WHO GUIDELINES FOR INDOOR AIR QUALITY



HOUSEHOLD FUEL COMBUSTION

World Health Organization

WHO guidelines for indoor air quality: household fuel combustion

WHO indoor air quality guidelines: household fuel combustion.

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Foreword

Energy use in the home is a vital and ubiquitous feature of human society. Energy is used for a wide variety of purposes, including cooking, space heating, lighting, small-scale income generation, various household tasks, and entertainment. Although all home energy use can impact health in various ways, globally by far the most important direct health risk is household air pollution caused by the incomplete combustion of fuel in low-efficiency stoves and lamps used for cooking, space heating and lighting. For the year 2012, the World Health Organization (WHO) estimated that close to 3 billion people, mostly in low- and middle-income countries (LMICs), lacked access to clean or modern energy services for cooking resulting in some 4.3 million premature deaths worldwide.

Clean air in and around the home is essential to a healthy life. WHO has a long tradition in synthesizing the evidence on health aspects of air quality and in preparing technical recommendations to ensure clean and healthy air both in the indoor and outdoor environments. This volume, the third in the series, following indoor air quality guidelines for selected pollutants and for dampness and mould, provides technical recommendations on the requisite performance of the fuels and technologies used in the home. These guidelines recognize the challenges faced by Member States when trying to implement household energy interventions, and provide guidance on the best approaches for securing rapid adoption and sustained use of low emission household energy technologies and fuels to protect health.

These new guidelines are particularly timely as the global community transitions toward a more sustainable and equitable future, guided by the post-2015 sustainable development framework. Currently, although there are many global and national initiatives aimed at ensuring access for all households to clean and modern energy, there is a lack of clarity about what technologies and fuels can be considered clean and safe.

Elimination of the substantial inequalities in energy access and air quality in and around the home that exist in the world today will bring substantial health and development benefits. These new guidelines will inform policy- and decision-makers in the health sector and in other sectors, as well as researchers and technical staff, when designing and implementing interventions to address this problem.

The guidelines were developed and peer-reviewed by scientists from all over the world and the recommendations were informed by a rigorous review of all currently available scientific knowledge on this subject. I would like to thank these experts for their work in developing a product which I believe can stimulate a major new effort to improve global health.

Dr Margaret Chan
Director-General
World Health Organization

Glossary

Combustion, air pollution and health related terminology

Term	Acronym	Explanation
household air pollution	HAP	Air pollution generated by household fuel combustion, leading to indoor air pollution, and contributing to ambient air pollution.
ambient air pollution	AAP	Air pollution in the ambient environment, that is, in outdoor air, but able to enter homes.
acute lower respiratory infections	ALRI	Acute illness affecting the lungs, such as acute bronchitis and bronchiolitis, influenza and pneumonia.
WHO air quality guideline	AQG	Value at or under which a pollutant is considered to have no, or minimal impact on health.
carbon monoxide	CO	Colourless, odourless, toxic gas produced by incomplete combustion of carbon-containing materials.
chronic obstructive pulmonary disease	COPD	A collection of chronic lung conditions characterized primarily by a persistent blockage of airflow from the lungs.
cardiovascular disease	CVD	Disorders of the heart and blood vessels including disease of the coronary blood vessels supplying the heart (coronary heart disease) and the blood vessels supplying the brain (cerebrovascular disease).
greenhouse gases	GHGs	Gas compounds in the atmosphere that absorb and emit radiation within the thermal infrared range.
integrated exposure-response function	IER	Models that combine exposure and risk data for four sources of combustion-related pollution, namely outdoor air, second-hand smoke, household air pollution and active smoking.
ischaemic heart disease	IHD	Disease characterized by reduced blood supply to the heart.
interim target-1	IT-1	A pollutant level higher than that set by the AQG, established as an interim target to assist implementing agencies to make progress towards meeting the AQG levels.
products of incomplete combustion	PICs	Mixtures of pollutant particles and gases formed by incomplete burning of fuels or other material.
particulate matter	PM	A mixture of solid particles and liquid droplets suspended in the air.
respirable particulate matter	PM_{10}	Particles (complex mixtures of pollutants) with aerodynamic diameters of 10 µm or less
fine particulate matter	$PM_{2.5}$	Particles with aerodynamic diameters of less than 2.5 µm
tuberculosis	TB	Infectious disease caused by *Mycobacterium tuberculosis*, which most commonly affects the lungs.
vector-borne disease	VBD	Infectious disease caused by microbes transmitted to people by blood-sucking arthropods (insects or arachnids).
solid biomass fuel	–	Wood, animal dung, crop wastes and charcoal used as fuel.
solid fuel	–	Solid materials burned as fuels, includes coal as well as biomass fuels.

Additional acronyms and abbreviations

Acronym	Explanation
CCT	Controlled cooking test
CRA	Comparative risk assessment
EPRG	External peer-review group
GDG	Guidelines development group
GEPHI	Grading of Evidence for Public Health Interventions
GRADE	Grading of Recommendations Assessment, Development and Evaluation
IARC	International Agency for Research on Cancer
ITT	Intention to treat
ISO	International Organization for Standardization
IWA	International Workshop Agreement
KPT	Kitchen performance test
LMICs	Low- and middle-income countries
LPG	Liquefied petroleum gas
M&E	Monitoring and evaluation
NGOs	Nongovernmental organizations
OR	Odds ratio
RCTs	Randomized controlled trials
RR	Relative risk
SG	Steering group
SHS	Second-hand smoke
SRMA	Systematic review and meta-analysis
UN	United Nations
UNEP	United Nations Environment Programme
WBT	Water boiling test

Major policy and implementation agencies and initiatives

Term	Acronym	Explanation
Climate and Clean Air Coalition	CCAC	A UNEP-led partnership of governments and UN and other agencies, with the goal of securing combined health and climate benefits from reduction of short-lived climate pollutants. **http://www.unep.org/ccac/**
Department for International Development	DFID	United Kingdom development cooperation agency. **https://www.gov.uk/dfid**
United Nations Foundation Global Alliance for Clean Cookstoves	GACC	An alliance of public and private partners established by the UN Foundation in 2010 to address the global problems associated with traditional cooking methods. **http://www.cleancookstoves.org/**
Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH	GIZ	German development cooperation agency. **http://www.giz.de/en/**
Indian Council of Medical Research	ICMR	Indian medical research body. **http://icmr.nic.in/**
International Energy Agency	IEA	An autonomous organization working in the field of energy. **http://www.iea.org/**
International Organization for Standardization	ISO	A nongovernmental organization and network of the national standards organizations. **http://www.iso.org/**
Sustainable Energy for All	SE4All	An initiative of the UN Secretary-General to develop a public-private partnership to achieve universal access to modern energy services by 2030. **http://www.sustainableenergyforall.org/**

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The guidelines had a WHO steering group with the following members: Heather Adair-Rohani, Sophie Bonjour, Nigel Bruce, Jennifer De France, Carlos Dora, Arunachalam Gunasekar, Marie-Eve Heroux, Michal Krzyzanowsky, Mohd Nasir Hassan, Mazen Malkawi, David Meddings, Kate Medlicott, Mariam Otman del Barrio, Payden, Annette Pruss-Ustun, Nathalie Roebbel, Agnes Soares Da Silva, Kutane Waltaji Terfa, Martin Weber, and Raki Zghondi (please see Annex 1 for affiliations).

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Executive summary

Almost 3 billion of the world's poorest people still rely on solid fuels (wood, animal dung, charcoal, crop wastes and coal) burned in inefficient and highly polluting stoves for cooking and heating, currently resulting in some 4 million premature deaths annually among children and adults from respiratory and cardiovascular diseases, and cancer. Together with widespread use of kerosene stoves and lamps, these household energy practices also cause many deaths and serious injuries from scalds, burns and poisoning. The use of solid fuel for heating in more developed countries is also common and contributes significantly to air pollution exposure. Air pollution from household fuel combustion is the most important global environmental health risk today.

These new guidelines bring together the most recent evidence on fuel use, emission and human exposure levels, health risks, intervention impacts and policy considerations, to provide practical recommendations to reduce this health burden, which build on existing WHO air quality guidelines (AQGs) for specific pollutants. Implementation of these recommendations will also help secure the additional benefits to society, development and the environment – including climate – that will result from wider access to clean, safe and efficient household energy.

Drawing on a broad range of newly commissioned, or recently published, systematic reviews of the scientific literature, the guidelines apply strict criteria for assessing the quality of available evidence and the suitability for developing recommendations. Among the key findings is that for several important health outcomes, including child acute respiratory infections, exposure to the key pollutant – fine particulate matter, or $PM_{2.5}$ – needs to be brought down to low levels in order to gain most of the health benefit. The other main finding is that most of the solid fuel interventions promoted in recent years have not even come close to these levels when in everyday use, and there is a need for much more emphasis on accelerating access to clean household fuels.

The recommendations focus particular attention on reducing emissions of pollutants as much as possible, while also recognizing the importance of adequate ventilation and information and support for households to ensure best use of technologies and fuels. They encompass general considerations for policy, a set of four specific recommendations, and a good practice recommendation for addressing both health and climate impacts. The general considerations address issues such as the need for community-wide action, as pollution from one house or other sources affects neighbours, and vice-versa, and the fact that safety of new fuels and technologies cannot be assumed and must be assessed. The specific recommendations address the following:

- emission rate targets which specify the levels of emissions from household energy fuels and technologies that pose minimal health risks, and which are designed to guide assessment of how well various interventions can meet the air quality concentrations specified in WHO guidelines;
- policies for the period of transition from current practices to community-wide use of clean fuels and household energy technologies, recognizing that intermediate steps will be needed for some time to come among lower income and more rural homes reliant on solid fuels;
- the need to avoid the use of unprocessed coal as a household fuel, in light of the specific health risks;
- the need to avoid the use of kerosene as a household fuel, in light of concerns about emissions and safety.

The good practice recommendation encourages policy-makers to recognize that many of the pollutants from household fuel combustion lead to both health risks and climate change.

The guidelines are targeted at public health policy-makers and specialists working with the energy, environment and other sectors to develop and implement policy to reduce the adverse health impacts of household fuel combustion.

This publication is linked to ongoing work by WHO and its partners to provide technical support for implementation of the recommendations, as well as monitoring progress and evaluating programme impacts, for example, through the WHO database on household fuel combustion. Further details of the guidance, tools and other resources are available on the guidelines web pages: http://www.who.int/indoorair/guidelines/hhfc.

1. Introduction

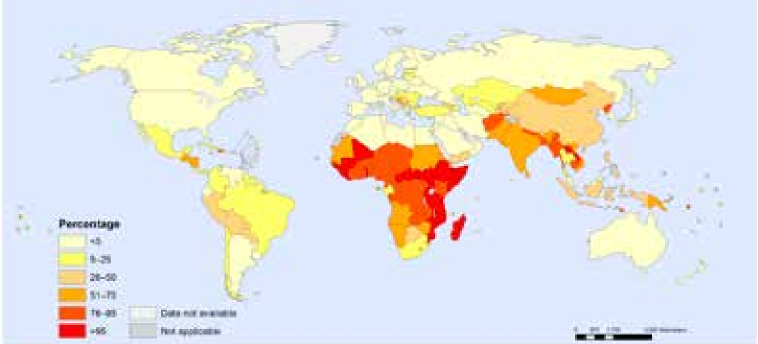
1.1 The health burden from household fuel combustion

Well into the 21st century, 2.8 billion people (Figure 1.1) still rely on solid fuels (wood, dung, crop wastes, charcoal, coal, etc.) and simple stoves for cooking and heating (Figure 1.2), and 1.2 billion light their homes with simple kerosene lamps (Figure 1.3) *(1)*. Many studies show that these household energy practices result in very high levels of household air pollution (HAP). Global burden of disease estimates have found that exposure to HAP from cooking results in around 4 million premature deaths *(2,3)*, with the most recent estimates from WHO reporting 4.3 million deaths for 2012. *(4)*. HAP is responsible for nearly 5% of the global disease burden (expressed as disability-adjusted life-years (DALYs)), making it globally the single most important environmental risk factor *(3)*.

HAP is also a substantial contributor to outdoor air pollution-related deaths due to emissions into the ambient environment, responsible for around 0.4 million deaths (12% of the total from ambient air pollution (AAP)) *(3)*.

These household energy practices are also linked to a high risk of burns (e.g. from children falling into fires, spilled fuel, etc.) and poisoning (mainly from children ingesting kerosene) (Figure 1.4). Women and children may also be at risk for injury and violence during fuel collection. Fuel gathering may take many hours per week, limiting other productive activities and taking children away from school (Figure 1.5). Figure 1.1, developed from WHO's household energy database *(5)*, shows the global extent of reliance on solid fuels for cooking and how this is concentrated in low and middle-income countries (LMICs) across Asia, Africa and Latin America. More than 95% of the population uses solid fuels for cooking in a significant number of countries, most of which are in sub-Saharan Africa.

Figure 1.1: Percentage of population relying on solid fuels as the primary cooking fuel in 2012, by country



Source: WHO (5)

Data for heating and lighting fuels are currently less complete and are not included in Figure 1.1. Further information on the distribution of fuels and technologies for these other household energy requirements, including the use of other sources of combustion pollution such as insect repellent coils, is provided in Review 1, available at: http://www.who.int/indoorair/guidelines/hhfc.

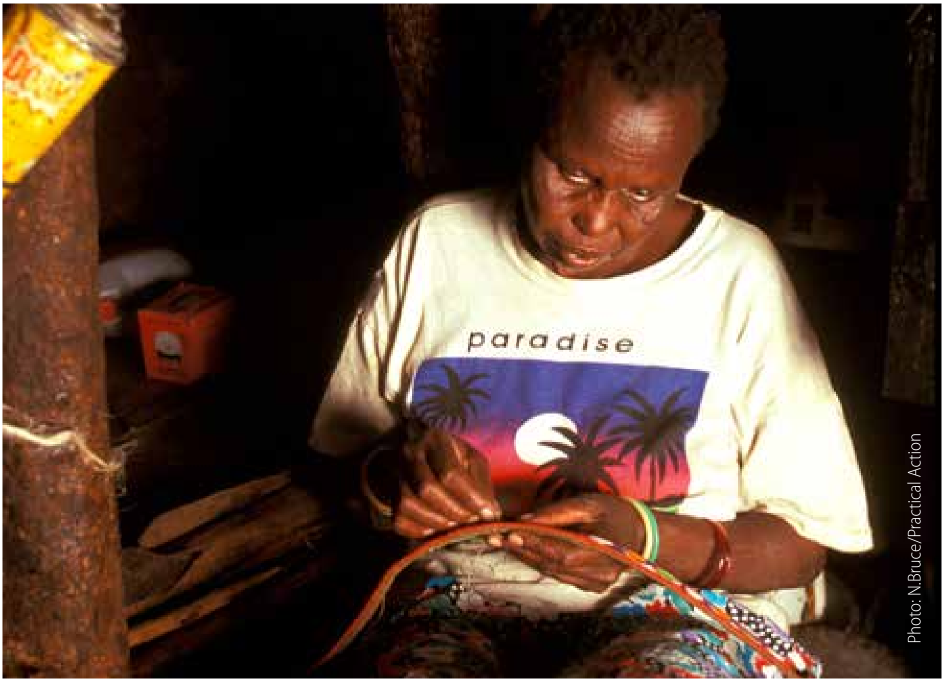
Figure 1.2: Exposure of family members to household air pollution (HAP) from cooking and heating

(a) *Women and young children receive the highest exposure because they spend the most time in or near the kitchen when the stove is alight.*

(b) *Other members of the family are also exposed, including men, the elderly and the sick.*

(c) *The concentrations of pollutants in the home commonly reach very high levels, hundreds or more times WHO guideline levels for important pollutants such as fine particles.*

Figure 1.3: Exposure from lighting and other household activities involving fuel combustion



(a) *Kerosene lamps are the most common form of lighting among 1.2 billion people with no electricity and for many others for whom electricity supply is intermittent, inadequate and/or unaffordable. These simple lamps emit high levels of health damaging pollutants and pose a risk for fires.*

(b) *Other sources of combustion pollution in and around the home include preparing animal feed and burning waste.*

(c) *Another source of exposure are teh steam baths common in Central America (temescales), located near the home and typically used several times per week; these can result in very high levels of exposure to pollutants, including carbon monoxide.*

Figure 1.4: Safety risks

(a) Kerosene is typically bought in small quantities, often in soft drink bottles; young children are at risk of drinking the fuel, leading to many cases of poisoning. ***(b)*** *Many deaths, and much larger numbers of physically and mentally debilitating injuries, are caused by burns from solid fuel stoves and kerosene stoves and lamps. Scalds are also common, as pots with hot food and liquid on simple stoves on the floor of the home are easily knocked over by young children, especially where the home is poorly lit.*

Figure 1.5: Other impacts on health, development and environment

(a) *The production of charcoal, one of the most commonly used cooking and heating fuels in Africa, has a substantial impact on forests and on climate.*

(b) *Wood fuel is an important contributor to deforestation in areas where demands on reserves are high and are not managed sustainably.*

(c) *Combustion emissions from households can make an important contribution to ambient (outdoor) air pollution, and in rural areas may be the main source.*

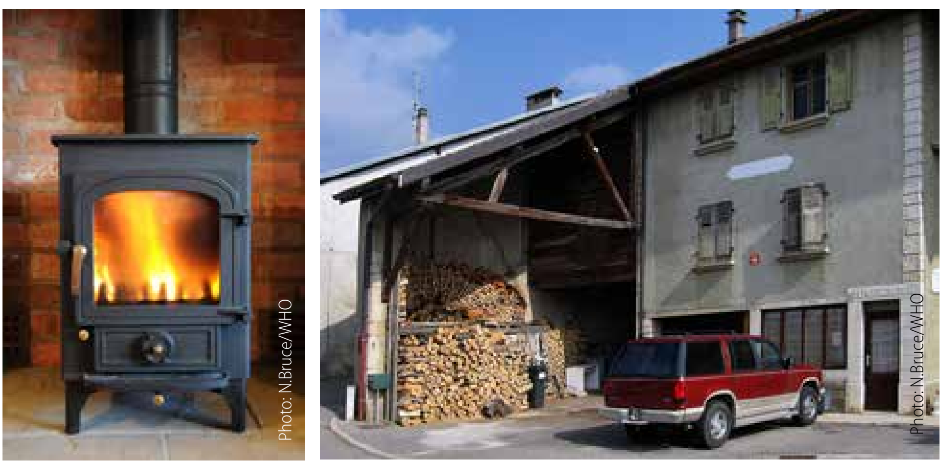
(d) *Emissions from fuel combustion in the home are not contained and affect neighbors as well as re-entering the house.*

(e) *Collecting fuel wood is a task that falls mainly to women and can take up many hours each week, as well as subject them to dangers including sexual violence. Older children may also help their parents, often taking time away from their schooling.*

While HAP from household fuel combustion presents less risk to health in high-income countries, it remains an issue in some settings where solid fuel (mainly wood and other biomass) and kerosene are used for heating (Figures 1.6, 1.7, 1.8).

Figure 1.6: Solid fuel use in high-income countries

(a) *Many rural, mountain and other communities experiencing cold winters use wood for heating (left). Older and poorer quality stoves are not uncommon, and can emit pollutants directly into the home (right).*



(b) *Even more modern wood burning stoves may result in emissions which contribute to ambient air pollution exceeding guideline levels. The use of wood as a heating fuel may be increasing in part as a response to higher fossil fuel prices.*

Figure 1.7: Hazards with gas and kerosene

(a) *Although gas is a relatively clean-burning fuel, combustion does result in emissions of nitrogen oxides which have been linked to asthma and wheeze. Cookers and boilers should be vented to the exterior.*

(b) *Kerosene (paraffin) heaters remain common in some parts of the world, and emissions of particulates and some other pollutants exceed WHO AQG levels and can present additional risk for fires and burns in homes.*

Figure 1.8: Contributions from solid fuel use to ambient (outdoor) air pollution

(a) *Emissions from solid fuel wood stoves vented to the outside can be re-enter the home.*

(b) *Where use of solid wood fuel is widespread across a community, emissions may result in ambient air pollution exceeding WHO AQG, especially in conditions of temperature inversion which traps cold air near the ground.*

Action to address this problem has historically been slow, under-funded, and marked by many ineffective and/or unsustainable interventions. Efforts to implement interventions to improve use of household energy have a history extending back for at least 30–40 years. However, much of the emphasis was on reducing biomass fuel consumption, fostering local economic development and supporting the role of women, rather than on measures to directly improve health. Projects and programmes on use of solid fuel stoves range from small scale-local initiatives of nongovernmental organizations (NGOs) to very large national programmes, including those in India and China *(6)*. This experience has been partially documented, in for example, resources such as Energypedia[1] and ad hoc evaluation studies in India *(7)* and China *(8)*.

During this period, many households made their own (often incomplete) transition from solid fuels to modern fuels including liquefied petroleum gas (LPG) natural gas and electricity as their socioeconomic circumstances improved. Although the percentage of homes relying primarily on solid fuels for cooking has gradually fallen from 60% in 1980 to 41% in 2010, population growth means the actual number of users has remained stable at 2.8 billion over the same period *(1)*. Some large national programmes have been able to implement or support transition to clean fuels. For example, Indonesia has implemented a very large project enabling more than 40 million homes to convert from kerosene use to LPG *(9)*, and Brazil used targeted financial assistance to support low-income families to access LPG *(10)*.

In recent years, several initiatives including the Global Alliance for Clean Cookstoves (GACC); Sustainable Energy for All (SE4All) and the Climate and Clean Air Coalition (CCAC)[2] have been mobilizing international efforts to secure achievable health, poverty reduction and environmental (including climate) benefits. These guidelines have been developed to help ensure that health gains are achieved through efforts to increase access to clean and safe household energy.

Given the mixed results of past intervention projects and programmes, and the fact that reliance on traditional solid fuels is closely linked to poverty *(11)*, securing a rapid transition to clean, efficient and modern household energy systems for cooking, heating, lighting and other household uses will present challenges, especially for lower-income households.

