristics of included studies on LPG, by study category

Author (year) *(reference no.)*	Country/ Setting	Study design and sampling	Data collection	Data analysis*	Quality appraisal[#]	Adoption (A) vs sustained use (S)	Baseline fuel	Technology package
				QUANTITATIVE STUDIES (QN)				
Edwards and Langpap (2005) *(83)*	Guatemala (rural/urban)	ENCOVI survey (n=3,424 rural + n=3,852 urban)	Household interviews	Multivariable approach adjusting for confounders	Strong	A	Firewood	LPG stove and gas bottle
Heltberg (2005) *(84)*	Guatemala (rural/urban)	ENCOVI survey (n=3,424 rural + n=3,852 urban)	Household interviews	Multivariable approach adjusting for confounders	Strong	A	Firewood	Not specified
Rogers (2009) *(82)*	India (rural)	Cross-sectional survey (124 users + 124 non-users)	Face-to-face interviews with heads of household	Analytical and multivariable approaches adjusting for confounders	Moderate	A/S	Firewood, crop residues	Not specified
				CASE/POLICY STUDIES (CS)				
Bates (2009) *(81)*	Sudan (urban)	Community-based project (n=1,100) with a participatory approach.	Not described	Descriptive narrative	Weak	A	Firewood, charcoal	LPG stove, gas bottle, connectors and hotplates
Budya and Arofat (2011) *(76)*	Indonesia rural/urban)	Baseline survey (n=500), user surveys (n=550 and n=288)	Several approaches, including market surveys	Descriptive narrative and statistics	Moderate	A	Kerosene	LPG stoves, 3 kg bottle, hose pipe and regulator
Elgarah (2011) *(86)*	Morocco (rural/urban)	Interviews with KI (n=3)	Phone interviews	Descriptive narrative	Weak	A	Not specified	LPG stove and gas bottle
Lucon et al. (2004) *(77)*	Brazil (rural/urban)	Ecological study covering 1970–2002	National statistics	Descriptive narrative and statistics	Moderate	S	Firewood	LPG stoves, 13 kg bottles
Pandey and Morris (2006) *(52)*	India (rural/urban)	Ecological study on LPG subsidisation	National statistics	Descriptive narrative and statistics	Weak	S	Not specified	Not specified
Terrado and Eitel (2005) *(79)*	Nicaragua (rural/urban)	Cross-sectional surveys with HHs (n=unknown) and business (n=93)	Interview-based questionnaires	Descriptive narrative and statistics	Moderate	A	Firewood	Not specified
USAID (2005) *(85)*	Mozambique (urban)	FGDs (overall n=40) and market surveys (n=400)	Interviews with customers, fuel traders and food vendors	Descriptive narrative	Weak	A	Mainly charcoal	One/two burners LPG stoves and 5.5 kg bottles
USAID (2010) *(80)*	Haiti (rural)	Surveys and FGDs	Interviews with	Descriptive narrative	Weak	A	Mainly	Not specified

Author (year) ***(reference no.)***	**Country/ Setting**	**Study design and sampling**	**Data collection**	**Data analysis***	**Quality appraisal[#]**	**Adoption (A) vs sustained use (S)**	**Baseline fuel**	**Technology package**
		(n=unknown)	food-vendors and customers				charcoal	
Viswanathan and Kumar (2005) *(78)*	India (rural/urban)	Cross-sectional survey for three survey periods (n=unknown)	Sample collected by the National Sample Survey Organisation	Descriptive narrative and statistics	Moderate	A	Firewood, dung	Not specified

ENCOVI=Encuesta Nacional de Condiciones de Vida; FDG=focus group discussion; HH=household; KII=key informants interview; PO=participant observation; SSI=semi-structured interview.
*Quality appraisal of studies was conducted using three separate quality assessment tools resulting in an overall score of strong, moderate or weak. It is, however, important to note that quality appraisal across study designs is not directly comparable.