The overall objective of these guidelines is to inform and support governments and their implementing partners to bring about the transition to modern household energy as quickly and equitably as is feasible. The guidelines focus on the following three areas of policy:

- What can realistically be done? This includes the development of a practical tool for selecting the best options for stoves and fuels based on their emission rates of key health-damaging pollutants.
- How clean is clean enough? This is a question of the best approach for ensuring

[1] See for example: https://energypedia.info/wiki/Portal:Improved_Cooking

[2] See Glossary for further explanation and web links.

that, during the transition from solid–fuel to cleaner burning fuels, those who cannot make an immediate and complete transition to clean, modern fuels (e.g. gas, electricity) still obtain substantial health benefits in the interim.

- What fuels should be restricted or avoided?

1.2 Scoping questions

Based on the policy objectives described above, the following four main scoping questions setting out the issues to be addressed by the guideline recommendations were developed:

1. What device and fuel emission rates are required to meet the WHO (annual average) air quality guideline and intermediate target-1 for $PM_{2.5}$, and the (24-hour average) air quality guideline for carbon monoxide (CO)?
2. In light of the acknowledged challenges in securing rapid adoption and sustained use of very low emission household energy devices and fuels, particularly in low-income settings, what approach should be taken during this transition?
3. Should coal be used as a household fuel?
4. Should kerosene be used as a household fuel?

1.3 WHO guidelines relating to this topic

Prior to 2009, WHO had not produced guidelines for indoor air quality outside of occupational settings, and no internationally agreed health-based guidance with recommendations for policy was available on how to effectively address the public health impacts of household fuel combustion.

In recent years, WHO has been addressing this need through the development of a series of guidelines for indoor air quality. (AQGs). In 2005, when the global update of ambient (outdoor) air quality guidelines was prepared, it became clear that there was a need for guidance on indoor air quality. A planning meeting held in Bonn in 2006 set out the path for this work, and included plans for three indoor AQG volumes:

1. dampness and mould (published in 2009) *(12)*
2. selected pollutants (published in 2010) *(13)*
3. household fuel combustion (these guidelines)

The 2005 global update and the AQGs for selected pollutants (13), set guideline values for specific pollutants, but were not intended to provide practical recommendations and guidance to assist countries and implementing agencies to put those standards into practice. Furthermore, those guidelines did not specifically address household fuel combustion, nor the particular needs of LMIC populations.

The current guidelines are designed to provide this guidance and support, and build on the published WHO guidelines for indoor air quality: specific pollutants.

1.4 Target audience

The primary audience for these guidelines is decision-makers developing, implementing and evaluating policy to secure health benefits in the area of household energy, with a primary (but not exclusive) focus on LMICs, as follows:

- national government departments responsible for addressing this issue. including political, management and technical personnel from a range of ministries in charge of health, energy, environment, development/planning, infrastructure, forestry, etc;
- testing, standards and certification agencies and providers;
- public and private energy production and supply utilities;
- health authorities and health practitioners engaged in planning and delivery of preventive services at national, regional and local levels;
- multisectoral groups working to develop and implement country action plans/ investment strategies for improving access to cleaner, safer and more efficient household energy;
- development cooperations and international nongovernmental organizations (NGOs) working to improve access to cleaner, safer and more efficient household energy;
- international initiatives working on improving access to cleaner, safer and more efficient household energy, including the UN Foundation's Global Alliance for Clean Cookstoves (GACC), and the UN Secretary-General's Sustainable Energy for All initiative (SE4All);
- researchers whose work focuses on investigating the causes of disease and the effectiveness of preventive interventions.

The primary audience for the systematic evidence reviews are researchers and technical staff (working in the organizations and ministries noted above) in the fields covered, that is combustion science and emissions, air pollution, environmental health, safety (burns and poisoning risks), and policy for the adoption and sustained use of interventions.

The best practice recommendation addressing synergies between the health and climate impacts of household energy is intended for those formulating policy on climate change mitigation. This includes a wide range of partners engaged with climate change mitigation strategies, including the Climate and Clean Air Coalition (an initiative focused on the shorter-acting climate pollutants, which are the main concern in respect of incomplete combustion of household fuels).

Finally, it is intended that these guidelines should contribute to general raising of awareness of an issue that has not received the attention that the health burden and other impacts of current household fuel combustion practices would warrant.

2. Guideline development process

2.1 Scope of the guidelines

Development of these guidelines began with the WHO global update 2005: particulate matter, ozone, nitrogen dioxide and sulfur dioxide, and a subsequent planning meeting on WHO guidelines for indoor air quality held in Bonn in 2006. A proposal for indoor air quality guidelines for household fuel combustion was developed based on the outline plan drawn up in Bonn in 2006, relevant existing guidelines and consultation with partners.

Following planning approval and establishment of the WHO Steering Group (SG) and Guidelines Development Group (GDG), a planning meeting was held in Geneva in January 2011 attended by members of the GDG and WHO staff. This set out the scope, topic areas and priorities, and defined the approach for conducting systematic reviews and obtaining other evidence required for the recommendations.

At this meeting, the group decided it was not necessary to review the evidence informing the published WHO guidelines for air quality(AQG) *(13, 14)* and that these AQGs would provide the air pollutant standards for the current guidelines. For convenience, the guidelines for particulate matter (PM_{10} and $PM_{2.5}$) published in 2006, and all other combustion-derived indoor pollutants reviewed in 2010, are reproduced here (Table 2.1).

Table 2.1: Summary of published WHO air quality guideline values

Pollutant (unit for guideline)	Mean concentration over averaging time							Unit risk	Comments	Ref.
	10 min	15 min	30 min	1 hour	8 hours	24 hours	1 year			
$PM_{2.5}$ (µg/m^3)	–	–	–	–	–	25[a]	10	–	24-hour guide-line max 3 days/ year	WHO 2006 *(14)*
PM_{10} (µg/m^3)	–	–	–	–	–	50[b]	20	–	24-hour guide-line max 3 days/ year	WHO 2006 *(14)*
Benzene (risk of leukaemia per 1 µg/m^3)	–	–	–	–	–	–	–	6.0 x 10^{-6}	No safe level	WHO 2010 *(13)*

Continues…

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Pollutant (unit for guideline)	Mean concentration over averaging time							Unit risk	Comments	Ref.
	10 min	15 min	30 min	1 hour	8 hours	24 hours	1 year			
CO (mg/m³)	–	100		35	10	7	–	–	–	WHO 2010 *(13)*
Formaldehyde (mg/m³)	–	–	0.1	–	–	–	–	–	–	WHO 2010 *(13)*
Naphthalene (mg/m³)	–	–	–	–	–	–	0.01	–	–	WHO 2010 *(13)*
Nitrogen dioxide (μg/m³)	–	–	–	200	–	–	40	–	–	WHO 2010 *(13)*
Polycyclic-aromatic hydrocarbons[a] (risk of lung cancer per 1 ng/m³ B[a]P	–	–	–	–	–	–	–	8.7×10^{-5}	No safe level	WHO 2010 *(13)*

[a] In view of the difficulties in developing guidelines for PAH mixtures, benzo[a]pyrene was considered to represent the best single indicator compound (see WHO 2010) *(13)*.

[b] The 24-hour average values for PM_{10} and $PM_{2.5}$ refer to the 99th percentile of the distribution of daily values, i.e. the fourth next highest value of the year.

Evidence reviews were then commissioned, and drafts which had undergone a first round of external peer review were discussed at the main GDG and SG meeting, held in April 2012, in Delhi, in collaboration with the Indian Council of Medical Research (ICMR). At this meeting the scope was finalized, recommendations were drafted and decision tables used to set the strength of the recommendations.

2.2 Evidence review

2.2.1 Evidence required to address scoping questions

The first step in the evidence search and retrieval procedure was to identify and define the evidence required to address the scoping questions. Due to the nature of the policy challenges being addressed and the scarcity of experimental studies directly assessing the impact of household energy interventions on health, several distinct areas of evidence were required for each scoping question. These areas of evidence are summarized in Table 2.2. Those amenable to PICO (population, intervention, comparator, outcome) framing are indicated, and elaborated further below.

Table 2.2: Areas of evidence sought for each scoping question

Scoping question	Evidence required for scoping question	Framing of evidence requirement (topic)
1. Emission rates to meet AQGs	a. Published WHO AQGs	a. Reference to AQGs ($PM_{2.5}$, CO).
	b. Emission rates of key pollutants from traditional devices/fuels and intervention options	b. Summary of laboratory and field test results for $PM_{2.5}$, CO (and other important pollutants).
	c. Relationships between emission rates and indoor air quality	c. Model relating emission rates to predicted kitchen concentrations for $PM_{2.5}$ and CO.
2. Policy during transition	a. Disease risks from household air pollution (HAP) and estimated effect sizes for impacts of interventions	a. Summary of evidence relating HAP to specific disease outcomes, strength of evidence for causal inference and intervention effect sizes: defined by **PICO-1** (see Section 2.2.2).
	b. Relationships between level of exposure and level of risk for important[1] disease outcomes across the full range of exposure seen with intervention options	b. Summary of evidence on exposure-response relationships for important disease outcomes.
	c. Levels of HAP and exposure experienced by populations using traditional stoves/fuels, and intervention options	c. Summary of observational population-based studies with measured average $PM_{2.5}$ and CO.
	d. Impacts of interventions on HAP levels achieved with stoves/fuels in everyday use	d. Summary of observational (where relevant) and experimental studies (randomized and non-randomized) with measured average $PM_{2.5}$ and CO: defined by **PICO-2** (see Section 2.2.2)
	e. Nature and extent of barriers to transition to improved solid fuel stoves and clean fuels	e. Summary of evidence on factors influencing the adoption and sustained use of interventions.
3. Coal use	a. Health impacts of solid fuel use	a. As for 2(a) and (b) above.
	b. Health risks specific to household use of coal	b. Summary of evidence on carcinogenicity, toxic contaminants, and constraints on clean combustion of coal.
4. Kerosene use	a. Health risks specific to household use of kerosene	a. Summary of evidence on kerosene use, levels of pollutants, and health impacts.

It was determined that a range of different types of reviews would be required to capture the varied and broad nature of the evidence required; accordingly, the following types of review have been conducted:

- a **systematic review** (with meta-analysis if included);
- a **summary of a systematic review** (with meta-analysis if included), where the review summarized is a recently conducted or published systematic review on a relevant topic;

[1] See PICO-1 table in Section 2.2.2 (below) for details of important health outcomes.

- a **summary and synthesis of systematic reviews and other evidence**, where the review brings together summaries of completed systematic reviews (with meta-analyses if included), and other evidence, and includes some synthesis of this evidence;
- a **model**, which is used here to describe the emissions rate model in Review 3, and the IERs in Review 4;
- a **narrative review**, where an overview of a set of issues that have not been the subject of asystematic, defined literature search is provided.

Details of the type of review used for each area of evidence, and the nature of evidence included, are provided in Table 2.3, Section 2.2.3.

2.2.2 Framing of questions

As noted in Table 2.2, it was possible to frame questions on two topics using the PICO format. These addressed (i) impacts of interventions on health outcomes (PICO-1, 2(a) in Table 2.2), and (ii) impacts of interventions on household levels of $PM_{2.5}$ and CO (PICO-2, 2(d) in Table 2.2). These are presented below, with additional explanation of the rationale for the outcomes selected.

Impacts of interventions on health outcomes (PICO-1)

Although it was judged important to review evidence for all child and adult health outcomes linked to HAP exposure, the GDG determined that the focus should be on specific important outcomes, that is, those that have an impact on child survival and development (e.g. acute lower respiratory infections (ALRI), low birth weight, stillbirth) and those responsible for a large burden of disease in the 2010 Global burden of disease (GBD) study (i.e. Global burden of disease chronic obstructive pulmonary disease (COPD), cardiovascular disease (CVD) and lung cancer) *(3)*. These outcomes are indicated in the PICO-1 table below with an asterisk (*).

The epidemiological studies of these important health outcomes provide the largest and most robust source of evidence on the expected impacts of interventions on the risk of disease. The lack of HAP and/or exposure measurement in most, however, means that the exposure levels associated with these impact effect findings can only be estimated.

This leaves the question of risk levels with intermediate exposure reductions essentially unanswered. This latter (and critical) area evidence is provided by the exposure-response evidence, in particular the IER functions covered by topic 2(b) in Table 2.2, although not available for all of the important disease outcomes listed in the PICO-1 table. Where such evidence is available it is indicated in the PICO-1 table below by inclusion of [IER].

PICO-1: Impact of interventions reducing HAP exposure on health outcomes: outcomes identified with an asterisk (*) are those assessed by the GDG as most important

PICO-1	Description	
Population	The 2.8 billion people *(15)* using solid fuels, that is biomass (wood, animal dung, crop wastes, charcoal) or coal as their primary cooking and heating fuel, with open fires or traditional stoves.	
Intervention	Clean fuels (LPG, electricity) and/or a range of 'improved' solid fuel stoves, delivering substantial reductions in HAP exposure. Exposure levels have mostly not been measured in the relevant studies, but have been estimated to lie between the WHO annual IT-1 of 35 µg/m³ $PM_{2.5}$ at the lower end of the range and 75 µg/m³ $PM_{2.5}$ at the upper end.	
Comparator	Households using solid fuels with traditional stoves	
Outcome	**Young child (under 5 years)**	**Adult**
	Acute lower respiratory infections (ALRI)* [IER]	Chronic obstructive pulmonary disease (COPD)* [IER]
	Low birthweight*	Lung cancer with coal exposure* [IER]
	Stillbirth*	Lung cancer with biomass exposure* [IER]
	Stunting*	Cardiovascular disease*[a] [IER]
	All-cause mortality under 5 years*	Cataract
	Cognitive development	Other cancers
		Asthma (adult and child)

a Very few primary studies are available on the risk of cardiovascular outcomes with exposure to solid fuels or associated HAP levels, and health risk assessment has relied on interpolation from risk functions for other combustion sources; as a consequence, GEPHI assessment of evidence quality (explained below) has not been applied to this outcome.

Impact of interventions in everyday use on household levels of $PM_{2.5}$ and CO (PICO-2)

The second area of evidence amenable to the PICO format examines the impacts of solid and clean fuel interventions on kitchen levels of $PM_{2.5}$ and CO, when these devices and fuels are in everyday use. Eligible studies were not found for all of the interventions listed. The important outcomes considered were average 24- or 48-hour kitchen levels of the above pollutants. Evidence of effect on personal $PM_{2.5}$ and CO exposure was also sought (and reported in the systematic review), but as this evidence was very limited and only available for some interventions, these are not included in the PICO table.

PICO-2: Impact of interventions on average levels of household air pollution

PICO-2	Description	
Population	The 2.8 billion people using solid fuels, that is biomass (wood, animal dung, crop wastes, charcoal) or coal as their primary cooking and heating fuel, with open fires or traditional stoves.	
Intervention	**Improved solid fuel stoves**	**Clean fuels**
	With chimney	Liquefied petroleum gas (LPG)/natural gas
	Without chimney	Ethanol
	Mixed (stove plus other improvements to kitchen and cooking arrangements)	Biogas
		Solar cookers
		Electricity
Comparator	Households using solid fuels with traditional stoves	
Outcome	Average 24-hour (or 48-hour) concentrations of: • Kitchen $PM_{2.5}$ • Kitchen carbon monoxide (CO)	

Other questions and topics

Evidence reviews were also conducted on the following three topics:

- Safety: although not an outcome of poor air quality, the risks associated with household energy use (burns, scalds, poisoning from ingestion of liquid fuel) were identified as important because it cannot be assumed that interventions that reduce emissions of health damaging pollutants are safer. The findings of the systematic review on this topic (Review 10) have informed the general considerations for implementation presented in Section 4, which apply to all of the specific recommendations. This review also contributed to the evidence used for the recommendation on the household use of kerosene.
- Adoption: as noted in the introduction and in scoping question 2, achieving rapid and sustained adoption of much cleaner household energy interventions poses significant policy challenges, particularly in low-income settings. The systematic review of factors influencing the adoption and sustained use of improved stoves and clean fuels (Review 7) informs plans for the development and testing of guidance and tools to support implementation, described further in Section 5.
- Synergies between health and climate impacts: household fuel combustion can have significant impacts on climate through both efficiency of combustion and the nature of the emissions. A review of evidence on the net climate impacts (warming) from inefficient use of non-sustainable biomass and emissions from incomplete fuel combustion was carried out (Review 11). This informs a good practice recommendation on maximizing health co-benefits in climate change mitigation policy that addresses household energy, presented in Section 4.7.

2.2.3 Evidence reviews and other information supporting recommendations

Evidence reviews

A series of reviews were conducted to obtain the evidence set out in Table 2.2, with the exception of topic 1(c) which used a modelling approach (see below), and topic 2(b) for which recently developed models combining risk data for multiple combustion sources were the primary source. Table 2.3 below shows how evidence has been reviewed or generated through models and how the evidence quality was assessed. Assessment of the overall quality of evidence for each topic is provided in Annexes 4–7, and full details of the rationale and methods used are available in *Methods used for evidence assessment* available at: http://www.who.int/indoorair/guidelines/hhfc.

As noted in Section 2.2.1, the evidence was summarized in different ways, depending on whether a new systematic review was conducted and reported in full, or whether existing (mostly published) systematic reviews were summarized.

Summaries nitrogen dioxide (of reviews were used where evidence on a range of outcomes was required and space would not have allowed full reporting of all systematic reviews, and/or high quality systematic reviews on the topic had recently been published. Where it was judged important to combine systematic review findings with other evidence, a synthesis was included. In one case (climate impacts and finance) a narrative review was judged to be the best approach, given the complex, multidisciplinary nature of this issue and the fact that this evidence served as context for implementation of the recommendations.

As noted, new systematic reviews were conducted for the purposes of these guidelines, unless a recent completed review meeting content, quality and peer-review criteria was available. In practice, this applied to recently published systematic reviews of (i) risks of asthma and wheeze in children with gas cooking and NO_2 exposure *(16)* and (ii) health risks of kerosene use *(17)*. In each case, the methods (key questions, search terms and strategy) for the published review were assessed, and a summary prepared (see Review 5, Section 4: Health risks of gas; Review 9: Health risks from kerosene).

For all new systematic reviews, search, data extraction and study quality assessment methods (described in Table 2.3 and in detail in the full texts of the systematic reviews, see: http://www.who.int/indoorair/guidelines/hhfc) were broadly similar. The details varied according to the type of evidence incorporated, e.g. laboratory testing, epidemiological studies, policy and case studies of adoption. There are also some variations in databases searched (in part as appropriate to the topic) and in languages included. For the systematic reviews of coal use (Review 8), Chinese language studies were included because a high proportion of the world's coal using households are located in China and important research had been conducted there. For other topics, where non-English languages were included (e.g. Chinese) it was found that searching databases in other languages made little, if any, difference to the included set of studies.

The quality of individual studies contributing to these reviews was assessed using standard methods applicable to the type of study. This varied considerably, ranging from laboratory emission studies to epidemiological studies, and case studies of implementation programmes. A summary of the methods used is provided in column 3 of Table 2.3, with further details in the full texts of the reviews (available at: http://www.who.int/indoorair/guidelines/hhfc).

Methods used for assessing the quality of the overall evidence provided by these reviews are described in section 2.3 below, and summarized in column 4 of Table 2.3.

Table 2.3: Summary of systematic and other evidence reviews, methods for individual study quality assessment, and overall evidence quality assessment. Further details of the assessment of quality, including upgrading and downgrading for specific outcomes, are available in the assessments of evidence quality for each of the specific recommendations (Annexes 4–7)

Review number, (short) title and area of evidence (topic) addressed	Type of review and evidence included	Methods for assessment of individual study quality	Methods for assessment of quality of the set of evidence compiled in the review
Review 1: Fuel use Global and regional summary of household fuel and technology use for cooking, heating and lighting	**Synthesis and analysis:** Includes a synthesis and analysis of survey data and national statistics reports from low, middle and high income countries on the fuels and technologies used by households for cooking, heating and lighting, as well as a summary of trends in solid cooking fuel use based on modelled estimates.	All surveys or reports included in the analysis had to meet minimum criteria for date, population representation, and methods of data collection (e.g. survey questions used).	A global dataset was available for cooking fuel use. Data related to heating, lighting and cooking devices were less comprehensive and in some cases no aggregated figures by region could be calculated and only national level statistics are presented. Inconsistencies in data collection or reporting methods were reconciled through grouping of response data or exclusion from analysis.
Review 2: Pollutant emissions Summary of laboratory and field test results for $PM_{2.5}$, CO (and other important pollutants).	**Systematic review:** Includes mainly laboratory and a smaller number of field-based measurements of emissions of major pollutants from a representative range of stove and fuel types.	Suitability of the emission test protocol used, adherence to protocol and quality assurance of methods used.	Suitability of test protocols used for emissions testing, and extent of adherence to protocols and quality control/assurance by laboratories. Identification of issues for interpretation of results from laboratory and field testing.