ANNEX 3: Characteristics of included studies on biogas, by study category

Author (year) *(reference no.)*	**Country/ Setting**	**Study design and sampling**	**Data collection**	**Data analysis***	**Quality appraisal#**	**Adoption (A) vs sustained use (S)**	**Prevalent biogas digester type**	**Capacity**	**Prevalent feeding material**
QUALITATIVE STUDIES (QL)									
Jian (2009) *(95)*	China (rural)	Ethnography. Survey (n=247), SSI (n=38), FGD (n=12) and PO	Case histories with 3 plant users. SSI with users. Self-completed questionnaires and FGD with non-users (male and female)	Method not specified	Strong	A/S	Fixed dome	2 to 8 m^3	Human/pig dung and straw/stalks
Sovacool and Drupady (2011) *(40)*	Bangladesh (rural/urban)	Case study based on interviews (n=not specified)	Interviews with users and stakeholders	Narrative synthesis	Moderate	A/S	Brick and fibreglass biogas units	2 to 3 m^3	Cattle and poultry dung
QUANTITATIVE STUDIES (QN)									
Christiaensen and Heltberg (2012) *(94)*	China (rural)	Cross-sectional baseline survey (n=2,700)	HHs selected from project and control villages, including users and non-users.	Multivariable approach adjusting for confounders	Strong	A	Not specified	10 to 12m^3	Pig dung
Mwirigi et al. (2009) *(100)*	Kenya (rural)	Cross-sectional survey (n=100 users + n=100 non-users)	Face-to-face interviews with users and non-users	Analytical approach without adjustment	Moderate	A/S	Fixed dome; Floating drum and flexible bag	4 and 16 m^3 8 to 10 m^3	Cattle dung
CASE/POLICY STUDIES (CS)									
Bajgain and Shakya (2005) *(90)*	Nepal (rural)	Case study: survey (n=600) and interviews	Poorly reported. Interviews with users	Descriptive narrative	Weak	S	Small fixed dome	Mainly 6 m^3	Cattle dung
Bhat et al. (2001) *(101)*	India (rural)	Case study: survey (n=187), biogas measurements and interviews (n=10)	Survey with users. Interviews with biogas entrepreneurs and implementing agencies	Descriptive narrative and statistics	Moderate	S	Floating drum and fixed dome	3 to 8 m^3	Cattle dung
BSP and CEDA (1998) *(103)*	Nepal (rural/urban*)	Mixed-method approach. HH survey (n=866) and 9 FGDs (n=8 each)	Interviews with HH heads. FGDs with local people	Descriptive narrative and statistics	Moderate	S	Not specified	4 to 10 m^3	Cattle dung
Daxiong et al. (1990)	China	Case study: 2 cross-sectional surveys (n=58 and n=242)	Survey with users and biogas plant inspections	Descriptive narrative and statistics	Weak	S	Not specified	6 to 10 m^3	Animal and human dung; straw
de Alwis (2002) *(88)*	Sri Lanka (rural/urban)	Review study based on two cross-sectional surveys (n=303 in 1986 and n=369 in 1996)	Not described	Descriptive narrative and statistics	Moderate	S	Fixed dome (Chinese type)	6 m^3	Cattle dung
Dutta et al. (1997) *(89)*	India (rural)	Case study based on inspected plants (n=482)	Poorly reported. Interviews with users and NGO staff	Descriptive narrative	Moderate	S	Fixed dome designs	2 to 6 m^3	Cattle dung

Author (year) *(reference no.)*	**Country/ Setting**	**Study design and sampling**	**Data collection**	**Data analysis***	**Quality appraisal#**	**Adoption (A) vs sustained use (S)**	**Prevalent biogas digester type**	**Capacity**	**Prevalent feeding material**
World Bank (2010d) *(91)*	Bangladesh (rural)	Literature review supported by surveys with users (n=142)§ and FGDs and KIIs	Survey with women users (n=70)#, interviews with technicians and other stakeholders (n=41)§	Descriptive narrative	Moderate	S	Fixed dome (2 types)	6 sizes	Cattle dung
World Bank (2010e) *(102)*	Bangladesh (rural)	Literature review supported by surveys with users (n=142)# and FGDs and KIIs	Survey with women users (n=70), interviews with technicians and other stakeholders (n=41)#	Descriptive narrative	Moderate	S	Fixed and floating models	5 sizes	Cattle and poultry dung
Ghimire (2005) *(92)*	Bangladesh (rural)	HH survey (n=72)	Face-to-face interviews with users, including family and key community members	Descriptive narrative and statistics	Moderate	S	Fixed dome (3 types)	2 to 6 m^3	Cattle dung
iDE (2011) *(93)*	Bangladesh (rural)	Mixed-method approach. Cross-sectional survey (n=300), FGDs	Structured questionnaire with users. FGDs with users and non-users. Interviews with stakeholders.	Descriptive narrative and statistics	Moderate	S	Not reported	1.6 to 4.8 m^3	Cattle and poultry dung
Kumargoud et al. (2006) *(98)*	India (rural)	Cross-sectional survey (n=200)	Face-to-face interviews with users	Descriptive narrative	Moderate	S	Deenabandhu and KVIC models	Not reported	Cattle dung
Planning Commission (2002) *(96)*	India (rural)	Cross-sectional survey (n=620 users + n=744 non-users)	Not described	Descriptive narrative	Moderate	A/S	Mostly Deen Bandhu and KVIC models	2 to 8 m^3	Cattle dung
Qi and Li (2010) *(99)*	China (rural)	Cross-sectional survey (n=400)	Interviews with users and non-users	Descriptive narrative	Weak	A	N/A	Not reported	Not reported

FDG=focus group discussion; SSI=semi-structured interview; KII=key informants interview; KVIC=Khadi and Village Industries Commission; PO=participant observation, HH=household. *Quality appraisal of studies was conducted using three separate quality assessment tools resulting in an overall score of strong, moderate or weak. It is, however, important to note that quality appraisal across study designs is not directly comparable. §These figures are cumulative for all the World Bank 2010 (a–e) case studies; a breakdown for each case study is not available.