Review number, (short) title and area of evidence (topic) addressed	Type of review and evidence included	Methods for assessment of individual study quality	Methods for assessment of quality of the set of evidence compiled in the review
Review 3: Emissions model Model relating emission rates to predicted concentrations for $PM_{2.5}$ and CO.	**Model:** Includes a review of alternative modelling approaches, and a description of the single zone box model using Monte Carlo simulation to link emission rates (inputs) with distributions of average concentrations $PM_{2.5}$ and CO in the home (outputs).	Not applicable, although the limitations of the model and currently available data inputs are discussed.	Validation of predicted kitchen concentrations of $PM_{2.5}$ and CO against empirical data from homes in India and countries from other regions; interpretation of findings in light of evidence of emissions from multiple sources in real-life settings, including from neighbouring homes and other sources of combustion-derived air pollution.
Review 4: Health impacts of household air pollution (HAP) Summaries of evidence relating HAP to specific disease outcomes, causal evidence and effect sizes: defined by PICO-1, exposure-response evidence, risk from use of gas, and impacts of smoke reduction on vector-borne disease.	**Summary and synthesis of systematic reviews, modelling and other evidence:** 1. Summary and synthesis of completed systematic reviews and meta-analyses (SRMA) of epidemiological studies linking HAP exposure (from solid fuels and gas) to a range of health outcomes.	1. Intervention impact estimates: Evaluation of study quality was carried out using versions of Newcastle-Ottawa scale, adapted to each type of study design.	1. Intervention impact estimates: Bradford Hill viewpoints to assess strength of causal evidence; assessment using GEPHI[a] for quality and precision of intervention effect estimates (details of grading by disease outcome are provided in Annex 5).
	2. Summary of all available exposure-response evidence including newly developed integrated exposure-response models for several disease outcomes.	2. Integrated exposure-response functions: all studies of risk associated with household air pollution which contributed to these integrated models were assessed individually as described above.	2. IER functions: GRADE[b] domains (number of studies, study design, risk of bias, indirectness, imprecision, inconsistency, and publication bias) were used as a guide, and applied in the most appropriate way given the nature of the available evidence. Assessment was made (i) generically for the IER approach and model assumptions, and (ii) in respect of specific issues for each disease outcome.
	3. Summary of published SRMA of health risks from household use of gas.	3. Individual study quality assessment was not available, but general quality issues for studies (especially for exposure assessment) were identified and discussed.	3. Assessment focused on the inconsistency across findings of the SRMA between the two measures of exposure (gas and NO_2) and the two outcomes (wheeze and asthma), and potential explanations for this.

Continues…

[a] GEPHI: Grading of evidence for public health intervention (see Section 2.3.3)

[b] Grading of recommendations assessment, development and evaluation.

Continued

Review number, (short) title and area of evidence (topic) addressed	Type of review and evidence included	Methods for assessment of individual study quality	Methods for assessment of quality of the set of evidence compiled in the review
	4. Summary of published systematic review of risk of vector-borne disease (VBD) from potential interventions to reduce HAP exposure.	4. Individual study quality assessment was not available, but general quality issues including confounding are discussed.	4. Meta-analysis was not attempted, so formal assessment with GEPHI not conducted. Assessment focuses on lack of experimental studies, and potential for confounding.
Review 5: Population levels of HAP and exposure Summary of observational population-based studies with measured average $PM_{2.5}$ and CO.	**Systematic review:** Includes studies which have measured 24-hour or 48-hour concentrations of PM and CO in kitchens, other rooms within homes, in the local ambient air, and personal exposure to these same pollutants for men, women and children.	Methods used for selecting samples of homes and individuals, protocols for measurements of $PM_{2.5}$ and CO, and evidence of quality assurance procedures.	GRADE domains (number of studies, study design, risk of bias, indirectness, im precision, inconsistency, and publication bias) were used as a guide. All eligible studies provided measures of long-term average (e.g. 24 hour or 48 hour) levels of pollutants, which increased consistency of the findings.
Review 6: Intervention impacts Summary of observational (where relevant) and experimental (randomized and non-ranomized) studies with measured average $PM_{2.5}$ and CO defined by PICO-2.	**Systematic review and meta-analysis:** Includes studies which provide data on average home-based 24-hour or 48-hour kitchen and/or personal $PM_{2.5}$, PM_4 or CO using either experimental designs, or observational studies of intervention programmes.	Evaluation of study quality using versions of Newcastle-Ottawa scale, adapted to each type of study design, including adequacy of description and application of standardized HAP measurement.	Assessment using GEPHI to assess the quality and precision of estimates for each pollutant ($PM_{2.5}$, CO), and for each group of stove or clean fuel intervention (details of grading by intervention type and pollutant are provided in Annex 5).
Review 7: Factors influencing adoption Summary of evidence on factors influencing the adoption and sustained use of interventions.	**Systematic review:** Includes quantitative, qualitative and policy/case studies in LMICs reporting on factors influencing adoption and/or sustained use of improved solid fuel stoves, and four types of clean fuel (LPG, biogas, alcohol, solar cookers)	*Quantitative studies***:** Used versions of Newcastle-Ottawa scale, adapted to each type of study design. *Qualitative studies***:** Used methods described by Harden et al. 2009 *(18)*. *Policy and case studies:* Used methods for case studies described by Atkins & Sampson 2002 *(19)*.	GRADE domains (number of studies, study design, risk of bias, indirectness, inconsistency, imprecision for quantitative evidence, publication bias) were used as a guide, and applied in the most appropriate way given the nature of the available evidence; consistency of findings across different study designs and settings was important.

Review number, (short) title and area of evidence (topic) addressed	Type of review and evidence included	Methods for assessment of individual study quality	Methods for assessment of quality of the set of evidence compiled in the review
Review 8: Coal Summary of evidence on carcinogenicity, toxic contaminants, and interventions to reduce adverse health effects including bans and other restrictions on household use of coal.	**Summary and synthesis of systematic reviews and other evidence:** 1. Synthesis of studies on health risks from coal arising from products of incomplete combustion, drawing on published systematic review, and other studies identified through systematic search.	For carcinogenicity, methods used are those described by the International Agency for Research on Cancer (IARC).	Three distinct components contributed to the overall evidence available for coal: carcinogenicity, health effects from products of incomplete combustion (PICs), and toxic contaminants. *Carcinogenicity:* IARC methods are based on assessment of human epidemiology, animal evidence and mechanistic evidence.
	2. Summary of evidence from IARC monograph on carcinogenicity of emissions from household coal use. 3. Systematic review of studies (intervention and observational) relating to health risks from toxins in coal.	Quality assessment of studies of health risks from coal use (from products of incomplete combustion, and from toxic contaminants) was based on evaluation of methods used for sampling, exposure and outcome assessment, and analysis including adjustment for confounding. This information was used to provide an overall quality assessment.	*PIC effects:* For lung cancer, the GEPHI assessment from Review 4 (Health impacts of household air pollution) was used. For other (non-cancer) outcomes, due to small numbers of studies and heterogeneity of outcome definitions, meta-analysis was not conducted and GEPHI was not applied. GRADE domains (number of studies, study design, risk of bias, indirectness, inconsistency, imprecision, publication bias) were used as a guide. *Toxic contaminants:* Assessment of quality was based on the combination of studies (including experimental studies) reporting coal toxin content, emission and area concentrations of toxins, and population studies of specific outcomes (e.g. fluorosis, arsenicosis) in areas where households burn coal.
Review 9: Kerosene Summary of evidence on kerosene use, levels of pollutants, and health impacts.	**Summary of systematic review:** Includes studies reporting on kerosene use (fuel type/grade and devices) for cooking, heating and lighting; emissions of major pollutants and area concentrations; epidemiological studies on health risks with kerosene use in the home.	Evaluation of study quality was based on methods used for exposure and outcome assessment, and analysis. A formal quality scoring tool was not used.	Due to the substantial heterogeneity in study methods, quality and findings, meta-analysis was not attempted for any of the health outcomes, and GEPHI assessment was not applied. GRADE domains (number of studies, study design, risk of bias, indirectness, inconsistency, imprecision for quantitative evidence, publication bias) were used as a guide.

Continues…

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Review number, (short) title and area of evidence (topic) addressed	Type of review and evidence included	Methods for assessment of individual study quality	Methods for assessment of quality of the set of evidence compiled in the review
Review 10: Safety Summary of evidence on burns, scalds and poisoning.	**Systematic review:** Includes studies reporting on rates of burns and poisoning from household energy use, risk factors, impact of interventions. Also includes a description of a newly developed safety testing protocol for solid fuel stoves.	Evaluation of intervention study quality using versions of the Newcastle-Ottawa scale, adapted to each type of study design.	For studies of risk factors, methodological issues such as case selection – most were drawn from facilities with few population studies – were a quality concern. Experimental studies (both randomized and non-randomized designs available) were generally of good quality, but too variable in terms of interventions and outcomes to carry out meta-analysis.
Review 11: Climate impacts Summary of evidence on climate impacts (warming) from inefficient use of non-sustainable biomass, and emissions from incomplete fuel combustion.	**Narrative review:** In view of the complexity of climate science (and this not being the main focus of the guidelines), a narrative review providing an overview of the impacts of household fuel combustion on climate was provided. This draws on a recent comprehensive United Nations Environment Programme (UNEP) report on the effects on climate of short-acting pollutants and other published studies.	Individual climate science studies on the impacts of household fuel combustion pollutants on climate warming were not assessed separately.	The overall evidence provided by the climate science studies on the impacts of household fuel combustion pollutants on climate warming was not assessed. The consistency of evidence indicating substantive net warming effects draws strongly on the conclusions of the UNEP report.

Emissions model

In order to select a model suitable for the purposes of these guidelines, three commonly employed methods were reviewed (see full description in Review 3). Each of these combines the rate of pollutant emission (in terms of mass) within a room (e.g. kitchen) with mathematical models of pollutant transport and fate to provide estimates of indoor pollutant concentrations. These three types of model range from simple constructs to complex computer-based simulations and all have the capacity to provide indoor concentration estimates indicative of those observed in homes due to the device and fuel in question. These are:

- The **single zone** model, which assumes that the pollutant emitted into room air is uniformly mixed throughout the space. Concentration is determined by emission rate and a number of other factors that can be incorporated into the model, including duration of combustion, room volume and air exchange rate.

- The **three zone** model, which divides the room into three zones – a plume rising above the combustion device; warm air within a given distance from the ceiling; and the rest of the room. It is assumed that uniform mixing occurs in each zone. In other respects, this approach is similar to the single zone model.
- The **computational fluid dynamics** model, which considers the forces involved in determining transport of air and pollutants within a room, by dividing the space into a large (or very large) number of small units, and developing equations incorporating momentum, thermal energy and conservation of mass for determining the resulting air pollutant concentrations.

Single zone models have been applied in work on household energy and air pollution for around 30 years, and this approach was adopted for the current purposes. The single zone model has the merit of simplicity in respect of the assumptions used. This is important when developing an approach that can be applied to populations. Such a model needs to account for a wide variation in factors (i.e. room size, air exchange rate, and duration of device use) which determine area concentration for any given emission rate. These have been incorporated by using a range of empirically-derived values for each factor combined in a Monte Carlo simulation. The input data used for the model were obtained from measurements made in India, and are summarized in Table 2.4.

Table 2.4: Input distributions for air exchange rates and kitchen volumes

Parameter	Unit	Geometric mean	Range		SD[1]
			minimum	maximum	
Air exchange rate (α)	per hour	15	5	45	7.5
Kitchen volume (V)	m^3	30	5	100	15
Device burn time	hours per day	4	0.75	8	2

[1] SD: Standard Deviation

The output of the model for any given emission rate is therefore a distribution of air pollution concentrations, which can be used to describe the percentage of homes that achieve a specific air pollution goal, such as those in the air AQG. Examples of these distributions are provided in the full description of the model (Review 3). This modelling approach can be applied to any of the pollutants for which AQGs have been determined by WHO, if emissions data are available. For practical reasons, the model has been used to provide guidance just for $PM_{2.5}$ and CO, as these pollutants together serve as sufficient indicators of the health damaging potential of household fuel combustion in most situations.

Assessment of the quality of this evidence for the purpose of these guidelines (i.e. providing guidance on emission rates that will allow the AQGs to be met), is based on validation studies. The approach to this assessment is summarized in column 4 of Table 2.3, described in more detail in Annex 4 (Assessment of evidence for Recommendation 1), and in full in Review 3.

2.3 From evidence to recommendations

2.3.1 Overview

Potential interventions for addressing the health consequences of current global patterns of household fuel combustion tend to be complex. That is, they are actually a combination of interventions, not only use of effective technologies and cleaner fuels, but also action by multiple stakeholders to ensure equitable and lasting adoption.

The development of recommendations to address these issues therefore needs to draw on a wide range of evidence. This includes population studies of fuel use and exposure, laboratory emission data, epidemiological studies of exposure and health outcomes risk, intervention impact studies, qualitative evidence on user perceptions about change, and policy analysis. These sources of evidence use very disparate methods and research paradigms. In this field, randomized controlled trials – the gold standard of evidence of effectiveness – are rare. This is partly due to the practical difficulties of conducting these, but also because their relevance for evaluating the effect of complex interventions can be limited.

Grading of recommendations assessment, development and evaluation (GRADE), the standard WHO method for assessing certainty of effect ('quality of evidence') and setting the strength of a recommendation, provides a valuable framework for moving from evidence to recommendations. However, this system does not allow for comprehensive assessment of all evidence sources relevant to this topic. It also categorizes much of the evidence available as low or very low quality, an assessment that may undervalue the contribution such evidence can make.

In order to apply GRADE principles to the development of recommendations in this field, modifications have been made to the standard method. This revised approach, termed grading of evidence for public health interventions (GEPHI), is outlined in Section 2.3.2 below. A more detailed explanation of how each stage in the process has been applied for all types of evidence contributing to the guidelines is described in 'Methods used for evidence assessment', available at: http://www.who.int/indoorair/guidelines/hhfc. This includes an explanation of how results from this revised approach can be compared with standard GRADE methods.

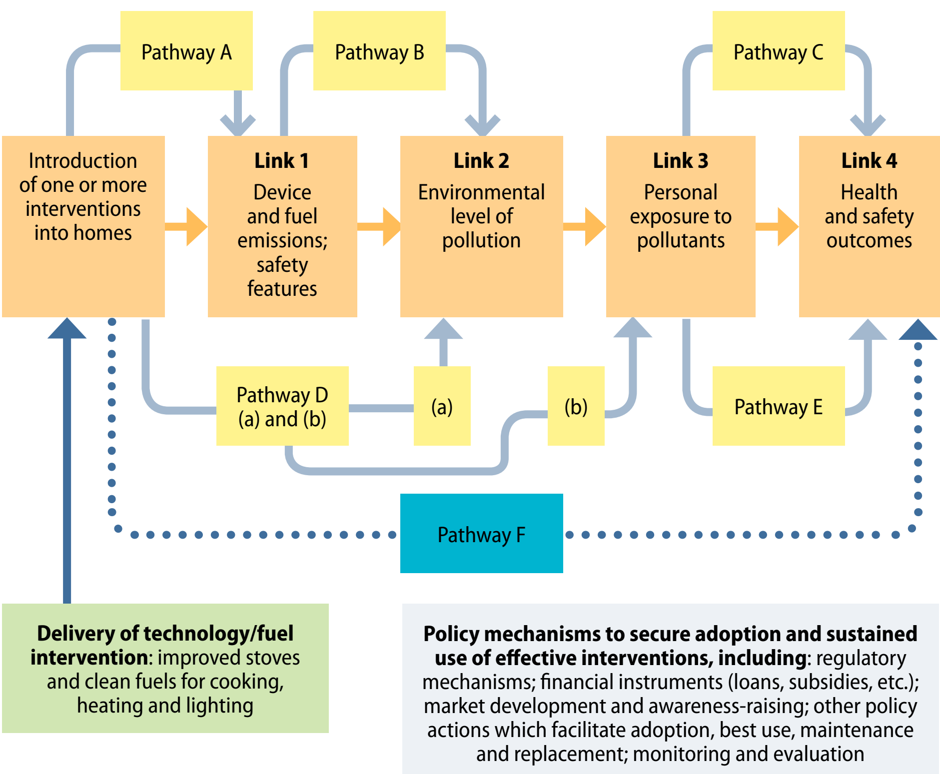
The final stage of the process, that is, using GRADE decision tables to determine the strength of each recommendation, is relevant and applicable to this topic and was carried out in the standard manner. Since one component of the table (quality of evidence) has been derived from the modified GEPHI approach, for the purposes of clarity these tables have been renamed 'decision tables for strength of recommendations.

2.3.2 The causal chain

A causal chain approach has been adopted to provide a framework for assessing the relationships between the varied types of evidence and complex interventions, (Figure 2.1). Using this approach, evidence that informs sequential and multiple links in the chain can be evaluated, and the overall coherence of evidence relating interventions to health outcomes can be assessed. For further explanation of the causal chain diagram and its application to the process of evaluating evidence, please refer to *Methods used for evidence assessment*, available at: http://www.who.int/indoorair/guidelines/hhfc.

The focus of this causal pathway is the source of the combustion emissions (for cooking, heating, lighting and other purposes in the home), since reduction of emissions is the most critical underlying factor for measures aimed at achieving the AQGs.

Figure 2.1: Causal chain relating household energy technology, fuel and other interventions to health and safety outcomes via intermediate links



It is recognized, however, that other aspects of the home environment (for example, ventilation through chimneys, windows and eaves) and behaviour (how the stove is used, time spent by individuals in various micro-environments in and around the home) also play a part in the total dose of air pollutants and hence health effects. These have an impact on the causal chain at varying points, and insofar as available evidence allows, these other aspects are considered. Examples of the factors that can be assessed at each stage of the causal chain are shown in Table 2.5. The ways in which the different types of evidence described above provide information on different components of the causal chain are illustrated by the 'pathways' shown in Figure 2.1, and elaborated in Table 2.6.

Table 2.5: Examples of factors that may be assessed at each link

Interventions	Emissions and safety features	Environmental level	Personal exposure	Health and safety outcomes
Improved solid fuel stoves Clean fuels and associated technologies for cooking, heating and lighting	Emission rates of toxic pollutants directly into homes Emissions (e.g. via flue) to ambient air Inherent safety (e.g. stability, enclosed flame, raised surface)	Concentrations of pollutants in kitchen and other areas of the home Concentrations of pollutants in ambient air that can enter the home	Exposure of children, women and men to pollutants Function of time spent in various micro-environments Exposure to open flame or risk of falling pots with hot liquids	Range of child and adult health outcomes from exposure to pollutants (ALRI, COPD, lung cancer, CVD, etc.) Safety outcomes (e.g. burns, scalds) Other health and socio-economic impacts

Table 2.6: Examples of the types of evidence providing information on pathways in the causal chain

Pathway	Type of evidence	Explanation
A	Laboratory emissions testing	Provides information on the rates of emissions of toxic pollutants, for example in relation to a unit of energy delivered
B	Emissions model	Relates emission rates to predicted concentrations in the home, based on assumptions about duration of use, air exchange rates and kitchen volume
C	Epidemiological studies	Investigate the risk of a range of disease outcomes among those using more polluting fuels compared to groups with lower exposure, for example using clean fuels; such studies may or may not include measurement of HAP and/or exposure
D (a, b)	Experimental studies	Randomized and non-randomized experimental studies that measure the impact of introducing an improved stove or clean fuel on pollutant concentrations or personal exposure
E	Epidemiological studies	Studies which include exposure assessment may allow investigation of the relationship between exposure and disease risk
F	Experimental and observational studies	Randomized and non-randomized experimental, and some observational, studies that investigate the impact of an improved stove or clean fuel directly on risk of health outcomes

Not included in the illustration of pathways in Figure 2.1 is evidence on factors influencing effective and equitable adoption of improved technologies, cleaner fuels and other interventions, as well as maintenance and replacement. These are indicated in the box in Figure 2.1, and reported in full in Review 7, *Factors influencing adoption,* available at: http://www.who.int/indoorair/guidelines/hhfc.

2.3.3 Assessment of the quality of the evidence

Assessing the strength of evidence for causal inference

When assessing the strength of evidence, a distinction was drawn between:
i) assessment of ***strength of evidence for causal inference,*** and
ii) assessment of ***confidence in effect sizes***.

The reason for taking this approach was that evidence may support causation and therefore removal of HAP exposure would result in a health benefit. The same evidence may not, however, support a high level of confidence in the estimate of health impact (i.e. risk reduction). The Hill viewpoints were used (as relevant) for the former, and GEPHI, the revised version of GRADE (described below) was used for the latter, recognizing that some aspects of the evidence could be assessed by both methods. This approach of distinguishing causal inference from confidence in effect size was used mainly for estimating the impacts of interventions on specific health outcomes.

2.3.4 Adaptation of the GRADE methodology

Modifications of the GRADE method for evidence evaluation, called in this guidelines project GEPHI include:

- Entering non-randomized experimental evidence as 'moderate quality' (but with non-controlled before and after studies more likely to be downgraded), see rationale below;
- Allowing upgrading by one level for each of the following where present:
    1. If studies carried out using different designs and in widely different settings reported a similar direction of effects (note: statistical heterogeneity led to downgrading), see rationale below.
    2. If there was supportive analogous evidence from other combustion sources, namely AAP, second-hand and active smoking.
- Assessing the coherence of evidence contributing to different parts of the causal chain.

Details of the methods used for each review are provided in column 4 of Table 2.3, and in the Assessments of quality of evidence for each recommendation (Annexes 4–7). The GEPHI assessment tables for the two evidence reviews using the PICO format (impacts of intervention on health outcomes; impacts of interventions on kitchen HAP) are presented in tabular format in Annex 5. In the interests of transparency, an explanation is provided in *Methods used for evidence assessment* available at http://www.who.int/indoorair/guidelines/hhfc of how comparison between the standard GRADE and the GEPHI assessments can be made.

Rationale for assessment of strength of non-randomized experimental studies

Experimental studies, even if non-randomized, were judged to provide stronger evidence for these guidelines, for the following reasons.

Their main application was provision of evidence on the impact of improved stoves and cleaner fuels on household air pollution and personal exposure levels. The available studies fall into two main groups:

- Those using cross-sectional or other designs in which comparison is made between homes that have started using the intervention fuel/technology mostly of their own volition and at their own expense with those continuing to use traditional methods.
- Those using experimental designs where the new fuel/technology has been introduced into the home as part of a project or study, and comparison can be made using the home as its own control, and/or with parallel groups of control homes, where available.

The GDG judged that the first approach provides weaker evidence because the decision to adopt improved fuels/technologies is very strongly associated with socioeconomic and other development-related factors. These, in turn, may influence the way the new technology is used. These factors may differ markedly between groups of homes in the first study design and can (at best) be only partly controlled for. In the second study design these factors are controlled for by virtue of the house being its own control.

Nonetheless, factors such as seasonal practices and numbers of family members being cooked for will change over time. In the better quality experimental studies, these factors have been recorded and controlled for. Non-randomized experimental studies that had not examined or addressed these issues and were therefore subject to bias were downgraded in the GEPHI assessment.