ANNEX 4: Characteristics of included studies on solar cookers, by study category

Author (year) ***(reference no.)***	**Country/ Setting**	**Study design and sampling**	**Data collection**	**Data analysis**	**Quality appraisal***	**Adoption (A) vs sustained use (S)**	**Technology characteristics**
QUALITATIVE STUDIES (QL)							
Otte (2009) *(105)*	Tanzania (rural)	SSI (not specified), 5 KIIs and PO	Interviews with women users, project co-ordinators and other staff	'Meaning categorisation' according to seven dimensions	Strong	A	Box and parabolic cookers
Sesan (2012) *Findings on solar cookers (62)*	Kenya (urban**)	15 SSIs, 9 KIIs, PO	Interviews with women users and stakeholders	Method not stated; descriptive narrative	Moderate	A	CooKit (panel cooker)
Velasco (2008) *(43)*	Mexico (rural)	10 SSIs, PO	Interviews with women users	Method not stated; descriptive narrative	Weak	A	HotPot solar oven
QUANTITATIVE STUDY (QN)							
Levine and Beltramo (2012) *(72)*	Senegal (rural)	Phased randomised controlled study (n=50 HHs) with 50% cookers distributed at baseline and 50% after 6 months to control groups	Baseline survey + self-reported utilisation monitoring survey at 6 months	Multivariable approach adjusting for confounders	Strong	A	HotPot solar oven
CASE/POLICY STUDIES (CS)							
Ahmad (2001) *(110)*	India (urban)	Interviews (n=28), workshops and PO	Repeated interviews with users and disusers, including husband/wife and children	Descriptive narrative	Moderate	S	Box cooker
Baptista et al. (2003) *(109)*	Kenya (rural)	KII (n=unknown) and field-tests	Phone and face-to-face interviews with stakeholders	Descriptive narrative	Weak	A	HotPot solar oven
Biermann et al. (1999)/Sejake (1998)*** *(104, 106)*	South Africa (rural/urban)	A one-year comparative field-test of cookers (n=66 HH users, n=30 controls)	Weekly interviews and FGDs with families owning a specific cooker for certain amount of time	Descriptive narrative	Moderate	A	Seven different including box and parabolic cookers
Toonen (2009) *(108)*	Burkina Faso (urban)	Survey (n=86, of whom 59 were beneficiaries)	Self-reported use of solar cookers by women users	Descriptive narrative	Moderate	A/S	CooKit (panel cooker)
Wentzel and Pouris (2007) *(107)*	South Africa (rural/urban)	Review of empirical studies (survey n=100; market studies n=200, etc.).	Range of methods including interviews at homes, telephone interviews, observation, and focus groups; detail not described	Descriptive narrative based on synthesis of multiple empirical studies	Moderate	A/S	Different models, including box and parabolic cookers

FDG=focus group discussion; SSI=semi-structured interview; KII=key informants interview; PO=participant observation; HH=household.
*Quality appraisal of studies was conducted using three separate quality assessment tools resulting in an overall score of strong, moderate or weak. It is, however, important to note that quality appraisal across study designs is not directly comparable. **This study was conducted in a peri-urban setting. ***These two published studies describe the same pilot project conducted in South Africa so they have been treated as one study and results are combined.

ANNEX 5: Characteristics of included studies on alcohol fuels, by study category

Author (year) ***(reference no.)***	**Country/ Setting**	**Study design and sampling**	**Data collection**	**Data analysis**	**Quality appraisal***	**Adoption (A) vs sustained use (S)**	**Fuel used****	**Stove**
				CASE/POLICY STUDIES (CS)				
Couto (2007) *(118)*	Brazil (rural/urban)	Pilot intervention study with 100 HHs (repeated surveys over three months)	Face-to-face interviews with participants	Descriptive narrative	Moderate	A	Ethanol	Dometic CleanCook (1 burner)
Imam (2011) *(121)*	Indonesia (rural)	KII with stakeholders (n=5)	Face-to-face and telephone interviews	Descriptive narrative	Weak	A	Ethanol	Locally produced E-stoves
Murren (2006) *(117)*	Ethiopia (urban)	Pilot intervention study with 409 HHs, (repeated bi-weekly surveys over 3 months and qualitative interviews with users)	Face-to-face interviews with participants	Descriptive narrative	Moderate	A	Ethanol	Dometic CleanCook (assumed 2 burners)
Obueh (2008) *(119)*	Nigeria (urban)	Pilot intervention study with 150 HHs, (repeated bi-weekly surveys over 3 months)	Face-to-face interviews with participants	Descriptive narrative and frequencies	Moderate	A	Methanol	Dometic CleanCook (assumed 2 burners)
Practical Action Consulting (2010) – Component B *(113)*	Madagascar (rural/urban)	Controlled cooking tests and comparison of cooking stoves with interviews and FGD (n=8).	Face-to-face interviews with participants	Descriptive narrative and statistics	Moderate	A	Ethanol	Imported CleanCook (1 burner)
Practical Action Consulting (2011) – Component A *(120)*	Madagascar (rural/urban)	Socio-economic cross-sectional survey (n=270) and exposure monitoring	Face-to-face interviews with participants	Multivariable approach[#] adjusting for confounders	Strong	A	Ethanol	Imported CleanCook (1 burner)

FDG=focus group discussion; SSI=semi-structured interview; KII=key informants interview; PO=participant observation. *Quality appraisal of studies was conducted using three separate quality assessment tools resulting in an overall score of strong, moderate or weak. It is, however, important to note that quality appraisal across study designs is not directly comparable. **Fuel previously denaturated. [#]Multivariable approach=summary of factors associated with adoption after adjustment for potential confounders/covariates.

References

1. Lewis JJ, Pattanayak SK. Who Adopts Improved Fuels and Cookstoves? A Systematic Review Environ Health Perspect. 2012;120(5):637–45.
2. Puzzolo E, Stanestreet D, Pope D, Bruce NG, Rehfuess EA. Factors influencing the large scale uptake by households of cleaner and more efficient household energy technologies: a systematic review. EPPI Centre London. Available at: http://eppi.ioe.ac.uk/cms/Default.aspx?tabid=3426 (Accessed 17 July 2014).
3. Harden A, Brunton G, Fletcher A, Oakley A. Teenage pregnancy and social disadvantage: systematic review integrating controlled trials and qualitative studies. British Medical Journal. 2009;339, doi: 10.1136/bmj.b4254.
4. Dherani M, Pope D, Mascarenhas M, Smith K, Weber M, Bruce N. Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis. Bull WHO 2008;86:390-8.
5. Pope D, Mishra V, Thompson L, Siddiqui A, Rehfuess E, Weber M, et al. Systematic review and meta-analyses of risk of low birth weight and stillbirth associated with indoor air pollution in developing countries Epidemiologic Reviews 2012;32:70-81.
6. Voss P, Rehfuess E. Quality appraisal in systematic reviews of public health interventions: an empirical study on the impact of choice of tool on meta-analysis. J Epi Comm Health. 2012. doi:10.1136/jech-2011-200940.
7. Atkins C, Sampson J. Critical appraisal guidelines for single case study research. Proceedings of the Tenth European Conference on Information Systems, Poland Available at: http://is2lseacuk/asp/aspecis/20020011pdf [accessed 12 November 2013] 2002.
8. Household Cookstoves, Environment, health and Climate Change. A new look at an old problem. Washington DC: World Bank. 2011.
9. Bruce N, Rehfuess E, Smith K. Household energy solutions in developing countries. In: Nriagu JO (ed.) /Encyclopedia of Environmental Health/, volume 3, pp. 62–75. Burlington, Elsevier 2011.
10. Thomas J, Harden A. Methods for the thematic synthesis of qualitative research in systematic reviews. BMC Medical Research Methodology. 2008;8(45):1-10.
11. Pine K, Edwards R, Masera O, Schilmann A, Marrón-Mares A, Riojas-Rodríguez H. Adoption and use of improved biomass stoves in Rural Mexico. Energy for Sustain Dev. 2011;15(2):176-83.
12. Ruiz-Mercado I, Masera O, Zamora H, Smith K. Adoption and sustained use of improved cookstoves. Energy Policy 2011;39:7557-66.
13. ISO. IWA 11:2012. Guidelines for evaluating cookstove performance. Geneva: International Organization for Standardization. 2012.
14. World Bank. Evaluation of Improved Stove Programs in Guatemala: Final Report of Project Case Studies. *Case Study 1: Tezulutlan Project (pp. 21-44)* ESMAP Technical paper, No. 60. Washington DC: World Bank: 2004a.
15. Amarasekera RM. Sri-Lanka - Status of Improved Woodstove Dissemination in Sri-Lanka. In R Caceres et al eds Stoves for People, proceedings of the 2nd International workshop on Stoves Dissemination, 4-10 October, Antigua, Guatemala Exeter: IT Publications, 118-121. 1989.
16. Barnes DF, Kumar P,Openshaw K. Cleaner Hearths, Better Homes: New Stoves for India and the Developing World. *Chapter 3: Maharashtra - Commercial Approach* (pp. 24-35). New York. Oxford University Press. 2012a.
17. Barnes DF, Kumar P, Openshaw K. Cleaner Hearths, Better Homes: New Stoves for India and the Developing World. *Chapter 4: Haryana - Women's Involvment Approach,* (pp. 36-49) New York. Oxford University Press. 2012b.
18. Barnes DF, Kumar P, Openshaw K. Cleaner Hearths, Better Homes: New Stoves for India and the Developing World. *Chapter 5: Karnataka - Techincal Innovation and Institutions* (pp. 24-35). New York: Oxford University Press 2012c.
19. Barnes DF, Kumar P, Openshaw K. Cleaner Hearths, Better Homes: New Stoves for India and the Developing World. *Chapter 6: Gujarat - Rural development Approach* (pp 64-77). New York: Oxford University Press. 2012d.
20. Barnes DF, Kumar P, Openshaw K. Cleaner Hearths, Better Homes: New Stoves for India and the Developing World. *Chapter 7: Andhra Pradesh - Interagency Coordination* (pp 78-94). New York: Oxford University Press. 2012e.