Rationale for upgrading with consistency of effect across differing settings and study designs

This draws on the Hill viewpoint which refers to the importance of *broadly the same answer being found in quite a wide variety of situations and techniques (20).* For the diverse sets of epidemiological studies reviewed for the current guidelines, techniques has been interpreted as study designs *(21).*

2.3.5 Determining the strength of recommendations

The GDG used the decision tables for strength of recommendations to agree on the quality of evidence and certainty about harms and benefits, values and preferences, feasibility and resource implications and drew on these domains to set the strength of the recommendations.

These tables are further described in *Methods used for evidence assessment* available at: http://www.who.int/indoorair/guidelines/hhfc, and the complete versions are presented in Annexes 4–7.

The **strength of the recommendation** was set as either:

- **strong**: the guideline development group agrees that the quality of the evidence combined with certainty about the values, preferences, benefits and feasibility of this recommendation means it should be implemented in most circumstances; or
- **conditional**: there was less certainty about the combined quality of evidence and values, preferences, benefits and feasibility of this type of recommendation meaning there may be circumstances or settings in which it will not apply.

2.3.6 Procedure for group decisions

All decisions were reached by consensus, either at the GDG meetings or through the WHO-hosted EZCollab web facility which was used for finalizing wording of the recommendations, and responding to the external peer review comments on the recommendations. It was agreed at the beginning of the GDG meeting that, should there be disagreement a vote would be taken and a two thirds majority would be required for a decision to be carried.

3. Individuals and partners involved in the development of these guidelines

3.1 WHO steering group (SG)

Details of the members of the WHO steering group (SG) are provided in Annex 1. The SG has been involved in all stages of planning, review of evidence, the main recommendation drafting meeting (New Delhi, April 2012), and all rounds of consultation on revisions following peer review, managed through the EZCollab web facility.

3.2 Guideline development group (GDG)

The guideline development group (GDG) was made up of people with content expertise in all areas covered by these guidelines, including relevant experience in LMICs and expertise in evidence-based guideline development. GDG selection also took into consideration the need to ensure gender balance and regional diversity. The group's members worked to define key questions, priorities and systematic review methods, served as the authors of the systematic reviews, and worked to draft the recommendations, determine the strength of these, and respond to external peer review comments.

GDG members served as chair, co-chair and rapporteurs. The full list of GDG members along with their specific roles, expertise, affiliations and geographical base is provided in Annex 1.

Figure 3.1: Guidelines development group

Participants at the main GDG meeting held at ICMR, New Delhi, April 2012

3.3 External peer-review group (EPRG)

External reviewers were drawn from subject experts, implementing agencies and partners working on various aspects of policy to secure health and related benefits from increased access to cleaner and safer household energy. Each member's name, affiliation, area of interest and geographical base is provided in Annex 1. External reviewers were asked to evaluate and comment on all evidence reviews, through two rounds, and the final recommendations. For evidence reviews, reviewer comments were made available to author groups to inform revisions, with responses documented. For the recommendations, the secretariat used external reviewer comments to make suggested revisions. The reviewers' comments and suggested changes to the recommendations were then circulated to the GDG and WHO SG for final agreement.

3.4 Management of conflicts of interest

All members of the GDG and the EPRG completed WHO declaration of interest forms. These were then reviewed by the secretariat for potential conflicts of interest (see Annex 2). A number of conflicts of interest were declared, but none required any member of the GDG or EPRG to be excluded from his or her respective role.

A briefing was provided at the beginning of the main GDG meeting in New Delhi (April, 2012) on the nature of all types of competing interests (i.e. financial, academic/intellectual and non-academic). Each member of the GDG was asked to discuss and declare to the meeting any conflicts they may have. The session took about an hour and was facilitated by a member of the WHO Guidelines Review Committee (GRC) secretariat. No further conflicts of interest were identified at this meeting and no member of the GDG was excluded from his or her respective role.

4. Recommendations

4.1 Focus of recommendations

These recommendations focus on reduction of emission rates and reduction of use (and ultimate replacement) of specific fuels (coal, kerosene) for which there are additional concerns about the risks associated with the pollutants they emit and the safety problems with their use (burns, poisoning).

It is recognized that other types of intervention, including improved ventilation and behaviour changes, may contribute to reducing levels of HAP, or exposure, or both, and are an important part of all interventions. However, reducing emission rates remains central to achieving AQGs because pollutants generated in the home enter the ambient environment, contributing to outdoor air pollution exposures, and re-enter homes, exacerbating indoor pollution. Furthermore, it is important that information, training, support and other measures to ensure best use of new technologies and fuels will be an integral part of any promotion effort, whether these are delivered through public, NGO or private sector initiatives, or – as is often likely to be the case – a mix of these.

4.2 General considerations

The following general considerations apply to the implementation of all the specific recommendations:

1. Emissions to the outdoor environment reduce ambient air quality, which in turn contributes to lower indoor air quality. Maximizing the cleanliness of combustion in household energy devices is therefore critical for both unvented **and** vented sources.
2. Local ambient air quality conditions must be considered if indoor air quality is to reach WHO AQGs given the possibility of infiltration of outdoor air into the indoor environment. Given consideration (1) (above), household energy interventions of low emission technologies will be more likely to result in achieving WHO AQGs if they are undertaken comprehensively at the community level, and ensuring that contributions to ambient air from other non-household sources are successfully mitigated.
3. Households have multiple energy needs, including for cooking, heating and lighting. Account should be taken of compensatory actions in response to, for example, replacing an open fire for cooking with a clean fuel or enclosed and well-insulated solid fuel stove. Since these new technologies will provide less

radiant heat and light, or be unaffordable as a heating fuel, the household may revert to use of the open fire to obtain light and warmth.

4. Policy directed at increasing access to alternative, cleaner household combustion devices and fuels should ensure these products are available and affordable. If such fuels and devices are priced beyond the reach of the poorest groups, and/or supply is insufficient, harms may result from energy poverty, including inadequate food preparation, space heating and lighting.
5. A systematic approach to monitoring and evaluation (M&E), with feedback to government, manufacturers, suppliers, development groups, the research community and the public, is critical to ensure progress towards meeting these guidelines. Further consideration of approaches to M&E is provided in Section 5.7.
6. Safety: Household fuel combustion, particularly in LMICs is associated with a substantial risk of injury, including through burns, scalds, and house fires. Technologies and fuels introduced with the purpose of reducing emissions have the potential to reduce these risks, but such risk reduction should not be assumed. Accordingly, approaches to minimize exposure to emissions should be taken in a way that incorporates safety concerns, and efforts (including during design and through testing and field-based evaluation) should be made to reduce such risk of injury as much as possible.

SPECIFIC RECOMMENDATIONS

4.3 Recommendation 1: Emission rate targets

Scoping question 1: What device and fuel emission rates are required to meet WHO (annual average) air quality guidelines and interim target-1 (IT-1) for $PM_{2.5}$ and the (24-hour average) air quality guideline for CO?

Recommendation	Emission rate targets		Strength of recommendation
Emission rates from household fuel combustion should not exceed the following emission rate targets (ERTs) for $PM_{2.5}$ and CO.	$PM_{2.5}$ (unvented)	0.23 (mg/min)	**Strong**
	$PM_{2.5}$ (vented)	0.80 (mg/min)	
	CO (unvented)	0.16 (g/min)	
	CO (vented)	0.59 (g/min)	

Remarks

1. These ERTs will result in 90% of homes meeting WHO AQG values for $PM_{2.5}$ (annual average) and CO (24-hour average). This assumes model inputs for kitchen volume, air exchange rate and duration of device use per 24 hours, as set out in Table R1.1.
2. Intermediate emission rate targets (IERTs) show the rates that will result in 60% of homes meeting IT-1 for $PM_{2.5}$ (Table R1.2) and 60% of homes meeting the 24-hour AQG for CO (Table R1.3). The value of 60% is arbitrary, but was selected so that a majority of homes would meet the specified guideline level.
3. Separate guidance is provided for unvented and vented stoves as those technologies with chimneys or other venting mechanisms can improve indoor air quality through moving a fraction of the pollutants outdoors.
4. Table R1.2 illustrates the percentage of homes that would meet IT-1 (35 $\mu g/m^3$) for $PM_{2.5}$.
5. Devices should meet both $PM_{2.5}$ and CO ERTs to be considered to have met the recommendation.
6. For this recommendation, a high quality of evidence was available on the average concentrations of $PM_{2.5}$ and CO at which health risks are minimal, as described in previously published WHO AQGs (i.e. WHO air quality guidelines, 2005 update *(14)*, WHO guidelines for indoor air quality: selected pollutants *(13)*). A moderate quality of evidence was available for laboratory testing of emissions from fuel and technology combinations, and for the emissions model. A low quality of evidence was available for field testing of emissions from fuel and technology combinations.

Table R1.1: Input distributions for air exchange rates, kitchen volumes and device burn times used in the development of the ERTs

Parameter	Unit	Geometric mean	Range		SD[a]
			minimum	maximum	
Air exchange rate (α)	per hour	15	5	45	7.5
Kitchen volume (V)	m^3	30	5	100	15
Device burn time	hours per day	4	0.75	8	2

[a] Standard deviation

Table R1.2: Emission rate targets (ERT) for meeting WHO AQGs for $PM_{2.5}$

ERT	Emission rate (mg/min)	Percentage of kitchens meeting AQG (10 µg/m^3)	Percentage of kitchens meeting AQG IT-1 (35 µg/m^3)
Unvented			
Intermediate ERT	1.75	6	60
ERT	0.23	90	100
Vented			
Intermediate ERT	7.15	9	60
ERT	0.80	90	100

Table R1.3: Emission rate targets (ERT) for meeting WHO AQGs for CO

ERT	Emission rate (g/min)	Percentage of kitchens meeting 24-hour. AQG
Unvented		
Intermediate ERT	0.35	60
ERT	0.16	90
Vented		
Intermediate ERT	1.45	60
ERT	0.59	90

Summary of the evidence

Three sources of evidence inform this recommendation, namely:

a) published WHO AQGs for $PM_{2.5}$ and CO;
b) a systematic review of health damaging pollutant emissions from household stoves;
c) a model linking emission rates with predicted indoor $PM_{2.5}$ and CO concentrations.

a) WHO AQGs for $PM_{2.5}$ and CO

Published guidelines for air quality include those for $PM_{2.5}$ and CO, which are stated to apply to all non-occupational micro-environments, that is, both indoor and outdoor *(13, 14)*. These values, which are based on the systematic reviews conducted for the 2006 and 2010 AQGs, are those for which there is no or minimal excess risk of adverse health outcomes and are therefore considered to be the goal for all populations. This evidence was assessed as **high quality**.

The annual average concentration for $PM_{2.5}$ and the 24-hour average for CO are used as reference values for this recommendation. In 2006, as part of the 2005 update, WHO published **interim air quality targets** for $PM_{2.5}$ (see Box 1), in order to provide incremental steps for air quality improvement in settings where baseline levels are high (or very high) and short-term achievement of the guideline levels might be unrealistic in practice *(14)*. IT-1 has been selected for use as an incremental step in the current recommendation.

Box 1 – WHO interim targets (IT) for annual mean $PM_{2.5}$ (μg/m^3)

IT-1	35
IT-2	25
IT-3	15
Guideline	10

Source: WHO 2006

b) Systematic review of health damaging pollutant emissions from household stoves

A systematic review was conducted to summarize the evidence from both laboratory and field-based studies of emission rates of major health-damaging pollutants from household combustion devices and fuels (Review 2: Pollutant emissions). The data available from laboratory studies are generally well-standardized in contrast to the relative paucity and variability in quality of data from field-based (in-home) studies. This is due in part to the lack of appropriate protocols for, and practical difficulties in, conducting in-home measurements of typical stove usage. Results from the laboratory studies confirm the high emission rates from traditional solid fuel stoves, and the very much lower rates from clean fuels such as LPG. For example, $PM_{2.5}$ emission rates were 1.2 and 0.015 g/MJ energy delivered for traditional biomass stoves and LPG, respectively, and for CO the rates were 19.5 and 0.6 g/MJ energy delivered, respectively. There were very few studies of advanced combustion (e.g. fan-assisted) solid fuel stoves but the laboratory data available for these stoves found reductions in $PM_{2.5}$ emission of around 80%. Comparison of the few field studies with laboratory evidence found generally higher $PM_{2.5}$ emissions from field studies, but differences between laboratory and studies varied by stove type. Findings were assessed as of **moderate quality** for the laboratory evidence, and of **low quality** for the field evidence. This highlights the need for more extensive measurement of emissions in situations reflecting more closely real-life usage, and with protocols which are better adapted to this purpose.

c) Model linking emission rates with household air pollution

The emissions model (see Review 3) was developed to provide a practical means of selecting between alternative intervention options, based on the rate of emission of two critical pollutants, $PM_{2.5}$ and CO. This considers three alternative approaches to modelling air quality from emission rates, and selects a single zone box model as being the most practical for the current purpose. The model uses empirically-derived inputs of emission rates, room volume, air exchange rate and duration of device use, combined with a Monte Carlo simulation approach to predict distributions of indoor area concentrations of $PM_{2.5}$ and CO. The results are presented as the percentage of homes meeting the WHO annual AQG (10 $\mu g/m^3$) and IT-1 (35 $\mu g/m^3$) for $PM_{2.5}$ and the 24-hour AQG for CO (7 mg/m^3). Specifically, the ERT is set so that 90% of homes with the intervention would meet the AQGs for $PM_{2.5}$ and CO, and 100% would meet the IT-1 for $PM_{2.5}$. One less demanding intermediate ERT is also provided to illustrate the emission rate required for 60% of homes to meet the IT-1 for $PM_{2.5}$ and the 24-hour AQG for CO.

Input data for this model (air exchange rate; kitchen volume; duration of time the device is used per 24 hours) were derived from empirical evidence obtained from India. Although relatively limited to date, external validation of the model, which includes comparison with studies from both within and outside India derived from Reviews 5 and 6, shows good agreement for use of a standard rocket-type solid fuel stove. However, there is underestimation of observed kitchen concentrations for vented solid fuel stoves and for clean fuels. In particular, using laboratory emission data for liquefied petroleum gas (LPG), the model shows that 94% of homes would meet the AQG for $PM_{2.5}$, over 99% would meet the IT-1, and all homes would meet the 24-hour AQG for CO. In practice, higher levels of $PM_{2.5}$ have been observed in LPG-using homes, with the mean value generally above the IT-1. These findings are likely to be due to contributions from other combustion sources in and around the home, and include lighting from kerosene lamps and ingress of AAP from neighbouring homes and other external sources.

It was concluded that these findings do not threaten the validity of the model nor its application to these guidelines, but do emphasize the importance of controlling other pollution sources if AQGs are to be met. The quality of the evidence provided by the model was assessed as of **moderate quality**, as there is some room for improvement through use of regionally-adapted input data, and more extensive validation.

In recognition of the current limitations to the empirical basis for input data, a research recommendation has been included which proposes three primary objectives:

1. Building a regional and context specific database for model input data.

2. Defining a set of standardized protocols for collecting these data which can facilitate development of a systematic and comparable database.
3. Development of user-friendly software platforms for predicting indoor air quality based on location-specific input data.

Implementation guidance

1. For this recommendation, which provides guidance on emission rates for household technologies and fuels (for cooking, heating and lighting) required to meet the guidelines, we focus on the two most important products of incomplete combustion for health, CO and $PM_{2.5}$. However, we recognize the importance of other pollutants as well (e.g. the toxic components of coal or emissions of NO_2 from gas appliances).
2. The model allows emission rates to be related to indoor area concentrations of $PM_{2.5}$ and CO. By using distributions of values for the input variables (air exchange rates, kitchen volume and device burn time per day) and a Monte Carlo simulation approach, the results are presented as the percentage of all homes (receiving the intervention device/fuel) which would meet target levels of air quality (i.e. the AQG or IT-1). For further explanation of the model and data sources, please see Review 3 (Emissions model).
3. It is proposed that an interactive version of this model will be developed. This will allow users to input locally derived data on kitchen volume, air exchange rate and duration of use of the stove per day.
4. Programmes[1] promoting fuel/stove combinations for health should move toward the most stringent emissions level–the emissions target itself–over time, accompanied by measures to optimize use, and repair or replace non-compliant devices so that the emission levels are maintained.
5. There are many areas where outdoor or semi-outdoor cooking is prevalent, for which ventilation is clearly greater and would result in a higher percentage of homes meeting the AQGs than those estimated for the ERTs. Studies show that people cooking outdoors still receive high exposure when using traditional stoves. Furthermore, as previously discussed, emissions to the outdoor environment reduce community ambient air quality, which in turn contributes to lower indoor air quality. Thus, although the emission rate targets apply to indoor environments, maximizing protection can only be achieved if all devices meet these targets regardless of indoor or outdoor usage.

[1] The term programmes is used in an inclusive manner to include public, private and NGO actors contributing to the planning, delivery and evaluation of initiatives seeking to increase the use of cleaner, more efficient and safer household energy solutions.

6. The recommended ERT (and intermediate ERTs) protect against longer-term impacts of CO but are not directly related to short-term emissions limits needed to protect against acute effects of this gas (CO poisoning), including through malfunctioning appliances.
7. The use of multiple devices to meet total daily home energy needs is common. These ERTs apply to each individual device used for cooking, heating or lighting. If the sum of the duration of use per day across all devices is not exceeded by that assumed by the model, the percentage of homes meeting the AQGs will be the same, assuming all devices meet the ERTs.

Recommendation 1 is intended to provide guidance on predicted area concentrations of $PM_{2.5}$ and CO in kitchens, based on emission rates obtained through testing of the stove or other device under consideration. Effective management of HAP levels, however, also requires that assessment of use and performance in homes is also performed as part of a M&E strategy (see also Recommendation 2).

Research and development recommendation[1]

As inputs for the model (air exchange, kitchen volume, device use time per day) are based on data from India, the model could be enhanced by collection and application of more comprehensive and region-specific data for modelling the relationship between technology emissions and indoor air quality.

Table R.1.4: Emissions model

Current state of the evidence	Current data on kitchen volumes, ventilation rates, device usage times, and other potential model inputs are relatively scarce.
Population of interest	Populations, mostly in LMICs, currently relying mainly on solid fuels for cooking and heating, and kerosene for lighting.
Interventions of interest	Technologies with the most potential to result in homes meeting the AQGs for $PM_{2.5}$ and CO.
Comparisons of interest	Relative performance of stove/fuel combinations predicted to meet AQGs for specific regions/contexts.
Outputs of interest	Three primary outputs are identified: 1. Building a regional and context-specific database for model input data. 2. Defining a set of standardized protocols for collecting these data which can facilitate development of a systematic and comparable database. 3. Development of user-friendly software platforms for predicting indoor air quality based on location-specific input data.
Time stamp	Most recent data used in the modelling were from March 2012.

[1] All research recommendations in these guidelines are presented using the EPICOT framework: this summarizes key components of research recommendations under six headings: state of the **E**vidence; **P**opulation; **I**nterventions; **C**omparisons; **O**utcomes (or Outputs); **T**ime stamp.

4.4 Recommendation 2: Policy during transition to technologies and fuels that meet WHO air quality guidelines

Scoping question 2: In light of the acknowledged challenges in securing rapid adoption and sustained use of very low emission household energy devices and fuels, particularly in low-income settings, what approach should be taken during this transition?

Recommendation	Strength of recommendation
Governments and their implementing partners should develop strategies to accelerate efforts to meet these air quality guidelines ERTs (See Recommendation 1). Where intermediate steps are necessary, transition fuels and technologies that offer substantial health benefits should be prioritized.	**Strong**

Remarks

1. Implementing agencies should work to increase access to, and sustained use of, clean fuels as widely and rapidly as is feasible. Selection of optimal interim technologies and fuels should be made on the basis of evidence provided in these guidelines, as outlined below.
2. Evidence provided in the systematic review of *Intervention impacts on HAP and exposure* (Review 6) demonstrated that despite achieving large percentage reductions of $PM_{2.5}$ compared to baseline (solid fuels with traditional stoves) none of the improved solid fuel stoves reviewed reached the WHO IT-1 for annual average kitchen $PM_{2.5}$ (and therefore did not meet the AQG). A few types of vented (chimney) stoves did reach levels close to WHO IT-1, in the range of 40–60 µg/m^3. These findings can be used as a guide to the current in-field performance of a range of technology and fuel options.
3. Evidence provided on the relationship between exposure and risk of child acute lower respiratory infection (ALRI) described in the systematic review 'Health risks of HAP' (Review 4) can be used as a guide to assessing the magnitude of the health benefit from the intervention under consideration.
4. Technologies and fuels being considered for promotion should have emission rates tested (see Recommendation 1), and where possible, actual air pollution levels in everyday use in homes should be measured.
5. Plans for the development of guidance and tools to assist with the assessment of optimal interventions are described in Section 5 of the guidelines.
6. For this recommendation, quality of evidence was moderate for health risks, the IER functions and population levels of exposure to HAP. The quality of evidence for impacts of interventions on HAP was moderate for natural draft

solid fuel stoves, but low for advanced solid fuel stoves and clean fuels. The quality of evidence available for factors influencing adoption was moderate.

Summary of evidence

Four sets of evidence contributed to this recommendation, namely those addressing:

a) health impacts of HAP;
b) population levels of HAP and exposure;
c) impacts of interventions on HAP and exposure;
d) factors influencing the adoption and sustained use of improved stoves and clean fuels.

a) Health impacts of household air pollution

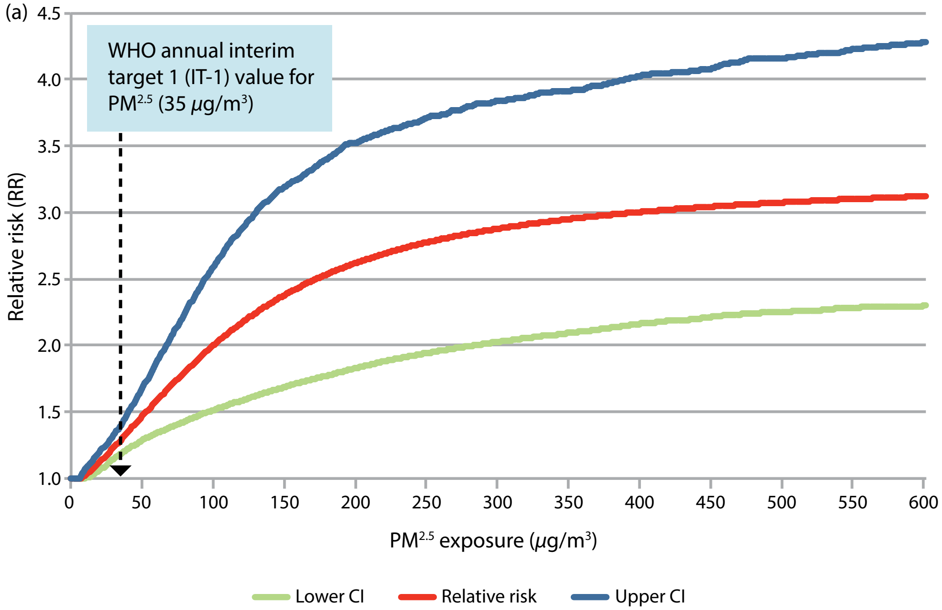
A review (a summary and synthesis of systematic reviews and other evidence) of health impacts of HAP (see Review 4) was prepared to assess the evidence on health risks from HAP exposure, including the relationships between exposure level and disease risks. A substantial number of child and adult health outcomes were found to be associated with HAP exposure, most with moderate to strong evidence for causal inference, indicating the range of health benefits expected from controlling this source of air pollution. Assessment of intervention effect estimates for the important outcomes (defined on the basis of disease burden and/or stronger causal evidence) found that reducing HAP to levels experienced by the unexposed groups in these studies (estimated to be 35–80 μg/m^3 $PM_{2.5}$) would reduce disease risk by between 20% and 50%. This evidence was assessed (GEPHI) as being of **moderate quality**.

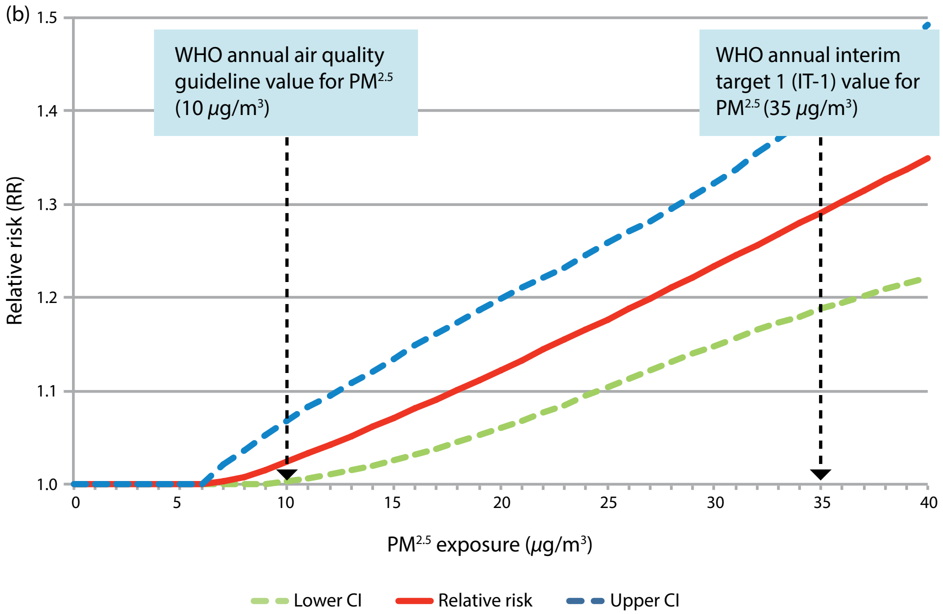
Exposure-response evidence was available from two studies of child ALRI, and modelled synthesis of exposure and risk data was obtained through systematic reviews for four sources of combustion pollution (AAP, second-hand tobacco smoke, HAP, and active tobacco smoking). These modelled exposure-response analyses are termed integrated exposure-response functions, or IERs. This evidence was assessed as being of **moderate quality.**

The strongest empirical exposure-response evidence for HAP was that for child ALRI, and is presented in Figure R.1 (a and b). This shows that the relative risk (RR) for ALRI is predicted to be 3.12 (95% confidence intervals (CI): 2.30, 4.28) by the model, that is, risk of ALRI is more than three times greater at high levels of $PM_{2.5}$, exposure (600 μg/m^3) than at the counterfactual level[1] and remains double at 100 μg/m^3, (RR=2.0 (95% CI: 1.51, 2.59)), Figure R.1 (a).

[1] The counterfactual level used in the IER function is a 'theoretical minimum risk exposure distribution' (TMRED) centred on 7.5 μg/m^3 $PM_{2.5}$.

Figure R.1: The relationship between level of $PM_{2.5}$ exposure (µg/m³) and relative risk (95% CI) of child ALRI, based on the integrated exposure-response (IER) function, for (a) exposure over the range 0–600 µg/m³, and (b) over the range 0–40 µg/m³ which spans the WHO annual AQG for $PM_{2.5}$ and the interim targets (IT-1 to IT-3).





At 35 μg/m³ (the WHO IT-1) the predicted RR is 1.29 (95% CI: 1.19, 1.40), implying that while there is some residual risk this is much reduced. Below 35 μg/m³, the RR continues to fall steeply, reaching 1.02 (95% CI:1.00, 1.07) at the WHO AQG level of 10 μg/m³, Figure R.1 (b).

The main conclusion from this evidence is that due to the non-linear shape of the IER for child ALRI and for three of the other outcomes (ischaemic heart disease (IHD), stroke, COPD), exposure needs to be reduced to levels at or below the WHO IT1 for $PM_{2.5}$ (35 μg/m³ annual average) to prevent most cases of disease attributable to HAP exposure.

b) Systematic review of population levels of HAP and exposure levels

This systematic review of population levels of HAP and exposure (Review 5) provides a representative description of average (24-or 48-hour) $PM_{2.5}$ and CO levels in kitchens, outdoor air close to homes, and personal exposure for women and children. It compiled observational rather than experimental studies, most from rural areas but a few from urban settings. The focus was on LMICs where solid fuels are widely used, but data from residential use of wood fuel in developed countries were also included.

In regions where solid fuels are widely used, average levels of $PM_{2.5}$ were very high in kitchens (972 μg/m³) and for personal exposure of women (267 μg/m³) and children (219 μg/m³). Average kitchen levels of CO were also high (8.6 ppm), but were lower outdoors (1.05 ppm) and were also lower for personal exposure of women (3.63 ppm) and children (2.66 ppm). Average outdoor levels of $PM_{2.5}$ in areas where solid fuels were widely used were also high (106 μg/m³). Improved solid fuel stove users had lower average kitchen levels of $PM_{2.5}$ (146 μg/m³) and CO (3.98 ppm) but only three studies were available. Users of LPG also had lower kitchen levels of $PM_{2.5}$ (66 μg/m³) and CO (1.30 ppm) but these results were also based on only three studies.

The evidence from these observational studies comes mostly from homes that have opted to adopt improved stoves or clean fuels, rather than obtaining them through a specific project or programme. The results show that such homes continue to experience high levels of HAP in kitchens, even with clean fuels, with concentrations well above the WHO IT-1 of 35 μg/m³ $PM_{2.5}$. This is probably due to some continued use of traditional fuels and stoves in homes that have adopted LPG, and the high levels of local AAP, even in rural areas. This evidence was assessed to be of **moderate quality** for solid fuels but of **low quality** for clean fuels due to the relatively few studies available for the latter.

Studies of residential wood combustion in developed countries which mainly report emissions or ambient (rather than indoor) air pollution were also reviewed. Contributions from residential wood combustion of up to 25 μg/m³ $PM_{2.5}$ are reported. Levels are rarely higher than this, although short-term concentrations of around 100 μg/m³ $PM_{2.5}$ may be experienced.

c) Impacts of interventions on HAP and exposure

A systematic review on the impacts of a range of interventions in everyday use (solid fuel stoves with and without chimneys, advanced combustion stoves, clean fuels) on HAP concentrations of average (24-or 48-hour) $PM_{2.5}$ and CO in homes (Review 6) was conducted. In contrast to the review of population levels of HAP and exposure summarized above (Review 5), this systematic review was restricted to experimental studies (the majority), and a smaller number of cross-sectional studies that related to intervention programmes. A total of 38 eligible studies (providing 98 estimates) were included, 27 studies providing data on kitchen PM, three on personal PM, 26 on kitchen CO and five on personal CO. There were relatively few studies describing the impacts of advanced combustion solid fuel stoves and clean fuels.

A key finding was that, despite achieving large percentage reductions of $PM_{2.5}$ compared to baseline (solid fuels with traditional stoves), none of the improved solid fuel stoves reached the WHO IT-1 for annual average kitchen $PM_{2.5}$ (and therefore not the AQG). A few types of vented (chimney) stoves did reach levels close to WHO IT-1, in the range of 40–60 $\mu g/m^3$. The weighted post-intervention averages were 370 and 410 $\mu g/m^3$ for solid fuel stoves with and without chimneys, respectively. This evidence was assessed (GEPHI) as being of **moderate quality**. The small number of studies of clean fuels (LPG, ethanol, electricity) found post-intervention weighted kitchen average levels in the range 80–280 $\mu g/m^3$, and this evidence was variously assessed as being of **moderate or low quality,** mainly due to the paucity of studies. As noted for the review of cross-sectional studies (above), the reasons for such high levels with clean fuels lie with continued multiple stove and fuel use in homes, emissions from neighbouring homes, and other combustion sources.

For CO, around two-thirds of the stoves and fuels (all types) resulted in kitchen concentrations below the 24-hour guideline. Post-intervention weighted averages were 4.2 and 6.6 ppm for solid fuel stoves with and without chimneys, respectively (the WHO 24-hr average AQG of 7 mg/m^3 is equivalent to 6.11 ppm at a temperature of 25 °C (77 °F) and a pressure of 1 atmosphere (760 mm Hg). This evidence was assessed as being of **moderate quality**.

Relatively few studies of personal exposure were available, and those available only assessed exposure for users of vented solid fuel stoves. This evidence was assessed as being of **low quality**.

d) Factors influencing the adoption and sustained use of improved stoves and clean fuels

A systematic review of factors influencing adoption of a range of solid and cleaner fuel interventions was conducted in order to identify the barriers to effective adoption at scale – especially for low-income communities – and to inform the development of a tool for the planning and evaluation of future programmes (Review 7). The review identified 101 relevant studies, including quantitative, qualitative and policy/case studies. More than 20 factors, many of them common across stove and fuel types, were found to act as barriers or enablers for adoption and sustained use. Factors were categorized under seven domains spanning community level issues (household characteristics, performance of the stove/fuel, user perceptions) through to national and policy level issues (financing, regulation, market development and programmatic factors).

A common finding was that many (if not most) households continue to use the existing device or fuel when a new one is introduced, for cultural and practical reasons such as lack of affordability and uncertain supply in the case of a commercial fuel such as LPG. An important conclusion therefore was that for most households, the transition to exclusive use of very low emission devices and fuels will occur over time, with a progressive shift towards a higher proportion of energy usage provided by the newer, cleaner options. It is also the case that in more economically challenging conditions, households may revert to increased use of traditional stoves and fuels.

While a rapid shift to clean fuel may well be possible for wealthier social sectors when policy ensures affordability, supply and safety through effective regulation, these are probably the minority among current solid fuel users. For poorer, more rural communities, the shift may be more gradual. The review identified factors which can inform policy for ensuring that this shift is as rapid, effective and sustained as possible. This evidence was assessed as being of **moderate quality**, although it was noted that there were no studies on adoption of advanced-combustion solid fuel stoves and relatively few studies for ethanol fuel.

Implementation guidance

1. To achieve large reductions in exposure to reach AQG levels of $PM_{2.5}$, the stove or fuel needs to be capable of meeting the specified emissions target and used more or less exclusively. These should displace the existing more polluting technologies and be maintained and replaced over time. Review 7 has summarized factors influencing adoption and sustained use of household energy interventions (solid fuel stoves, LPG, biogas, alcohol fuels and solar cooking), and will inform the development of implementation guidance and tools, further described in Section 5.
2. The term improved stove should be used with explicit reference to the parameter being improved. It is recognized that new stove designs may bring a wide range of benefits to households and communities, including fuel, cost and time savings, and safety, in addition to health benefits from reduced emissions. Any description implying a performance improvement in respect of health risks relative to open fires and traditional stoves, however, should be

based on measured emissions, and/or measured levels of HAP and exposure in the home. These should be measured using approved testing methodologies and in reference to the WHO AQGs air quality guidelines and the ERTs provided in Recommendation 1.

3. The systematic review of the impacts of interventions found that most of these achieved CO levels below the 24-hr WHO guideline of 7 mg/m^3. However, not all do so and the average kitchen post-intervention level for non-vented solid fuel stoves exceeded this value. These results for 24-hour average CO may hide short-term high exposures to this pollutant. Within a home, both the 15-minute (100 mg/m^3) and 1-hour (35 mg/m^3) WHO guidelines for CO may be breached by short-term high emissions of CO, while still meeting the 24-hour average of 7 mg/m^3 overall, if emissions for the rest of the day were low.

Research recommendations

The key gaps in evidence relating to this recommendation lie with (a) field evaluation of alternative technologies and fuels in everyday use, and (b) policies to achieve rapid and sustainable transitions to low emission, efficient and safe options suitable for different population groups.

Recommendations for research addressing these two priorities are proposed in the tables below (Table R.2.1, R.2.2).

Table R.2.1: Comprehensive field evaluation of intervention options

Current state of the evidence	The current evidence on the adoption, use and impacts of interventions, both low-emission improved solid fuel stoves and clean fuels, is scarce.
Population of interest	Populations, mostly in LMICs currently relying mainly on solid fuels for cooking and heating, and kerosene for lighting.
Interventions of interest	Clean fuels for cooking, heating and lighting and improved solid fuel stoves (those shown to reduce emission rates in a high percentage of homes to levels listed in Recommendation 1) in everyday use, and over time (i.e. 12 months or more).
Comparisons of interest	Traditional stoves and solid fuels used for cooking and heating and kerosene for lighting.
Outcomes of interest	Outcomes should include the following: intensity of use of all stoves in the households, and the extent to which multiple technologies and fuels are used; prospects for community-wide adoption; household air quality and personal exposure levels; fuel use (e.g. by use of the kitchen performance test); user satisfaction assessment and reasons for choices made and behaviours observed; health outcomes in selected settings where this can be carried out cost-efficiently.
Time stamp	Current systematic review included studies up to July 2012.

Table R.2.2: Development and evaluation of policy for rapid and sustainable transition

Current state of the evidence	The evidence available on policy for achieving rapid transition to clean household energy technologies and fuels is patchy. The systematic review on factors influencing adoption (Review 7) summarizes the available evidence on enabling and limiting factors, but there are a number of gaps. Evidence is not linked to intervention effectiveness, and further prospective research is required.
Population of interest	Populations, mostly in LMICs currently relying mainly on solid fuels for cooking and heating, and kerosene for lighting.
Interventions of interest	Policies supporting rapid transition to clean, efficient and safe household energy technologies, taking account of circumstances of different segments of society, and employing innovation and evidence-based best practice.
Comparisons of interest	Some contemporaneous comparisons may be possible, but generally – due to the need for policy to address multiple levels across society – evidence of effectiveness will be gathered through the evaluation that tracks inputs, outputs and outcomes, and using mixed methods (combining qualitative and quantitative approaches) to understand linkages between policy and impact.
Outcomes of interest	To be further developed, but including: scale and timeframe of adoption and sustained use of technologies and fuels meeting agreed standards; impacts on equity of access; costs at various levels (society, communities and households); effectiveness of financial instruments; HAP, exposure and (where possible) health impacts.
Time stamp	Systematic review included studies up to June 2012.

4.5 Recommendation 3: Household use of coal

Scoping question 3: Should coal be used as a household fuel?

Recommendation	Strength of recommendation
Unprocessed[1] coal should not be used as a household fuel.	**Strong**

Remarks:

1. This recommendation is made for the following three reasons, over and above the documented health risks from products of incomplete combustion of solid fuels.
   i. Indoor emissions from household combustion of coal have been determined by the IARC to be carcinogenic to humans (Group 1).

[1] Unprocessed coal refers to forms of this fuel that have not been treated by chemical, physical, or thermal means to reduce contaminants. Unless otherwise specified, this applies throughout the discussion of this recommendation, as the great majority of the available evidence reviewed draws on studies in which households used unprocessed coal. Where reference is made to one of the few studies on the use of coal which has been processed to reduce toxic emissions, this is stated.

   ii. Coal – in those parts of the world where coal is most extensively used as a household fuel and the evidence base is strongest – contains toxic elements (including fluorine, arsenic, lead, selenium and mercury) which are not destroyed by combustion and lead to multiple adverse health effects.
   iii. There are technical constraints on burning coal cleanly in households.
2. For this recommendation, a high quality of evidence was available from the IARC assessment of carcinogenicity, while a moderate quality of evidence was available for the risk estimates for lung cancer and toxic contaminants.

Summary of evidence

The evidence for this recommendation is drawn from the following sources:

a) assessment by IARC of the carcinogenicity of emissions from household combustion of coal;
b) systematic reviews of risk of specific outcomes with household use of coal, and evidence from the IER function relating $PM_{2.5}$ exposure level to lung cancer risk;
c) systematic review of health risks associated with toxic contaminants in coal.

a) Assessment of carcinogenicity

Emissions from the household use of coal are classified by IARC as a Group 1 carcinogen, based on a review of exposure data, studies of cancer in humans, studies of cancer in experimental animals, and mechanistic and other evidence *(22)*. It is noted that the type of coal used by households in most, if not all, of the epi demiological studies in this assessment, is raw coal (that is, it has not been processed to reduce potentially health-damaging emissions). This evidence was assessed as being of **high** quality.

b) Risk of specific disease outcomes

Review 4 (Health impacts of HAP) reported on systematic reviews of lung cancer and COPD associated with household coal use which found significantly increased risks for both outcomes. As per the IARC assessment, most (if not all) of the epidemiological evidence relates to household use of unprocessed coal. As relatively few studies were available for COPD, GEPHI assessment was only conducted for lung cancer. This found an intervention effect estimate of 0.46 (95% CI: 0.35, 0.62) which was assessed as being of **moderate** quality.

The IER function reported in Review 4 provides evidence on the relationship between $PM_{2.5}$ exposure and lung cancer at low levels of exposure. This is not specific to coal combustion, and where sources do include coal, a variety of types (including some processed ones) may have been used (Figure R.2). This shows that risk remains elevated down to the counterfactual level (around 7.5 $\mu g/m^3$

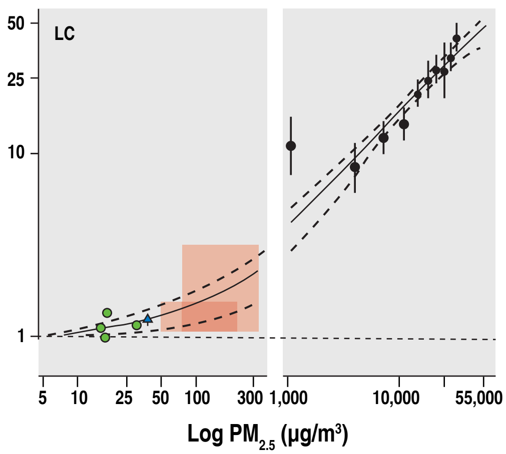
of $PM_{2.5}$), implying that even lower levels of $PM_{2.5}$ exposure falling between the AQG of 10 μg/m³ and the IT-1 of 35 μg/m³ present a risk of lung cancer.

c) Toxic contaminants

Coal commonly contains toxins including arsenic, fluorine, mercury, lead and selenium. These are not destroyed on combustion and have been linked to serious adverse health outcomes including arsenicosis, skeletal and dental fluorosis, particularly in China where household coal use has been (and remains) most widespread, and where this issue has been most extensively studied (Review 8). While these health impacts are well established, the evidence available does not provide a well-quantified estimate of population risk, and hence is of low quality. Furthermore, most evidence comes from studies in limited geographical areas of China.

Additional contextual evidence can be derived from the effects of bans on the use of coal in homes in urban areas in many developed countries. The key reason for these restrictions is that clean combustion of coal is not easy to achieve at household level. The benefits of this policy have been documented, for example in Dublin, Ireland, although approved (i.e. smokeless) coals are still permitted in some countries for household use in urban areas. In Dublin, banning household combustion of bituminous coal led to a 70% reduction in average black smoke levels and significant reductions in deaths from respiratory and cardiovascular disease *(24)*.

Figure R.2: Integrated exposure-response function for relationship between combustion-derived $PM_{2.5}$ exposure and lung cancer (LC)



X-axis is as stated; Y-axis is relative risk (RR)

Data points are shown in green = AAP; blue = SHS; pink squares = HAP; black = ATS. The predicted values of the Integrated Exposure-Response model are indicated by the solid line and 95% confidence interval by the dashed line, and similarly risk estimates (and 95% CIs) from the literature are shown for AAP, SHS and ATS, colour coded as described above. Risk estimates from the systematic review (see Review 4) for HAP are displayed as pink shaded boxes, the lower values for men, and the higher values for women. This form of presentation has been used since the studies from which the HAP risk estimates are derived have not measured HAP or exposure: the exposure level in these studies was estimated to be 300 μg/m³ in 'exposed' and 70 μg/m³ in 'unexposed' groups for women, and 200 μg/m³ in 'exposed' and 45.5 μg/m³ in 'unexposed' groups for men (65% of the women's values). The horizontal part of the shaded box represents the exposure contrast and the vertical part the risk from the meta-analyses.