21. Barnes DF, Kumar P, Openshaw K. Cleaner Hearths, Better Homes: New Stoves for India and the Developing World. *Chapter 8: West Bengal - Nongoveramental Organisations* (pp. 95-113) New York: Oxford University Press. 2012f.
22. GERES. Dissemination of domestic efficient cookstoves in Cambodia. Renewable Energy, Environment and Solidairty Group (GERES), 2009.
23. Kürschner E, Diehl E, Hermann-Friede J, Hornikel C, Rosenbusch J, Sagmeister E. Impact of basic Rural Energy Services in Bangladesh. SLE Publication Series – S238. University of Berlin. Available at: http://edoc.hu-berlin.de/series/sle/238/PDF/238.pdf [accessed 2 August 2011] 2009.
24. Mounkaila A. Niger - The Promotion and Dissemination of Improved Stoves. In R Caceres et al eds Stoves for People, proceedings of the 2nd International workshop on Stoves Dissemination, 4-10 October, Antigua, Guatemala Exeter: IT Publications, 46-50. 1989.
25. Namuye S.A. Survey on dissemination and impact of Kenya Ceramic Jiko in Kenya. In R Caceres et al eds Stoves for People, proceedings of the 2nd International workshop on Stoves Dissemination, 4-10 October, Antigua, Guatemala Exeter: IT Publications, 40-44. 1989.
26. Sawadogo A. Fuelwood consumption and improved stoves diffusion in Ouagadougou City. In Caceres R et al eds Stoves for People, proceedings of the 2nd International workshop on Stoves Dissemination, 4-10 October, Antigua, Guatemala Exeter: IT Publications, 3-9 1989.
27. Shastri CM, Sangeetha G, Ravindranath NH. Dissemination of efficient ASTRA stove: case study of a successful entrepreneur in Sirsi, India. Energy for Sustain Dev. 2002;6(2):63-7.
28. Miller G, Mobarak M. Gender differences in preferences, intra-household externalities and low demand for a new technology: experimental evidence on improved cookstoves. NBER Working Paper Series No 18964 Cambridge, MA: National Bureau of Economic Research Available: http://wwwnberorg/papers/w18964 [accessed 2 April 2013]. 2011.
29. Pandey S, Yadama GN. Community development programs in Nepal: a test of diffusion of innovation theory. Social Service Review. 1992;66(4):582-4.
30. Wallmo K, Jacobson SK. A social and environmental evaluation of fuel-efficient cook-stoves and conservation in Uganda. Environm Conserv. 1998;25(2):99-108.
31. Anderson ZC. Reducing indoor air pollution on developing countries: a case study investigating the utilization of improved stoves in rural India. Available at: http://www.hedon.info/Utilization+of+Improved+Cookstove (Accessed 17 July 2014).
32. Jagoe K, Bromley H, Chengappa C, Bruce NG. Standard Monitoring Packages for Household Energy and Health Field Projects. Evaluation of the health and socio-economic impacts of Development Alternatives pilot project "Energy Services for Village Households and Rural Enterprises in Bundelkhand - India". Final Report, December 2006. *Qualitative findings.* Personal communication. 2006a.
33. Chowdhury MSH, Koike M, Akther S, Miah Md D. Biomass fuel use, burning technique and reasons for the denial of improved cooking stoves by Forest User Groups of Rema-Kalenga Wildlife Sanctuary, Bangladesh. International Journal of Sustainable Development and World Ecology. 2011;18(1):88-97.
34. Person B, Loo JD, Owuor M, Ogange L, Jefferds ME, Cohen AL. "It Is Good for My Family's Health and Cooks Food in a Way That My Heart Loves": Qualitative Findings and Implications for Scaling Up an Improved Cookstove Project in Rural Kenya. Int J Environ Res Public Health. 2012;9:1566-80.
35. Simon G. Brokering development: Geographies of mediation and energy sector reforms in Maharashtra, India. Ph.D thesis. Seattle, WA: University of Washington. 2007.
36. Gordon JK, Emmel ND, Manaseki S, Chambers J. Perceptions of the health effects of stoves in Mongolia. Journal of Health Oganization and Management. 2007;21(6):580-7.
37. World Bank. Improved and Cookstoves and better health in Bangladesh: Lessons from Household Energy and Sanitation Programs. *USAID: Reduction of Exposure to Indoor Air Pollution Through Household Energy and Behavioral Improvements.* (pp.24-26) Washington DC: World Bank. 2010c.
38. Jagoe K, Bromley H, Chengappa C, Bruce NG. Standard Monitoring Packages for Household Energy and Health Field Projects. Evaluation of the health and socio-economic impacts of Development Alternatives pilot project "Energy Services for Village Households and Rural Enterprises in Bundelkhand - India". Final Report. *Quantitative findings*. University of Liverpool. Personal communication. 2006b.
39. Troncoso K, Castillo A, Masera O, Merino L. Social perceptions about a technological innovation for fuelwood cooking: Case study in rural Mexico. Energy Policy. 2007;35(5):2799-810.