(Source: Burnett et al. 2014) *(23)*

A number of interventions have been introduced to mitigate severe health problems caused by toxins in coal and reduce exposures to the high concentrations of HAP resulting from unvented coal stoves. Fixing agents have been shown to reduce fluorine and arsenic emissions by 65% and 75% respectively (although not eliminated). A study on a combined behaviour and stove intervention reported reductions of 75% in urinary arsenic levels among those with arsenicosis. However, those studies did not evaluate impacts of the interventions on health outcomes.

Cohort studies in Xuanwei have shown that long term use of an improved coal stove with a chimney has reduced the risks of lung cancer *(25),* COPD *(26)* and adult ALRI mortality *(27).* However, household coal combustion, even with the cleaner coals and higher quality stoves more commonly used in cities, still produces relatively high levels of emissions of PM, sulfur dioxide (SO_2), and black carbon. For this reason coal use has been banned in many urban areas around the world (see Dublin example above). This approach, reducing health risks from household coal combustion by restricting its use, is supported by the finding from the IER function (Figure R.2) that lung cancer risk remains elevated right down to the very low counterfactual level of 7.5 $\mu g/m^3$ of $PM_{2.5}$.

Although outdoor air is generally cleaner in rural areas, evidence from China shows that rural coal-using residents experience higher respirable PM exposures than urban residents. This is partly due to the longer duration of combustion of coal for cooking and more or less continuous combustion of coal for space heating. Unlike biomass, and particularly LPG and natural gas, it is hard to start or stop a coal fire quickly in a household cooking or heating stove.

Summary

In summary, the evidence reviewed provides **high** quality evidence of carcinogenicity of emissions from household coal use, and **moderate** quality evidence of actual risk levels for lung cancer. Although not specific to coal, there is **moderate** evidence that the risk of lung cancer from combustion-derived $PM_{2.5}$ extends to very low levels of exposure. While toxic contaminants in coal are found in different parts of the world and cause serious adverse health problems, much of the available evidence has been obtained from China. The evidence of adverse outcomes from toxic contaminants was assessed as being of **moderate** quality.

Research recommendations

1. Given the widespread use of coal as a household fuel in some regions of the world and noting that health risks are well-established, future research should evaluate policies for substituting coal with cleaner alternatives, and examine the extent to which household needs are met (Table R.3.1).

Table R.3.1: Policies and interventions for unprocessed coal

Current state of the evidence	There is good evidence of carcinogenicity and of other adverse health effects of the use of unprocessed coal as a household fuel. Evaluating policies to accelerate transition away from coal (to cleaner stoves and fuels) is a research priority.
Population of interest	Urban and rural households and communities currently using unprocessed coal for cooking and heating.
Interventions of interest	Policies and interventions to support transition to cleaner stoves and fuel options.
Comparisons of interest	Predominant use of unprocessed coal in stoves for cooking and heating.
Outcomes of interest	Extent of adoption (clean fuel vs. coal); impact on HAP and exposure (combustion pollutants and toxic contaminants); extent to which household energy needs are met; financial implications including for households; health impacts where feasible.
Time stamp	Systematic review included studies up to December 2013.

2. The recommendation on the household use of coal has been informed by an evidence base that relates mainly to the use of raw or unprocessed coal, except where specific studies of coal with (for example) fixing agents added to reduce toxic emissions, have been reported. Future research should examine the content, emissions of, and exposure to pollutants, including toxic contaminants (e.g. arsenic (As), mercury (Hg), etc.), of so-called clean and smokeless coals, when used with various stove technologies. This work should also review the related context and impacts of policies introduced to control or restrict the use of coal in homes (Table R.3.2).

Table R.3.2: Other coals

Current state of the evidence	Most available epidemiological on the health risks from household use of coal relates to raw coal, that is, coal that has not been processed to reduce potentially health damaging emissions. A few studies cited in Review 8 do report impacts of using coal with fixing agents, etc., but these do not represent comprehensively the emissions and risks that may be associated with so-called 'cleaner' coal, and stoves used to burn these.
Population of interest	Urban and rural households and communities currently using coal for cooking and/or heating.
Interventions of interest	Use of clean fuels (e.g. electricity); bans and other restrictions introduced to control the use of coal in households.
Comparisons of interest	So-called 'cleaner' and 'smokeless' coals.
Outcomes of interest	Content of, emissions from and exposure to, products of incomplete combustion ($PM_{2.5}$, CO, SO_2, etc.), and to toxic contaminants (Hg, lead (Pb), As, etc.), from use of so-called 'cleaner' and 'smokeless' coals; impacts of restrictions/bans on the foregoing, and on health outcomes.
Time stamp	Systematic review included studies up to December 2013.

4.6 Recommendation 4: Household use of kerosene (paraffin)

Scoping question 4: Should kerosene be used as a household fuel?

Recommendation	Strength of recommendation
The household use of kerosene is discouraged while further research into its health impacts is conducted.	**Conditional**

Remarks:

a) Existing evidence shows that household use of kerosene can lead to PM levels that exceed WHO guidelines, substantially so in developing country homes using simple unvented combustion technologies (e.g. wick cookstoves and lamps). Levels of CO, NO_2, polyaromatic hydrocarbon (PAH), and SO_2 may also exceed guideline levels provided in *Air quality guidelines - global update 2005* or *WHO Guidelines for indoor air quality: selected pollutants (13, 14).*
b) Epidemiological evidence on risks of respiratory and other health outcomes is currently not conclusive.
c) The risk of burns, fires and poisoning, associated with the use of kerosene in LMICs is a cause for concern.
d) For this recommendation, a low quality of evidence was available for disease risks from kerosene combustion emissions, and a moderate quality of evidence for safety risks with kerosene use.

Summary of evidence

Evidence to inform this recommendation was provided by two systematic reviews:
a) a recently published (2012) systematic review on the health risks of emissions from kerosene use as a household fuel *(17);*
b) a systematic review conducted for these guidelines on the risks of burns and poisoning associated with household fuel use.

a) Health risks from kerosene emissions

Kerosene is widely used in LMICs as a household fuel, for lighting and cooking. It is also used in a number of middle and high income countries for heating. Review 9 reports on kerosene use, emissions, area pollution levels and health risks. This is supplemented by four additional epidemiological studies published after completion of the systematic review.

Kerosene is burned in different types of device, depending on the purpose and setting. Combustion of kerosene emits many health damaging pollutants, including PM, CO, formaldehyde (CH_2O), polycyclic aromatic hydrocarbons (PAH), SO_2 and nitrogen oxides (NOx). Studies of micro-environmental levels of pollutants for the three main uses of kerosene have reported the following findings.

For heating applications, there is strong laboratory and field evidence that indoor concentrations of fine PM, NO_2 and SO_2 can exceed WHO guidelines in homes using kerosene as a heating fuel.

For lighting, wick type lamps result in the highest emissions. In-home indoor concentrations of PM can be substantial, with a range of 20–400 μg/m^3 $PM_{2.5}$ during use of wick lamps.

For cooking, both wick and pressurized stoves have been studied, with higher emissions for the former. Studies of kitchen and personal exposure levels found respirable PM in the range of 340 μg/m3 to more than 1000 μg/m^3, and CO also exceeding guideline levels under some conditions.

These concentrations of health-damaging pollutants are known to increase the risk of diseases linked to elevated levels of combustion pollutants. The systematic review also identified more than 20 epidemiological studies on cancer, respiratory conditions (symptoms, spirometry, ALRI and tuberculosis (TB)), allergic conditions and cataracts. While some of the studies included in the review reported elevated risks, overall, this set of studies was found to be inconsistent.

The four additional (recent) studies reported increased risks among kerosene users compared to clean fuel users (LPG/electricity) for stillbirth, low birth weight, neonatal deaths, cataract and child ALRI. While this new evidence lends some additional support to the conclusion that increased disease risks may be expected from the high levels of emissions, it was judged that further research is required to draw firm conclusions and derive reliably quantified risk estimates. The epidemiological evidence was assessed as being of **low quality**.

b) Burns and poisoning

The systematic review of burns, scalds and poisoning (Review 10) found evidence that household use of kerosene is an important cause of burns and fires, and of poisoning of children drinking the fuel (often stored in soft drink bottles), in LMICs. While these are important risks, reliable population-based data on rates, injuries and associated factors are lacking.

A small number of experimental studies (randomized and non-randomized) have investigated the impact of safety programmes on kerosene-related injury risk, but this body of evidence was not adequate for deriving reliable intervention effect estimates. Thus the evidence that household kerosene use presents a substantial safety risk was assessed as being of **moderate quality**, and that for risk estimates and intervention impacts was assessed as being of **low quality**.

Research recommendation

Given that kerosene is widely used for cooking, heating and lighting, and may be considered as one option in the transition from solid fuels, the research focus should be on investigation of risks associated with household kerosene use for cooking, lighting and heating (Table R.4.1). Separate investigation of these three uses is essential as they are burned in very different devices, for which user preferences, behaviours and associated exposures vary substantially.

While this is critical as a basis for deciding whether or not a strong recommendation against the use of kerosene as a household fuel is justified in the future, obtaining this evidence should not hold back efforts to implement alternative household energy options that are known to be clean, safe, convenient and affordable, nor should it prevent operational research aimed at supporting this process.

Figure R.4.1: Health impacts for domestic kerosene use

Current state of the evidence	There is limited and inconsistent evidence on the health risks associated with the household use of kerosene, particularly in respect of the technologies and fuel used for cooking, heating and lighting in LMICs There is also little information about risks associated with kerosene heaters.
Population of interest	Households using kerosene for cooking, heating and lighting in LMICs.
Interventions of interest	Fuels, stove and lighting technologies with low levels of emissions and greater levels of safety.
Comparisons of interest	Currently used kerosene stoves, heaters and lamps (particularly wick types) and fuel available to these households.
Outcomes of interest	A range of health outcomes should be included, with priority given to those with higher burden of disease (e.g. child pneumonia, adverse pregnancy outcomes) and also those for which available evidence suggests that there may be particularly high levels of risk (e.g. TB).
Time stamp	Systematic review by Lam et al. (2012) included material up to December 2011 *(17)*.

4.7 Good practice recommendation: securing health and climate co-benefits

Considering the opportunities for synergy between climate policies and health, including financing, we recommend that governments and other agencies developing and implementing policy on climate change mitigation consider action on household energy and carry out relevant assessments to maximize health and climate gains.

Remarks

- Evidence reported in these guidelines, in particular the IER functions describing risk of important health outcomes with increasing level of $PM_{2.5}$ exposure, provide an initial basis for assessing the health benefits of specific climate change mitigation actions on household energy.

- Guidance and tools for further characterization of impacts of climate change mitigation strategy on health, including both benefits and harms, require development.

Summary of evidence

Two sets of evidence inform this recommendation:

a) a summary of systematic reviews of health impacts of HAP;
b) a review of evidence on the climate co-benefits of cleaner household fuel combustion and opportunities for carbon finance.

(a) Health and HAP

The systematic reviews of health impacts of HAP (Review 4), summarized for Recommendation 2 (Section 4.4), provide extensive evidence of the increased risk of a wide range of child and adult disease outcomes due to emissions from incomplete combustion of solid and other fuels in the home. Review 9 summarizes the evidence for kerosene emissions.

(b) Climate impacts

The review of climate co-benefits (Review 11) draws on a range of sources, including the most recently available comprehensive assessment of this issue published by UNEP *(28)*. It also summarizes evidence for the effects on climate of a range of pollutants (many of which are health-damaging) emitted from inefficient combustion devices. Carbon dioxide (CO_2) emissions from non-sustainable use of biomass fuel also affect the climate, but in this context, this gas does not directly impact health.

Many currently used solid fuel stoves, and the simple lamps described in the review of kerosene use (Review 9) burn fuels very inefficiently. This leads to emissions of non-CO_2 components (so-called products of incomplete combustion – PICs) that affect climate even when (in the case of biomass) the fuel is sustainably harvested and does not lead to net CO_2 emissions. Fossil fuels, being non-renewable, affect climate through their CO_2 emissions and, in the case of incomplete combustion, emission of PIC. The extent of these impacts varies by fuel and the technology used for its combustion. For example, LPG emits fewer climate pollutants than coal per unit of energy delivered.

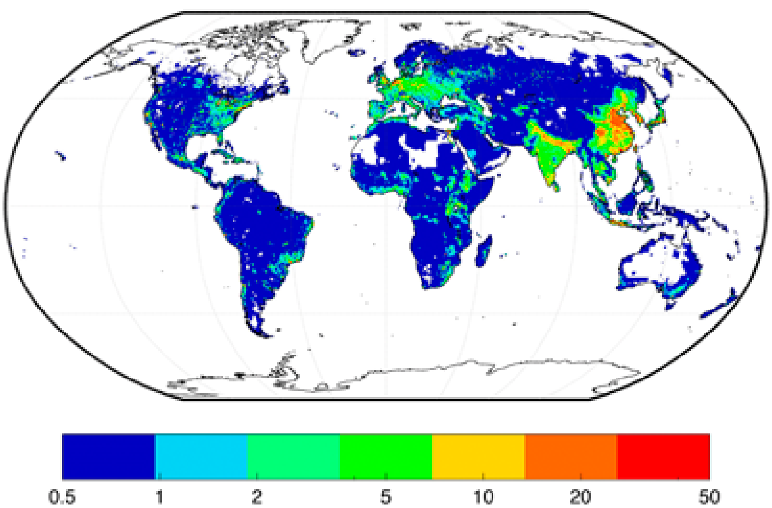
Many PIC components exert a radiative forcing of climate, either because they are greenhouse gases (GHGs) able to trap long-wave heat radiation from the Earth (methane, N_2O), they indirectly affect GHGs via chemical processes in the atmosphere (CO, non-methane volatile organic compounds), or because they interfere with short-wave solar radiation and/or they affect climate through impacts on clouds (particulate matter/aerosols – including black carbon) (Figure 4.3). These components (except N_2O) are often referred to as short-lived climate pollutants.

While there is strong evidence that short-lived climate pollutants disturb climate, their impacts have a strong regional signature due to short lifetimes, and there is uncertainty about the nature of their impacts on a global and regional scale. Nevertheless, the UNEP report concludes that there are substantial effects and important opportunities to mitigate climate change through action on household energy.

Research recommendation

While there are opportunities for synergy between climate policies and health, policies will need to be carefully designed to obtain these synergies and avoid unintended adverse effects on climate and/or health. Thus there is a need for research to support the development of co-control policies (Table R.5.1).

Figure 4.3: Global black carbon emissions from combustion, in gigagrams (Gg). This includes emissions from fossil fuels and biofuels such as household biomass (i.e. wood, charcoal, dung, crop waste) used for cooking.[a]



[a] Estimates are based on 2000 emissions. Data source and map production: Dr Tami Bond. This product was developed using materials from the The United States of America National Imagery and Mapping Agency and is reproduced with permission.

Table R.5.1: Climate and health co-control policies

Current state of the evidence	There is good evidence of climate forcing from emissions from incomplete combustion of household fuels, although the magnitude of the forcing through the various mechanisms at work is not fully resolved.
Population of interest	Households and communities, mostly in LMICs that are currently using solid fuels and/or kerosene for cooking, heating and lighting.
Interventions of interest	Policies and interventions to support transition to technologies and fuels that contribute both to better health and reduced climate forcing.
Comparisons of interest	Health and climate policies developed in isolation.
Outcomes of interest	Emissions of pollutants with adverse impacts on health and climate, impact on exposure; safety of interventions; extent of adoption; extent to which household energy needs are met; financial implications including for households.
Time stamp	The review included studies up to April 2013.

5. Implementation of the guidelines

5.1 Introduction

Although the scope of these guidelines is global, the main focus has been on the health impacts from household fuel combustion in LMICs where the burden is by far the greatest. Consequently, the primary concern of WHO in providing technical support for implementation of the guidelines lies with LMICs, recognizing that higher income countries identifying health risks (mainly from solid heating fuels) will have mechanisms and resources to address these more easily. WHO acknowledges that – particularly for lower income and/or more rural populations – implementing these recommendations will require coordinated effort from ministries, other national stakeholders (NGOs, public and private sectors), and often input from international development and finance organizations. WHO will work with countries to support this process through its regional and country offices, and is preparing web-based guidance and tools that build on the evidence reviews used to inform these guidelines.

In addition to the above general support, WHO will work closely with some of the countries most affected by this issue to learn from initial stages of implementation, and use this experience to revise the guidance and tools (see also updates, Section 6.2).

An overview of the main areas in which WHO will provide technical support for implementation is provided below. Further details are available at: http://www.who.int/indoorair/guidelines/hhfc.

5.2 Approach to implementation: collaboration and the role of the health sector

The multiple issues involved in achieving equitable and lasting adoption of cleaner and safer household energy demand inputs from a range of agencies. An effective mechanism for policy coordination at government level is therefore a critical first step. In most countries, mechanisms for cross-sectoral collaboration in respect of a range of policy areas involving ministries and other stakeholders are likely to be in place, and these can be built upon as needed.

To date, many ministries of health have not engaged fully with this problem, in part because it is considered the responsibility of other sectors including energy, environment and finance. However, in many cases cooking and heating technologies that improve energy efficiency to levels needed to reduce deforestation and deliver fuel and time savings for households, do not yield air quality improvements to levels that afford health protection. If the potential for large health benefits is to be realized, the health sector needs to play a key role. This can include assessing and communicating health risks and benefits, but in particular ensuring that proposed intervention technologies, fuels and other changes really do improve health and safety, and making the most of opportunities to change household energy practices through direct interactions between the public and health services. The health sector input can only be effective, however, if such efforts are coordinated with policy to ensure affordable supply of, and support for, the cleaner and more efficient household energy options required. WHO will work with ministries of health to support this role, and to ensure that health perspectives are strongly represented in policies.

5.3 Needs assessment

The first step in policy planning is assessment of household energy use and access to cooking, heating and lighting technologies and fuels across the country, and identification of associated health risks. WHO has a number of resources that can contribute to building a national needs assessment, including the following which are available at: http://www.who.int/indoorair/guidelines/hhfc.

- The household energy database which compiles nationally representative survey-based information on primary fuels used for cooking for all countries, and increasingly including data on heating and lighting fuels.
- A database of measured pollutant concentrations (mainly PM and CO) in kitchens, with some values for outdoor levels and personal exposure, derived from a recent systematic review (Review 5). This will be periodically updated.
- National estimates of numbers of premature deaths from child ALRI, IHD, stroke, COPD and lung cancer, attributable to HAP exposure are available through the WHO Global Health Observatory. Current estimates are for the year 2012, and these will be periodically updated.

WHO can provide technical support on planning for additional studies to provide more detailed and locally specific information. The planning tool outlined in Section 5.5 will include an assessment of key factors that influence the adoption and sustained use of new technologies and fuels, and this should be an important part of the needs assessment.

Section 5.7 describes elements of a M&E strategy, for which improved household energy survey instruments are being developed. These will, in due course, provide better quality information on the mix of fuels and technologies that homes are using.

5.4 Intervention options and strategies

5.4.1 Roles of clean fuels and lower emission solid fuel stoves

As addressed by Recommendation 2, it is recognized that rapid transition to household energy solutions that consistently meet WHO AQG values for $PM_{2.5}$ will take time, especially in low-income settings. Intermediate steps may be inevitable and appropriate to promote this transition to cleaner energy (Figure 5.1). Nevertheless, given the **current** evidence on the performance of so-called ‘improved’ solid fuel stoves in everyday use (Review 6), widespread and near-exclusive use of clean fuels will be required to achieve air quality in and around homes that meets the WHO AQG for $PM_{2.5}$.

LPG is the clean fuel alternative most widely available for replacing solid fuels and/or kerosene in households currently relying on them. In many such homes, other clean fuels may be impractical (e.g. piped natural gas in rural areas, electricity where reliable supply is unavailable, or biogas for homes with no farm animals) or more expensive (e.g. electricity). To date, however, there have been relatively few studies of LPG evaluating the acceptability, sustained use, impacts of policy on affordability and supply, impacts on HAP exposure and health, and safety regulation issues. Given the potentially wide availability of this fuel, it is important that such studies are carried out as soon as possible.

Figure 5.1: Examples of solid fuel stoves

Solid fuel stoves *A range of types of solid fuel stoves are available, including simple combustion types with and without chimneys (top left), standard ‘rocket’ stoves (top right) and more advanced combustion stoves with fans to improve combustion and/or achieve some degree of gasification. Performance in homes rarely lives up to laboratory emissions performance, however. Where it is judged that solid fuel stoves are still needed, all types under consideration should be subjected to emissions testing, preferably in conditions representative of real life use, and the best possible options promoted.*

Figure 5.2: Modern gaseous and liquid fuels and electricity

Clean fuels include biogas, ethanol, LPG, natural gas and electricity. Solar cook stoves may also play a part where conditions are suitable for meeting user needs. Policy on household energy should focus on extending access to clean fuels as widely as possible across communities. Safety should not be assumed, however, and testing and regulation of this aspect should be applied as for solid fuel stoves.

Other clean fuels will also make an important contribution. For example, in some areas of India with more reliable electricity supplies, inexpensive induction stoves are becoming increasingly popular and affordable for regular cooking due to their high efficiency. Comparative studies evaluating the use, supply, costs and impacts of electricity and other fuels including biogas, natural gas, alcohol fuels (ethanol, methanol), dimethyl ether (DME) and solar cookers, should also be a priority (Figure 5.2).

As recognized in these guidelines, and specifically in Recommendation 2, which addresses policy during transition, improved solid fuel stoves will continue to make an important contribution to the needs of a substantial proportion of lower income and rural homes where primary use of clean fuels is not feasible for some time to come. Work to develop substantially improved solid fuel stoves should continue in parallel with, but not hinder or displace, efforts to encourage transition to clean fuels. The contribution of solid fuel stoves to the mix of devices and fuels promoted will depend on the completeness of combustion that can be achieved when such technologies are in everyday use (as demonstrated through emissions testing), and the consequent reductions in health risks.

Three randomized clinical trials are currently under way, all studying the impacts of improved stoves (both standard natural draught rocket-type and fan-assisted) on birth outcomes (preterm birth, birth weight) and ALRI. The trial locations together with the lead investigating institutions, principal investigators, intervention technologies and fuels, main health outcomes and trial registration numbers are provided in Table 5.1 below. Three of these (Ghana, Nepal and Nigeria) will also include a clean fuel (LPG or ethanol) in the trial. The findings of these trials are expected to make an important contribution to the evidence base for intervention strategies.

Table 5.1: Randomized clinical trials testing health impacts of reducing HAP exposure that are in progress

Trial location	Main investigating institution (PI)	Intervention technologies/fuels	Main health outcomes	Trial registration number
Ghana	Columbia University (Kinney P.)	2 intervention arms: Biolite fan stove; LPG	Incidence of ALRI in children under 12 months; birth weight	NCT01335490
Nepal	Johns Hopkins (Tielsch J.)	2 intervention arms: Envirofit rocket stove; LPG	Incidence of ALRI in children under 36 months; birth weight	NCT00786877
Malawi	Liverpool School of Tropical Medicine (Mortimer K.)	Philips fan stove	Incidence of ALRI in children under 60 months	ISRCTN59448623
Nigeria	University of Chicago (Olopade C.)	Ethanol clean cook stove	Incidence of adverse pregnancy outcomes	Awaited

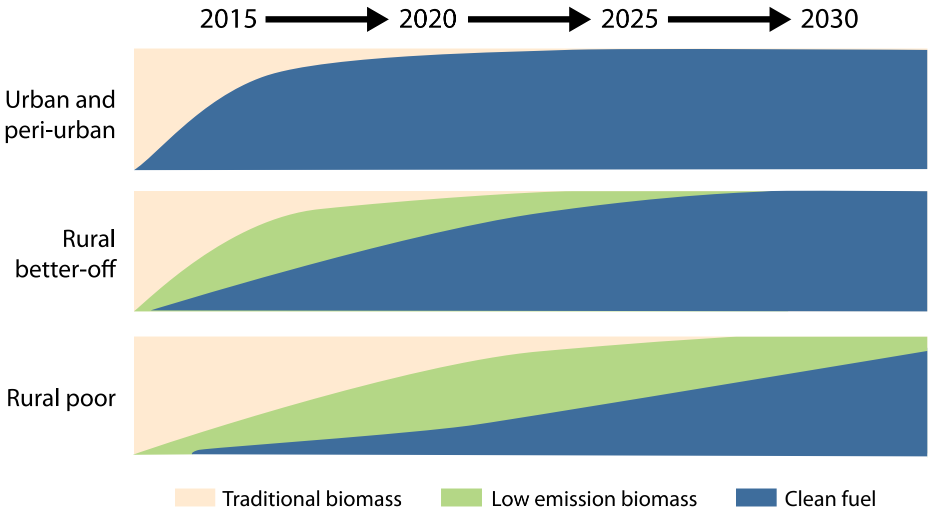
5.4.2 Patterns of adoption of new energy and fuel technologies across society

The use of energy in the home is characterized by use of several technologies and fuels for multiple household needs including cooking, heating, lighting, boiling water, bathing and washing clothes, and food processing. Studies consistently show that new technologies and fuels tend to be absorbed into existing practices and rarely displace older methods completely, at least not in the short-term. Furthermore, the rate of adoption and sustained use of more modern, clean and efficient household energy will differ according to socioeconomic circumstances, geography and other factors, as illustrated schematically for the primary cooking stove in Figure 5.1.

Similar considerations will apply to transitions in fuels and technology used for meeting heating and lighting requirements, and all of these need to be taken into consideration in assessing the expected impacts on total emissions and hence HAP and exposure levels.

Thus, when developing policy, it is important to recognize that multiple devices and fuels will be used, and that families will need to adapt to changing incomes, energy supplies and prices, seasonal and other needs, by altering the mix (Figure 5.4). Requirements must also be assessed – cooking and lighting are required by all homes, but some other needs, including heating and food processing (e.g. drying), will vary according to location, season and the nature of the local economy.

Figure 5.3: Hypothetical, simplified scenarios for rates of transition from predominantly traditional solid fuel use for cooking in the home to low-emission improved solid fuel stoves, clean fuels and/or electricity across three differing socially and geographically defined groups



Policy should therefore seek to maximize the share of household energy that is obtained from clean fuels, and work to ensure that these are (and remain) available and affordable. Where solid fuel technology continues to be needed, the lowest emission options – consistent with meeting household needs, safety and costs – should be developed and promoted. For those households needing to rely on these interim steps of improved solid fuel stoves, assessment should also be made of what can be done as soon as possible to prepare the way for starting or increasing the use of clean fuels.

5.4.3 Evaluating intervention options

Many factors need to be considered when evaluating alternative technologies and fuels, including acceptability, costs, emissions and safety. The most critical outcome for securing health benefits is human exposure to health damaging levels of emissions and the consequent risk of adverse health outcomes. WHO will support the development of tools to assist with this assessment, including an enhanced version of the emissions model, and an intervention assessment tool.

Figure 5.4: Fuel and technology stacking

An example of multiple fuel use in a home in rural Mexico, with a wood fired chimney stove used next to an LPG stove.

Enhanced emissions model

The single-zone emissions model, which underpins Recommendation 1, is described in Review 3. The following additional steps were recommended to increase the value and applicability of this model:

- Further empirical work to obtain more regionally representative data on the key model inputs, that is, on kitchen volume, air exchange rates and duration of use of the device. This will allow calculation of ERTs based on these regional data.
- Development of an interactive version which will allow users to enter locally-sourced data, and to determine emission rates for different percentages of homes meeting the AQG values.

Further details of the plans for, and status of, these developments to the model are available at: http://www.who.int/indoorair/guidelines/hhfc.

Intervention assessment tool

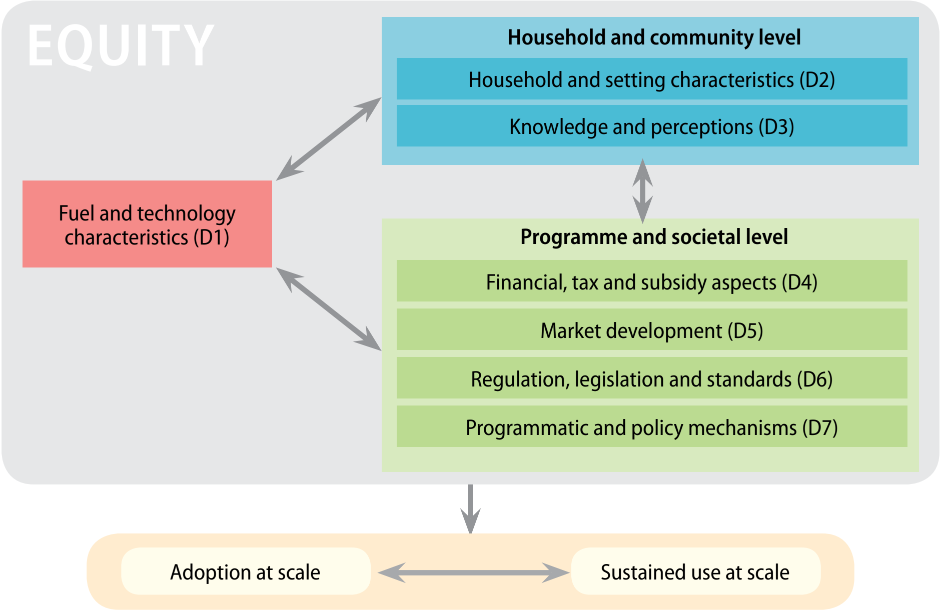
A number of tools are in development that are designed to estimate expected health benefits of alternative technologies and fuels. These are based on evidence reported in Review 4, specifically the IER functions, which allow estimation of the reduction in risk of several important health outcomes (child ALRI, IHD, stroke, lung cancer and COPD) following a specified reduction in exposure to $PM_{2.5}$. Further details on progress with the development and testing of these tools is available at: http://www.who.int/indoorair/guidelines/hhfc.

5.5 Policy for effective and sustained adoption

No matter how effective a stove or fuel is in terms of reduced emissions, if it is not used more or less exclusively and that use continued over time, health benefits will not be achieved. Review 7, and two recently published systematic reviews, *(6, 29)* have identified factors that influence the adoption and sustained use of improved solid fuel-burning stoves and four types of clean fuel (LPG, biogas, alcohol fuels, solar cookers).

These reviews show that a wide range of factors influence a household's adoption of new technology and/or fuel. Sole use of new technology and fuels–the extent to which it displaces existing arrangements–is also influenced by a wide range of factors. So, too, is maintenance of, and replacement of equipment when required. Review 7, which examined findings from more than 100 qualitative, quantitative and case studies, describes seven key domains influencing this process. These are summarized in Figure 5.6.

Figure 5.6: Factors enabling or limiting uptake of cleaner cooking technologies. This framework illustrates how seven domains (D) – one relating to the characteristics of the intervention, two operating at the household/community level, and four operating at the programmatic/societal level – affect adoption



The review found that while some factors are critical for success, none guarantees this and context is also important. For example, a household will not adopt and use a new technology or fuel fully if this cannot be used to cook their usual types of food. On the other hand, one that meets these requirements will not be used long-term if there is no support for replacing parts, or the fuel supply is unreliable and/or not affordable. It is therefore important to consider all factors that are relevant to the fuel, technology and setting.

This new evidence provides the opportunity to develop a tool to assist with planning and evaluating policy to support effective and sustained adoption. Further details are available at: http://www.who.int/indoorair/guidelines/hhfc.

5.6 Standards, testing and regulation

These guidelines emphasize reduction of emissions with Recommendation 1 providing specific guidance on ERTs for $PM_{2.5}$ and CO. Accordingly, systems (incorporating protocols, facilities and technical capacity) for carrying out testing in parts of the world where this is most needed, are critical for implementation of the guidelines.

An initiative to develop testing and associated voluntary standards for cookstoves in LMICs was launched in 2012 as an International Workshop Agreement (IWA) under the auspices of the International Organization for Standardization (ISO), a first step in the process of developing full ISO standards, and providing a basis for regulation. This process, and the content of the IWA, are described in Annex 9. The health component of the voluntary standards included in the IWA was informed by WHO AQGs on specific pollutants *(13, 14)* and is based on emission rates using an earlier (and simpler) version of the model described in Review 3. Work is currently under way to develop testing centres and technical capacity on a subregional basis (Figure 5.7). A new technical committee (ISO TC 285) was

Figure 5.7: Stove laboratory and testing

(a) *testing emissions from a Philips fan stove at the US Environmental Protection Agency (USEPA) laboratory.*

(b) *emissions testing facilities at the Indian Institute of Technology, New Delhi* set up in June 2013 to update the IWA and develop international standards for cookstoves and clean cooking solutions (Annex 9). This process also allows for existing standards for household energy technologies to be incorporated.

This initiative on standards, and the associated testing, protocol development, technical capacity and facilities, is an important complement to these guidelines. In consequence, WHO is acting as a Category-A Liaison Organization for this ISO process, which will allow close interaction between the development of new standards and testing and the work of WHO on the guidelines and associated health-based evidence.

In developed countries where solid fuel (mainly biomass) stoves are used for heating, it will be important to further develop (if necessary) and enforce regulations and by-laws for the use of wood-burning appliances and other stoves and boilers.

5.7 Monitoring and evaluation: assessing the impact of these guidelines

Health gains will only be achieved if cleaner and safer household technologies and fuels are used widely, maintained properly and replaced when necessary. Experience has shown that, even where improved stoves or clean fuels are newly adopted, conditions for sustained use cannot be assumed. Active M&E are therefore vital, and will also provide an indication of the impact of the guidelines.

Global monitoring of household energy fuels and related estimates of HAP are compiled by WHO in its Global database for household fuels and IAP drawing on over 700 national and international surveys.*(5)* This database is used to inform a number of global estimates, including the MDG database the SE4All global tracking framework and burden of disease estimates. These guidelines have identified a number of ways in which global information on household energy and fuels should be improved to provide a more complete description of household energy adoption and use from the perspective of health risk assessment. The measurements of air pollution levels inside and outside homes are also important for M&E purposes.

WHO can support these M&E needs in several ways as set out below, with additional information available at: http://www.who.int/indoorair/guidelines/hhfc.

Household energy surveys

A range of approaches for monitoring transition towards cleaner household energy are described in Chapter 9 of the WHO air quality guidelines 2005 Global update *(30),* including the contribution of population-based household surveys within a hierachy of methods. Surveys are considered the most useful method for population-based monitoring, while studies of household pollutant concentrations, personal exposure and intervention use, provide the most detailed information at household level.

Current survey instruments, such as that used for the Demographic and Health Survey, which provide data included in the WHO global household energy database, need to be revised for a number of reasons including the inability currently to distinguish between effective and ineffective solid fuel stoves, and the need to capture information on secondary technology and fuel use for cooking, heating and lighting (Figure 5.8). WHO is playing a leading role in this process, including for the UN's SE4All tracking framework[1] Further details of progress with the development and testing of revised survey instruments is provided at: http://www.who.int/indoorair/guidelines/hhfc.

Figure 5.8: Household surveys

Interview-based surveys will continue to provide the most efficient means of monitoring household fuel and technology use across populations, and can be used to estimate HAP levels if allied to regionally representative studies measuring pollutants in homes.

[1] See: http://www.sustainableenergyforall.org/tracking-progress

Air quality and exposure measurement

While interview-based surveys are a practical means of monitoring population health risks (for example, fuel and stove use), even the best-designed surveys – on their own – cannot provide reliable estimates of actual pollutant concentrations in and around homes, nor of levels of personal exposure (Figure 5.9).

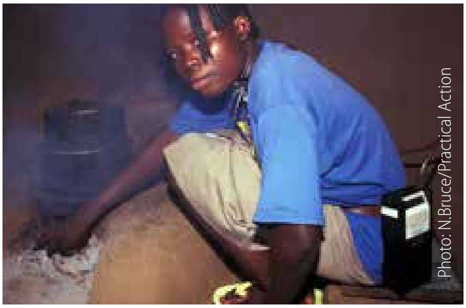
Recent published work from India *(32)*, reported in Review 5, has shown that population-based interview surveys, combined with local studies measuring air pollutant concentrations and collecting information on the household variables included in the survey, can be used to make reliable estimates of air pollution at population level through modelling.

Whether used for modelling or to increase certainty about the HAP levels populations are being exposed to, air pollution measurement studies are likely to play an important part in any M&E strategy. WHO can provide technical support to ensure quality of measurement and comparability with other studies, and in the further development of protocols for wider application of these methods.

Figure 5.9: Air quality and exposure measurements

(a) *The measurement of particulate matter (PM) exposure in young children has been a major challenge, and explains why so few studies have provided these data. A number have used simple diffusion tubes to measure carbon monoxide as a proxy for PM, but this is not ideal. It is expected that new instruments will start to transform prospects for the measurement of child PM exposure in the next few years.*

(b) *Carrying out air quality measurement requires use of standardized methods, and careful attention to equipment calibration and quality control/assurance.*



(c) *The measurement of personal exposure is especially important for studies assessing health risks or directly linking to health outcomes. Lighter, quieter equipment is starting to become available, and should make this less burdensome for subjects.*

Figure 5.10: Other sources of air pollution

Other sources of combustion such as brick kilns can contribute to air pollution in both rural and urban areas. In urban settings, there are likely to be contributions from a wider range of sources including traffic, industry, power generation, etc., in addition to household fuel combustion. As outdoor pollution enters homes, strategy for clean indoor air needs to be coordinated with policy for controlling these other sources.

The measurement of air quality in the ambient (outdoor) environment can also play an important part in HAP control strategy. Review 5 found that, in Indian villages, average outdoor concentrations of $PM_{2.5}$ can exceed 100 $\mu g/m^3$. This implies that, no matter how low the emissions are within a particular house, indoor air quality will not meet WHO guideline levels due to high levels of outdoor air pollution entering the home (Figure 5.10). Measurement of outdoor air quality should therefore be carried out more widely. In most rural, and many other settings where solid fuel use is widespread, household fuel combustion is an important (if not the main) source of pollution *(3)*. Biomass (usually as charcoal or wood) and kerosene are also still commonly used for cooking and heating in urban and peri-urban areas and can be expected to make substantial contributions to ambient air pollution in cities where that is the case *(3)*. It is therefore important to also monitor and evaluate the contributions to ambient air from household fuel combustion in cities, and to evaluate the use and impacts of clean fuels and energy technologies in these settings. WHO AQGs apply to pollutants in all settings and can serve as a basis for regulation and policy to support transition to low emission household energy.

Evaluation of health impacts

The M&E strategy should include ways to measure whether new technologies and fuels in everyday use are having the desired impact on important health outcomes. Studies should be carried out over several months of use at least; ideally for more than one year.

Levels of HAP and personal exposure, whether measured directly or estimated through modelling as described above, are useful indicators of risk. With improving evidence on exposure-response functions (for example, the IERs described in Review 4 and published) *(23),* it is now possible to estimate the reduction in important health outcomes – indeed this is what the intervention assessment tools are being designed to do (Section 5.4).

Reliably demonstrating the impacts on health outcomes such as child pneumonia or COPD introduces further complexities, many of which have recently been discussed by Martin and colleagues (Figure 5.11) *(31).* Such studies typically require substantial time and resources and use of optimal research designs (i.e. randomized trials) can impose constraints not easily accommodated within a mainly market-led scale-up. It is nevertheless essential to demonstrate the effects that large-scale programmes have on health outcomes. This is an important component of the M&E strategy and related research efforts; however, given the resources and technical challenges involved, it may be best managed with contributions from international partners.

Measuring the use, maintenance and replacement of technology and fuel interventions, and understanding why households make different choices is also important. Mixed methods, that is a combination of quantitative (e.g. stove-use monitors) and qualitative (in-depth interviews, focus group discussions) can provide a fuller picture of what is happening, and why. WHO will work with its partners, including the research community, to facilitate the development and application of improved M&E methods, and related research on health risks and intervention impacts. The findings of these research and evaluation activities will be incorporated into the guidelines, updating them where necessary, as described in Section 6.

Figure 5.11: Measuring health outcomes

Left: Measuring the incidence of major child health outcomes such as pneumonia requires the application of well-standardized diagnostic methods, assessment by a physician, and may also involve investigations including X-rays and analysis of samples to determine the causative organism (virus or bacteria). Right: Spirometry (the measurement of lung function) is key to a diagnosis of chronic obstructive pulmonary disease (COPD), and requires thorough staff training, with careful explanation to subjects being examined and expert quality control.

Finally, it will also be important to carry out evaluation of programmes designed to address the adverse health and other impacts resulting from inefficient, polluting and unsafe household energy. This should assess the organization of the programme (structure), process, activities and impacts, drawing on many of the components described above.

5.8 Research needs

Development of these guidelines has made evident some key knowledge gaps and research needs. The most important of these needs are presented in the research recommendations in Sections 4.4 to 4.8. More detailed discussion of evidence gaps and research needs is included in the evidence reviews available at: http://www.who.int/indoorair/guidelines/hhfc.

Among the most important of these research needs are studies on the use and impacts of improved household energy technologies and clean fuels under real life conditions to further estimate effectiveness of interventions for the major causes of disease, including cardiovascular disease (an outcome for which very few studies are available). These studies can provide a better handle on cost-effectiveness of home energy interventions in comparison to other preventative interventions. Other relevant questions to be further investigated include the role of black carbon, the impacts of kerosene, and factors for sustained adoption.

WHO will work with its partners and the research community to help ensure these research priorities are addressed, that high quality and well-standardized methods are used, and results are incorporated into policy in a timely manner.

6. Updating the guidelines

These guidelines will be updated using the following mechanisms.

6.1 Web-based updates

When new information that does not affect the recommendations becomes available, this will be incorporated into the web-based version of the guidelines. The following two aspects are those most likely to need periodic updating, although others may arise in due course:

- **Air quality guidelines for specific pollutants**. The existing WHO AQGs are fundamental to the recommendations (and in particular the ERTs in Recommendation 1). These are subject to periodic review – see for example the recently conducted 'Review of evidence on health aspects of air pollution' (REVIHAAP) *(32)*. If and when new AQGs and ITs for $PM_{2.5}$ and/or CO are published by WHO, the ERTs will require updating. As this does not change the underlying principles or methods, such updates will be made to the web-based version of the guidelines.
- **Emissions model.** Key input data for the model–kitchen volume, air exchange rates, duration of use–were obtained solely from studies in India. Although validation against studies carried out in several regions of the world shows the model performs moderately well, obtaining and testing data better reflecting housing and energy use practices in different regions is a priority. This information, together with the emission rates from these 'regionally adapted' models, will be made available on the website. Development of an interactive version of the model is also recommended. This would allow users to input their own locally-sourced data (kitchen volume, air exchange, duration of use per day) and provide a user-friendly software platform for applying the emission rate model in practice.

6.2 Updates based on substantial new evidence

Where important new evidence on areas currently uncertain (for example on household use of kerosene, for which evidence was limited and therefore rated as providing low quality and additional studies were recommended), a formal process for systematic assessment of this evidence will be established to determine whether the recommendations should be revised. It is expected that this will be carried out 2–3 years following publication of the guidelines.

Similarly, as evaluation-based evidence on the implementation guidance and tools described in Section 5 becomes available, this material will be systematically reviewed and updates prepared. It is expected that this will be carried out 3–5 years following publication of the guidelines.