40. Sovacool B, Drupady I. Summoning earth and fire: The energy development implications of Grameen Shakti (GS) in Bangladesh. Energy 2011;36(7):4445-59.
41. Christoff J. Benefits and barriers: Exploring complete and sustained ecological stove usage in rural Mexico. MPH thesis. New Haven, CT: Yale University; 2010.
42. Jagoe K, Bromley H, Dutta K, Bruce N. Standard Monitoring Packages for Household Energy and Health Field Projects (ARTI - India). Final report, July 2007. *Quantitative findings.* Personal communication. 2007b.
43. Velasco I. More sustainable cooking technologies – A case study in rural kitchens in Michoacan, Mexico. M.Sc. thesis. Lund: Lund University. Available at: http://www.lumes.lu.se/database/alumni/06.08/thesis/Ignacio_Velasco.pdf [accessed 12/07/2011], 2008.
44. Jagoe K, Bromley H, Dutta K, Bruce N. Standard Monitoring Packages for Household Energy and Health Field Projects (ARTI - India). Final report, July 2007. *Qualitative findings.* Personal communication. 2007a Reference no. 21084/21373.
45. Sudjarwo A, Herm UY, Suryaningati D, Sumarni, Sunarno. Indonesia - Pottery Stoves, their Production, Dissemination and Adoption. In R Caceres et al eds Stoves for People, proceedings of the 2nd International workshop on Stoves Dissemination, 4-10 October, Antigua, Guatemala Exeter: IT Publications, 32-38. 1989.
46. Improved and Cookstoves and better health in Bangladesh: Lessons from Household Energy and Sanitation Programs. *BCSIR: Improved Cookstove Program, Phase II* (pp. 15-21) Washington DC: World Bank. 2010a.
47. Simon G. Mobilizing cookstoves for development: a dual adoption framework analysis of collaborative technology innovations in Western India. Environ Planning 2010;42(8):2011-30.
48. Troncoso K, Castillo A, Merino L, Lazos E, Masera OR. Understanding an improved cookstove program in rural Mexico: An analysis from the implementers' perspective. Energy Policy. 2011;39(12):7600-8.
49. Sinton JE, Smith KR, Peabody JW, Yaping L, Xiliang Z, Edwards R, et al. An assessment of programs to promote improved household stoves in China. Energy for Sustain Dev. 2004;8(3):33-52.
50. USAID/Winrock. Commercialization of improved cookstoves for reduced indoor air pollution in urban slums of northwest Bangladesh. Washington DC: United States Agency for International Development. Available at: http://pdf.usaid.gov/pdf_docs/pnado851.pdf [accessed 2 August 2011], 2009.
51. World Bank. Evaluation of Improved Stove Programs in Guatemala: Final Report of Project Case Studies. *Case Study 2: Social Investment Fund Project (pp. 45-68)*. ESMAP Technical paper, No. 60. Washington DC: World Bank. 2004b.
52. Pandey J, Morris S. Efficient Subsidisation of LPG: A Study of Possible Options in India Today (Based on a Report Commissioned by the Petroleum Federation of India). Working Paper 2006-04-0. Ahmedabad: Indian Institute of Management 2006.
53. Levine DI, Cotterman C. What Impedes Efficient Product Adoption? Evidence from Randomized Variation in Sales Offers for Improved Cookstoves in Uganda. Working Paper Series, Institute for Research on Labor and Employment San Francisco, CA: University of California at Berkeley 2012.
54. Masera OR, Díaz R, Berrueta V. From cookstoves to cooking systems: the integrated program on sustainable household energy use in Mexico. Energy for Sustain Dev. 2005;9(1):25-36.
55. Pandey S. Some factors determining level of use of improved stoves by Brahmin and Chhetri women in Central Nepal. Ph.D. thesis. Cleveland, Ohio: Case Western Reserve University. 1989.
56. World Bank. Evaluation of Improved Stove Programs in Guatemala: Final Report of Project Case Studies. *Case Study 3: Intervida Project (pp. 69-90)*. ESMAP Technical paper, No. 60. Washington DC: World Bank. 2004c.
57. Damte A, Koch SF. Clean fuel saving technology adoption in urban Ethiopia. ERSA working paper 2292011.
58. Shrimali G, Slaski X, Thurber MC,Zerriffi H. Improved stoves in India: A study of sustainable business models. Energy Policy. 2011;39(12):7543–56.
59. Mwangi A. Analysis of wood energy production and consumption strategies among small-scale farmers in central Kenya. Ph.D. thesis. East Lansing: Michigan State University. 1992.
60. Agurto-Adrianzen M. The Role of Social Capital in the Adoption of Firewood Efficient Stoves in Northern Peruvian Andes. MPRA Paper No. 15918. Munich: Munich Personal RePEc Archive. Available: http://mpra.ub.uni-muenchen.de/15918/1/MPRA_paper_15918.pdf [accessed 1 August 2013]. 2009.
61. Bensch G, Peters J. Combating Deforestation? – Impacts of Improved Stove Dissemination on Charcoal Consumption in Urban Senegal. RUHR Economic Papers. 2011; #306.

62. Sesan TA. Navigating the limitations of energy poverty: lessons from the promotion of improved cooking technologies in Kenya. Energy Policy. 2012;47:202-10.
63. Inayatullah J. What makes people adopt improved cookstoves? Empirical evidence from rural northwest Pakistan. The Governance of Clean Development Working Paper Series N12. 2011:1-15.
64. George R, Yadla VL. Factors affecting perception of beneficiaries of National Programme on Improved Cookstoves regarding cost-benefit of adoption of Mamta stove. Procedeedings of solar 95. 1995:361-6.
65. El Tayeb Muneer,Mohamed M. Adoption of biomass improved cookstoves in a patriarchal society: An example from Sudan. Sci Total Environ. 2003;307(1-3):259-66.
66. Pushpa K, editor. Factors associated with the adoption of improved cook stoves in Southern parts of India. Humanities, Science & Engineering Research (SHUSER), International Symposium 2011; Kuala Lumpur, Malaysia.
67. Silk B, Sadumah I, Patel M, Were V, Person B, et al. A Strategy to Increase Adoption of Locally-produced, Ceramic Cookstoves in Rural Kenyan Households. BMC Public Health. 2012;13(359): doi:10.1186/471-2458-12-359.
68. USAID/Winrock. Peru Healthy Kitchen/Healthy Stove Pilot Project. Washington DC: United States Agency for International Development. Available at: http://pdf.usaid.gov/pdf_docs/PDACN009.pdf [accessed 2 August 2011], 2008.
69. World Bank. Improved and Cookstoves and better health in Bangladesh: Lessons from Household Energy and Sanitation Programs. *GTZ Sustainable Energy for Development Program: Improved Cookstoves Component* (pp.21-24) Washington DC: World Bank. 2010b.
70. Barnes DF, Kumar P, Openshaw K. Cleaner Hearths, Better Homes: New Stoves for India and the Developing World. New York: Oxford University Press. 2012.
71. Smith K, Dutta K, Chengappa C, Gusain P, Masera O, Berrueta V, et al. Monitoring and evaluation of improved biomass cookstove programs for indoor air quality and stove performance: conclusions from the Household Energy and Health Project. Energy for Sustain Dev. 2007;11(2):5-8.
72. Levine D.I., Beltramo T. The Effect of Solar Ovens on Fuel Use, Emissions, and Health: Results from a Randomized Controlled Trial. Draft paper Berkeley: University of California 2011.
73. Masera O, Saatkamp B, Kammen D. From linear fuel switching to multiple cooking strategies: a critique and alternative to the energy ladder model. World Development 2000;28(12):2083-103.
74. Osei RD. Toyola Charcoal Stove: Improving the environmenet and health of the poor in Ghana. GIM Case Study No. B095: New York: United Nations Development Programme. 2010.
75. JUNTOS: Programa Nacional de Apoyo a los más Pobres. Available from: http://www.juntos.gob.pe/ [accessed 25.07.2013] 2012.
76. Budya H, Arofat M. Providing cleaner energy access in Indonesia through the megaproject of kerosene conversion to LPG. Energy Policy. 2011;39(12):7575–86.
77. Lucon O, Coelho ST, Goldemberg J. LPG in Brazil: lessons and challenges. Energy for Sustain Dev. 2004;8(3):82-90.
78. Viswanathan B, Kumar K. Cooking fuel use patterns in India: 1983–2000. Energy Policy. 2005;33(8):1021–36.
79. Terrado EN, Eitel B. Pilot Commercialization of Improved Cookstoves in Nicaragua. Energy Sector Management Assistance Programme (ESMAP). Thecnical paper series No. 085: Washington DC: World Bank. , 2005.
80. Assessment of Haiti Alternative Cooking Technologies Program. Washington DC: United States Agency for International Development. http://transition.usaid.gov/our_work/economic_growth_and_trade/energy/publications/haiti_cookstoves_assessment.pdf [accessed 2 August 2011], 2010.
81. Bates E. Making LPG stoves accessible for low income communities in Kassala, Sudan. In "*Cookstoves and Markets: Experiences and Success and Opportunities*" Rai, K and McDonald, JU. London: GVEP International. 2009.
82. Rogers T. Liquid petroleum gas (LPG) as a fuelwood substitute in the Western Ghats of India: Effectiveness and influence of socioeconomic characteristics. Master of Science Degree. State University of New York, College of Environmental Science and Forestry, Syracuse, New York. 2009.
83. Edwards JHY, Langpap C. Startup Costs and the Decision to Switch from Firewood to Gas Fuel. Land Economics. 2005;81(4):570-86.
84. Heltberg R. Factors determining household fuel choice in Guatemala. Environment and Development Economics. 2005;10(03):337-61.

85. LPG market assessment study in Mozambique. Washington DC: United States Agency for International Development. Available at: http://transition.usaid.gov/mz/doc/misc/moz_lpg_market_assess.pdf [accessed 12/6/2012], 2005.
86. Elgarah W. Microfinance for Liquefied petroleum gas. GIM Case Study No. B103: New York: United Nations Development Programme. 2011.
87. Wickramasinghe A. Energy access and transition to cleaner cooking fuels and technologies in Sri Lanka: Issues and policy limitations. Energy Policy. 2011;39(8):7567–74.
88. De Alwis A. Biogas - a review of Sri Lankas performance with a renewable energy technology. Energy for Sustain Dev. 2002;6(1):30-7.
89. Dutta S, Ibrahim HR, Malhotra P, Ramana PV. Biogas: the Indian NGO experience. New Delhi: AFPRO-CHF Network Programme. 1997. 128 p.
90. Bajgain S, Shakya I, Mensid MS. The Nepal Biogas Support Program: A succesfull model of public private partnership for rural household energy supply. Published by Ministry of Foreign Affairs, The Netherlands. 2005.
91. Improved Cookstoves and Better Health in Bangladesh: Lessons from Household Energy and Sanitation Programs. *BCSIR/LGED: Biogas Program.* (pp. 27-30). Washington DC: World Bank. 2010d.
92. Ghimire PC. *Final Report on Technical Study of Biogas Plants Installed in Bangladesh*. National Program on Domestic Biogas in Bangladesh, a Partnership Program of Netherlands Development Organization (SNV) and Infrastructure Development Company Ltd (IDCOL). Available at: http://m.snvworld.org/sites/www.snvworld.org/files/publications/technical_study_of_biogas_plants_installed_bangladesh_2005.pdf [accessed 18.06.2012], 2005.
93. iDE. Annual Biogas Users Survey 2010. Submitted to Infrastructure Development Company Limited (IDCOL), National Domestic Biogas and Manure Programme (NDBMP), 2011.
94. Christiaensen L, Heltberg R. Greening China's Rural Energy: New Insights on the Potential of Smallholder Biogas. World Bank Policy Research Working Paper No 6102 Washington DC: World Bank. 2012.
95. Jian L. Socioeconomic barriers to biogas development in rural southwest China: An ethnographic case study. Human Organization. 2009;68(4):415-30.
96. Planning Commission, Programme Evaluation Organisation,Goverment of India. Evaluation Study on National Project on Biogas Development. SNV Publisher. 2002.
97. Daxiong Q, Shuhua G, Baofen L, Gehua W. Diffusion and innovation in the Chinese biogas program. World Development. 1990;18(4):555-63.
98. Kumargoud V, Mahesha M, Revanna ML, Venkatachalapathy K. Impact of Biogas Technology on Rural Women. Environment and Ecology. 2006;24S(0970-0420):468-71.
99. Qi Z, Li G, editors. Contributions and constraints of rural household biogas construction project in northeast China: A case study of Gongzhuling County. International Conference on Management and Service Science 2010; Wuhan, China: doi: 10.1109/ICMSS.2010.5576785p.
100. Mwirigi JV, Makenzi PM, Ochola WO. Socio-economic constraints to adoption and sustainability of biogas technology by farmers in Nakuru Districts, Kenya. Energy for Sustain Dev. 2009;13:106–15.
101. Bhat PR, Chanakya HN,Ravindranath NH. Biogas plant dissemination: success story of Sirsi, India. Energy for Sustain Dev. 2001;5(1):39-46.
102. World Bank. Improved Cookstoves and Better Health in Bangladesh: Lessons from Household Energy and Sanitation Programs. *IDCOL/SNV: National Domestic Biogas and Manure Program.* (pp. 30-32). Washington DC: World Bank. 2010e.
103. BSP & CEDA. A Study on the effective demand for biogas in Nepal - Final report. Biogas Support Programme (BSP) and Centre for Economic Development & Administration (CEDA). SNV World publications. 1998.
104. Biermann E, Grupp M, Palmer E. Solar cooker acceptance in South Africa: results of a comparative field-test. Solar Energy. 1999;66:401-7.
105. Otte P. Cooking with the sun - An analysis of Solar Cooking in Tanzania, its adoption and impact on development. M.Phil in Development Studies: Trondheim: Norwegian University of Science and Technology; 2009.
106. Sejake S. The Impact of an Energy Intervention: The Solar Cooker Field Test in South Africa. Journal of Energy in Southern Africa. 1998;9(1):14.
107. Wentzel M, Pouris A. The development impact of solar cookers: A review of solar cooking impact research in South Africa. Energy Policy. 2007;35(3):1909-19.

108. Toonen HM. Adapting to an innovation: Solar cooking in the urban households of Ouagadougou (Burkina Faso). Physics & Chemistry of the Earth - Parts A/B/C. 2009;34(1/2):65-71.
109. Baptista TL, Curnow K, Hiranaga BJ, Magnus BD, Perry D. Solar Household Energy, Incorporated: A Market-Based Strategy for Introducing Passive Solar Ovens in Kenya. Michigan Business School. 2003.
110. Ahmad B. Users and disusers of box solar cookers in urban India - Implications for solar cooking projects. Solar Energy. 2001;69:209-15.
111. Rajvanshi AK, Patil SM, Mendonca B. Low-concentration ethanol stove for rural areas in India. Energy for Sustain Dev. 2007;11(1):94-9.
112. Schlag N, Zuzarte F. Market barriers to Clean Cooking Fuels in Sub-Saharan Africa: A review of Literature. Working Paper, Stockholm Environment Institute Stockholm, Sweden 2008.
113. Practical Action Consulting (PAC). Ethanol as a Household Fuel in Madagascar: Health Benefits, Economic Assessment, and Review of African Lessons for Scaling-up. *Component B: Economic Assessment of the Ethanol Household Fuel Program*. Available online at: http://www.projectgaia.com/documents/Ethanol%20as%20a%20Household%20Fuel%20in%20Madagascar%20Component%20B-%20Economic%20Assessment.pdf [accessed 12.06.2012], 2010.
114. Stokes H, Ebbeson B. Project Gaia: Commercializing a new stove and new fuel in Africa. Boiling Point 50. 2005.
115. Ebbeson B, Stokes C, Stokes H. Project Gaia: converting biomass to a clean liquid fuel for domenist use. Energy for Sustain Dev. 2002;2:43-8.
116. Utria BE. Ethanol and gelfuel: clean renewable cooking fuels for poverty alleviation in Africa. Energy for Sustain Dev. 2004;8(3):107-114.
117. Murren J. User Responses - the Ethanol-fueled CleanCook Stove's Safety, Fuel Consumption and Efficiency Addis Ababa, Ethiopia. Available at: http://www.projectgaia.com/files/UserResponsesCleanCookAddisAbaba.pdf [accessed 2/06/2012] 2006.
118. Couto R. Tapping the Potential of Proalcool for the Household Energy Sector. Results of Project Gaia's 100 CleanCook Stove Pilot Study Minas Gerais State, Brazil. Shell Foundation Project 21316. 2007.
119. Obueh J. Project Gaia Nigeria Pilot Study Final Report - Results of Project Gaia's CleanCook Methanol Stove Delta State: Nigeria. 2008.
120. Practical Action Consulting (PAC). Ethanol as a Household Fuel in Madagascar: Health Benefits, Economic Assessment, and Review of African Lessons for Scaling-up. *Component A: Analysis of Household Air Pollution Interventions in Madagascar*. Available online at: http://www.projectgaia.com/documents/Ethanol%20as%20a%20Household%20Fuel%20in%20Madagascar-%20Component%20A%20-%20Health%20Benefits.pdf [accessed 12.06.2012], 2011.
121. Imam D. PPKT: Working With The Community To Grow The Business. GIM Case Study No. B086: New York: United Nations Development Programme. 2011.