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Annex 1: Steering, advisory and external review groups

A1.1 WHO steering group

Table A.1: WHO Headquarters (Geneva)

Name	Role	Department
Sophie Bonjour	Technical officer	Department of Public Health, Environmental and Social Determinants of Health (PHE)
Nigel Bruce	Consultant in Air Quality and Health (guidelines project coordination)	Department of Public Health, Environmental and Social Determinants of Health (PHE)
Carlos Dora	Unit coordinator: Interventions for Health Environments	Department of Public Health, Environmental and Social Determinants of Health (PHE)
David Meddings	Scientist	Department of Violence and Injury Prevention and Disability
Mariam Otman del Barrio	Technical officer	Department of Public Health, Environmental and Social Determinants of Health (PHE)
Annette Pruss-Ustun	Scientist	Department of Public Health, Environmental and Social Determinants of Health (PHE)
Heather Adair-Rohani	Technical officer (guidelines project coordination)	Department of Public Health, Environmental and Social Determinants of Health (PHE)

Table A.2: WHO Regional Offices

Name	WHO Region	Role	Department
Arunachalam Gunasekar	WHO South-East Asia Region	National Professional Officer	WHO Country Representative Office, India
Marie-Eve Heroux	WHO European Region	Technical Officer	Communicable Diseases, Health Security and Environment, European Centre for Environment and Health, Bonn
Michal Krzyzanowsky	WHO European Region	Retired	European Centre for Environment and Health, Bonn
Mohd Nasir Hassan	WHO Western Pacific Region	Team Leader	Environmental Health Building Healthy Communities and Population
Raki Zghondi	WHO Eastern Mediterranean Region	Environmental Health Officer	Centre for Environmental Health Activities, Amman
Mazen Malkawi	WHO Eastern Mediterranean Region	Technical Officer	Centre for Environmental Health Activities, Amman
Mrs Payden	WHO South-East Asia	Sanitary Engineer	Water, Sanitation and Health
Agnes Soares Da Silva	WHO Region of the Americas	Adviser, Environmental Epidemiology	Sustainable Development and Health Equity
Kutane Waltaji Terfa	WHO African Region	National Professional Officer	Public Health and Environment Ethiopia
Martin Willi Weber	WHO South-East Asia Region	Regional Adviser	Making Pregnancy Safer and Reproductive Health

A1.2 guidelines development group

Table A.3 lists all members of the guidelines development group (GDG). Relevant expertise contributed to the group is indicated in the table by an 'X', using the topics and numbers listed below.

Table A.3: guidelines development group

Area of expertise	Reference	Area of expertise	Reference
WHO air quality guideline development	1	Burns and injury prevention	8
Health effects of household air pollution (HAP)	2	Adoption and utilization of household interventions	9
Combustion and emissions science	3	Household use of coal	10
HAP and exposure measurement	4	Household use of kerosene	11
Data systems for monitoring global HH fuel use	5	Climate change science	12
Evidence review methodology for complex interventions	6	Health effects of liquefied petroleum gas (LPG) use	13
Household energy programme finance and economic evaluation	7	Standards and testing	14

Name	Position and affiliation	Sex	Area of expertise specifically sought for guidelines (see reference number above)													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
Kristin Aunan	Senior Research Fellow University of Oslo Oslo, Norway	F		X					X							
Kalpana Balakrishnan	Associate Professor Sri Ramachandra University Tamil Nadu, India	F				X	X									
John Balmes	Professor in Residence University of California (UCSF) San Francisco, The United States of America of America	M		X												X

Area of expertise	Reference	Area of expertise	Reference
WHO air quality guideline development	1	Burns and injury prevention	8
Health effects of household air pollution (HAP)	2	Adoption and utilization of household interventions	9
Combustion and emissions science	3	Household use of coal	10
HAP and exposure measurement	4	Household use of kerosene	11
Data systems for monitoring global HH fuel use	5	Climate change science	12
Evidence review methodology for complex interventions	6	Health effects of liquefied petroleum gas (LPG) use	13
Household energy programme finance and economic evaluation	7	Standards and testing	14

Name	Position and affiliation	Sex	Area of expertise specifically sought for guidelines (see reference number above)													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
Michael Bates	Adjunct Professor of Epidemiology University of California (UCB) Berkeley, The United States of America	M		X												
Michael Brauer	Professor The University of British Columbia Vancouver, Canada	M				X										
Kenneth Bryden	Professor Iowa State University The United States of America	M								X						
Aaron Cohen	Principal Scientist Health Effects Institute Boston, The United States of America	M	X	X												
Mukesh Dherani	Research Fellow University of Liverpool Liverpool, The United Kingdom	M		X				X		X						
Shane Diekman	Behavioural Scientist CDC Caribbean Regional Office Barbados	M								X						

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Continued

Area of expertise	Reference	Area of expertise	Reference
WHO air quality guideline development	1	Burns and injury prevention	8
Health effects of household air pollution (HAP)	2	Adoption and utilization of household interventions	9
Combustion and emissions science	3	Household use of coal	10
HAP and exposure measurement	4	Household use of kerosene	11
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Evidence review methodology for complex interventions	6	Health effects of liquefied petroleum gas (LPG) use	13
Household energy programme finance and economic evaluation	7	Standards and testing	14

Name	Position and affiliation	Sex	Area of expertise specifically sought for guidelines (see reference number above)													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
Xiaoli Duan	Associate Professor Chinese Research Academy of Environmental Sciences Beijing, China	F		X								X				
Rufus Edwards	Professor University of California (UCI) Irvine, The United States of America	M			X	X										
Elizabeth Fisher	Professor Cornell University New York State, The United States of America	F			X											
Santu Ghosh	Sri Ramachandra University Tamil Nadu, India	M			X	X										
Kirstie Jagoe	Independent Consultant Montreal, Canada	F		X												
Michael Johnson	Senior Scientist Berkeley Air Monitoring Group Berkeley, CA, The United States of America	M			X	X								X		X

Area of expertise	Reference	Area of expertise	Reference
WHO air quality guideline development	1	Burns and injury prevention	8
Health effects of household air pollution (HAP)	2	Adoption and utilization of household interventions	9
Combustion and emissions science	3	Household use of coal	10
HAP and exposure measurement	4	Household use of kerosene	11
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Evidence review methodology for complex interventions	6	Health effects of liquefied petroleum gas (LPG) use	13
Household energy programme finance and economic evaluation	7	Standards and testing	14

Name	Position and affiliation	Sex	Area of expertise specifically sought for guidelines (see reference number above)													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
Nathan Johnson	Postdoctoral Research Fellow HOMER Energy LLC, Colorado, The United States of America	M								X						
Sunny Karnani	Project Scientist University of California (UCI) Irvine, The United States of America	F			X											
Qing Lan	Senior Investigator National Cancer Institute Maryland, The United States of America	F		X												
Claudio Lanata	Professor and Science Director Instituto de Investigacion Nutricional Lima, Peru	M		X												
Weiwei Lin	Fellow Institute for Risk Assessment Sciences (IRAS), Utrecht University, Utrecht, The Netherlands	F		X												

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Continued

Area of expertise	Reference	Area of expertise	Reference
WHO air quality guideline development	1	Burns and injury prevention	8
Health effects of household air pollution (HAP)	2	Adoption and utilization of household interventions	9
Combustion and emissions science	3	Household use of coal	10
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Evidence review methodology for complex interventions	6	Health effects of liquefied petroleum gas (LPG) use	13
Household energy programme finance and economic evaluation	7	Standards and testing	14

Name	Position and affiliation	Sex	Area of expertise specifically sought for guidelines (see reference number above)													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
John McCracken	Head of the Unit of Emerging Infectious Diseases Universidad del Valle de Guatemala Guatemala City, Guatemala	M		X		X										
Sumi Mehta	Director of Programs Global Alliance for Clean Cookstoves Washington DC, The United States of America	F		X		X										
Lidia Morawska	Director Queensland University of Technology Brisbane, Australia	F			X	X										
Luke Naeher	Associate Professor University of Georgia Georgia, The United States of America	M		X		X										
Mark Nicas	Adjunct Professor University of California (UCB) Berkeley, The United States of America	M			X	X										

Area of expertise	Reference	Area of expertise	Reference
WHO air quality guideline development	1	Burns and injury prevention	8
Health effects of household air pollution (HAP)	2	Adoption and utilization of household interventions	9
Combustion and emissions science	3	Household use of coal	10
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Evidence review methodology for complex interventions	6	Health effects of liquefied petroleum gas (LPG) use	13
Household energy programme finance and economic evaluation	7	Standards and testing	14

Name	Position and affiliation	Sex	Area of expertise specifically sought for guidelines (see reference number above)													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
Michael Peck	Associate Medical Director Arizona Burn Center Phoenix, The United States of America	M								X						
Daniel Pope	Senior Lecturer in Epidemiology University of Liverpool Liverpool, The United Kingdom	M		X				X		X	X					
Elisa Puzzolo	Research Associate University of Liverpool Liverpool, The United Kingdom	F									X					
Eva Rehfuess	Senior Scientist University of Munich Munich, Germany	F	X	X				X			X					
Kirk R Smith	Professor of Global Environmental Health University of California (UCB) Berkeley, The United States of America	M	X	X	X	X	X				X	X	X	X		

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Area of expertise	Reference	Area of expertise	Reference
WHO air quality guideline development	1	Burns and injury prevention	8
Health effects of household air pollution (HAP)	2	Adoption and utilization of household interventions	9
Combustion and emissions science	3	Household use of coal	10
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Data systems for monitoring global HH fuel use	5	Climate change science	12
Evidence review methodology for complex interventions	6	Health effects of liquefied petroleum gas (LPG) use	13
Household energy programme finance and economic evaluation	7	Standards and testing	14

Name	Position and affiliation	Sex	Area of expertise specifically sought for guidelines (see reference number above)													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
Henock Solomon	Project Specialist University of South Carolina, The United States of America	M		X		X		X			X	X				
Debbi Stanistreet	Senior Lecturer University of Liverpool Liverpool, The United Kingdom	F						X			X					
James Tielsch	Professor Johns Hopkins Bloomberg School of Public Health Maryland, The United States of America	M														
Hisham Zerriffi	Assistant Professor University of British Columbia Vancouver, Canada	M							X							
Junfeng Zhang	Professor of Environmental Health University of Southern California Los Angeles CA, The United States of America	M		X		X						X				

A1.3 external peer review group

All members of the external peer review group are listed below, showing the subject areas which each individual reviewed, their affiliation and sex.

Evidence review topics	Name	Affiliation	Sex
Evidence review methods	Randy Elder	Scientific Director for Systematic Reviews Centers for Disease Control and Prevention (CDC) Atlanta, The United States of America	M
Fuel use for cooking, heating and lighting	Jill Baumgartner	Postdoctoral Researcher University of Minnesota, The United States of America	F
	Judy Guernsey	Associate Professor Dalhousie University Halifax, Canada	F
Emissions of health damaging pollutants	Andrew Grieshop	Assistant Professor North Carolina State University North Carolina, The United States of America	M
Emissions model	Ranyee Chiang	Senior Technical Manager Global Alliance for Clean Cookstoves Washington DC, The United States of America	F
	Morgan de Foort	Co-Director Department of Mechanical Engineering Colorado State University Colorado, The United States of America	M
	Jacob Kithinji	Lecturer University of Nairobi Nairobi, Kenya	M
Population levels of HAP and exposure	Ryan Allen	Associate Professor Simon Fraser University British Columbia, Canada	M
Health impacts of HAP	Ross Anderson	Professor of Public Health University of London, The United Kingdom	M
	Rogelio Perez-Padilla	Instituto Nacional de Enfermedades Respiratorias, Mexico City, Mexico	M
Health risks from coal	Marc Jeuland	Assistant Professor of Public Policy Duke University North Carolina, The United States of America	F
	Linwei Tian	Assistant Professor The Chinese University of Hong Kong New Territories, Hong Kong Special Administrative Region, China	M

Continues…

Continued

Evidence review topics	Name	Affiliation	Sex
Burns, scalds and poisoning	Mike Peck[a]	Director of International Outreach Programs Arizona Burn Unit Arizona, The United States of America	M
	Tom Potokar	Consultant Plastic Surgeon/Co-Founder and Director of Interburns Welsh Centre for Burns and Plastic Surgery Swansea, Wales	M
Impacts of interventions on HAP	Omar Masera	Professor National Autonomous University of Mexico Morelia, Mexico	M
	Julian Marshall	Associate Professor University of Minnesota Minnesota, The United States of America	M
Factors influencing adoption	Daniel Mausezahl	Senior Scientist Swiss Tropical and Public Health Institute Basel, Switzerland	M
Costs and financing, including climate co-benefits	Tami Bond	Associate Professor University of Illinois Illinois, The United States of America	F
	Guy Hutton	Senior Economist World Bank, Water and Sanitation Program Geneva, Switzerland	M
Recommendations Implementation guidance	Ross Anderson	Professor of Public Health St George's Medical School University of London, The United Kingdom	M
	Ranyee Chiang	Senior Technical Manager Global Alliance for Clean Cookstoves Washington DC, The United States of America	M
	Veena Joshi	Senior Advisor Energy Swiss Agency for Development and Cooperation New Delhi, India	F
	Christoph Messinger	Cookstove Specialist EnDev/GIZ Frankfurt, Germany	M
	Mike Sage	Guest Researcher/Consultant Centers for Disease Control and Prevention (CDC) Atlanta, The United States of America	F

[a] This reviewer participated in the first round of peer review then joined the team performing the safety review to share his valuable experience of the topic.

Annex 2: Summary of conflict of interest (COI) management

A2.1 guidelines development group

Name	Conflict declared yes or no	Details of conflict	How managed
Kristin Aunan	No	-	-
Kalpana Balakrishnan	No	-	-
John Balmes	No	-	-
Michael Bates	Yes	Research grant from NIEHS (2010–2016) to conduct study on TB risk factors and fuel use	Reviewed by WHO Secretariat: no action required
Michael Brauer	Yes	1) Annual income from Health Effects Institute for sitting on Review Committee of International Scientific Oversight Committee 2) Received grants and honorarium from British Columbia Lung Association Received fellowship award from East-West Centre	Reviewed by WHO Secretariat: no action required
Kenneth Bryden	No	N/A	N/A
Aaron Cohen	No	N/A	N/A
Mukesh Dherani	No	N/A	N/A
Shane Diekman	No	N/A	N/A
Xiaoli Duan	No	N/A	N/A
Rufus Edwards	No	N/A	N/A
Elizabeth Fisher	No	N/A	N/A
Santu Ghosh	No	N/A	N/A
Kirstie Jagoe	No	N/A	N/A
Michael Johnson	Yes	Employed by organization that conducts monitoring and evaluation of household energy programmes in developing regions. Has received reimbursements for travel on several occasions	Reviewed by WHO Secretariat: no action required
Nathan Johnson	Yes	Received financial support from the Global Alliance of Clean Cookstoves for research project	Reviewed by WHO Secretariat: no action required

N/A: not applicable

Continues…

Continued

Name	Conflict declared yes or no	Details of conflict	How managed
Sunny Karnani	No	N/A	N/A
Qing Lan	Yes	National Institute of Cancer contributed to costs for attending the WHO guidelines development group meeting.	Reviewed by WHO Secretariat: no action required
Claudio Lanata	Yes	Received financial support from the Optimus Foundation for a RCT with cookstoves in Peru	Reviewed by WHO Secretariat: no action required
Weiwei Lin	No	N/A	N/A
John McCracken	No	N/A	N/A
Sumi Mehta	No	N/A	N/A
Lidia Morawska	No	N/A	N/A
Luke Naeher	Yes	Research grant from Barrick Gold Corporation (2009) to conduct exposure monitoring in Peru	Reviewed by WHO Secretariat: no action required
Mark Nicas	No	N/A	N/A
Michael Peck	No	N/A	N/A
Daniel Pope	No	N/A	N/A
Elisa Puzzolo	No	N/A	N/A
Eva Rehfuess	No	N/A	N/A
Kirk R Smith	No	N/A	N/A
Henock Solomon	No	N/A	N/A
Debbi Stanistreet	No	N/A	N/A
James Tielsch	No	N/A	N/A
Hisham Zerriffi	Yes	1) Non-monetary support (including stove and customer details) during an emissions monitoring study from a cookstove company in India (First Energy). 2) Non-monetary support (loan of emissions testing) from colleagues at the University of Minnesota/North Carolina State University.	Reviewed by WHO Secretariat: no action required
Junfeng Zhang	No	N/A	N/A

N/A: not applicable

A2.2 external peer review group

Name	Conflict declared yes or no	Details of conflict	How managed
Randy Elder	No	N/A	N/A
Jill Baumgartner	No	N/A	N/A
Tami Bond	Yes	1) Received financial support from the USEPA for stove emissions measurements 2) Received financial support from the United States National Science Foundation, Department of Energy, National Aeronautical and Space Administration for climate change research programme 3) Honorarium for speaking at Health Effects Institute Conference 4) Gave testimony to committees in the US House of Representatives regarding the role of black carbon in climate change; 2007 and 2010	Reviewed by WHO Secretariat: no action required
Judy Guernsey	Yes	1) Per diem compensation (2010–2011) and research study contracts (2009–2001) from Health Canada 2) Indoor air quality monitoring equipment loan from Perkin-Elmer (2009–2011)	Reviewed by WHO Secretariat: no action required
Andrew Grieshop	No	N/A	N/A
Morgan de Foort	Yes	1) Research and development consultant for stove manufacturing company, Envirofit 2) Worked as a technical consultant to the Global Alliance for Clean Cookstoves 3) Receives funds from patent registered under Colorado State University	Reviewed by WHO Secretariat: no action required
Jacob Kithinji	Yes	1) Received financial support from the Global Alliance for Clean Cookstoves and Centers for Disease Control to establish cookstove laboratory in Nairobi 2) Chairs the Appropriate Technology Technical Committee at Kenya Bureau of Standards with the responsibility for setting standards of stoves for the next 6 months	Reviewed by WHO Secretariat: no action required
Ryan Allen	No	N/A	N/A
Rogelio Perez-Padilla	No	N/A	N/A
Marc Jeuland	No	N/A	N/A
Linwei Tian	No	N/A	N/A
Michael Peck[a]	No	N/A	N/A
Tom Potokar	No	N/A	N/A

N/A: not applicable

Continues…

Continued

Name	Conflict declared yes or no	Details of conflict	How managed
Omar Masera	No	N/A	N/A
Daniel Mausezahl	No	N/A	N/A
Mariam Otman del Barrio		Not required: WHO staff	
Guy Hutton	No	N/A	N/A
Ross Anderson	No	N/A	N/A
Ranyee Chiang	Yes	Employment by a public–private alliance/foundation interested in research, testing, and market approaches to improving health, environment, and livelihoods through cooking technologies and fuels	Reviewed by WHO Secretariat: no action required
Veena Joshi	No	N/A	N/A
Christoph Messinger	Yes	Salaried contract with Energizing Development Program/Deutsche Gesellschaft für Internationale Zusammenarbeit which has an interest in outcome of the indoor air quality guidelines recommendations as they may influence programmatic decisions	Reviewed by WHO Secretariat: no action required
Mike Sage	No	N/A	N/A

[a] Michael Peck appears as both a member of the guidelines development group (GDG) and of the external peer review group as he provided input to the first round of external reviews on material related to burns and poisoning and then became an author on account of his specialist knowledge and having conducted prior reviews.

N/A: not applicable

Annex 3: Summary of evidence reviews

For full text of all reviews listed here, please refer to website at: http://www.who.int/indoorair/guidelines/hhfc.

Review	Title	Aim and key questions for the review
1	Household fuel use	The aim of this review was to summarize the fuels and associated technologies used by different populations around the world for meeting household energy needs. The following questions were defined: 1. What sources of information are available on household energy use, and what are the strengths and limitations of these data? 2. What are the main fuels (and associated technologies) used by households for cooking, heating and lighting in both low- and middle-income countries (LMICs), and high-income countries? 3. What other sources of combustion are found in the home (other than tobacco smoking)?
2	Emissions of health-damaging pollutants from household stoves	The aim of this review was to assess the levels of emission of health damaging pollutants released from household combustion technologies. The following key questions were defined: 1. What are the levels of emission of health damaging pollutants from household solid fuel burning stoves in both laboratory and field tests, to be used as a basis for modelling indoor air concentrations? 2. What are the implications of differences between laboratory and field emission results?
3	Model for linking household energy use with indoor air quality	The aim of this review was to provide guidance on the emissions performance of household combustion technologies that would be required for households to meet WHO air quality guidelines (AQGs). Key factors that have an impact on the relationship between emissions and indoor air quality and the approaches that can be used to quantify this relationship are also discussed. The following questions are addressed by this review: 1. What considerations are important for linking indoor emissions to indoor pollutant levels? 2. What are the modelling options for linking emission rates with indoor air pollutant levels? 3. Based on the model, what particulate matter ($PM_{2.5}$) and carbon monoxide (CO) emission rates will correspond to achievement of goals involving various percentages of homes meeting WHO AQGs for both unvented and vented combustion technologies?

Continues…

Continued

Review	Title	Aim and key questions for the review
4	Health effects of household air pollution (HAP) exposure	The aim of the review was to compile and review the evidence on the impacts household fuel combustion have on child and adult health, with an emphasis on solid fuel use in developing countries. The review examined estimates of risk and strength of causal evidence, sought exposure-response evidence and estimates of intervention impacts. It also summarized the health risks of household use of gas, and any impacts the control of HAP have on vector-borne disease. The key questions for the review are as follows (note: further elaboration of these is provided in the sections relating to specific disease outcomes). 1. What child and adult disease outcomes are linked to solid fuel HAP exposure, and what are the estimated risks and strength of causal evidence? 2. What information is available on the relationships between exposure level and risk of important disease outcomes? What are the shapes of these relationships (exposure-response functions)? 3. What are the health risks of exposure to gas used as a household fuel? 4. What are the impacts of potential interventions to reduce HAP exposure (reduced smoke levels, increased ventilation) on the risk of vector-borne disease? What are the effects of smoke on insecticide treated nets (ITNs)?
5	Population levels of HAP and exposures	The aim of this review was to assess population levels of HAP and exposure. The following key questions were defined: 1. What are some of the key features of the HAP exposure setting? 2. What are some common methods and technologies used for estimating HAP concentrations or exposures? 3. How do selected household level determinants such as type of fuel or location of stove affect levels of HAP exposure that are experienced by household members? 4. How do the pooled estimates of exposure from studies reviewed compare to pollutant-specific WHO AQGs?
6	Impacts of interventions on HAP concentrations and personal exposure	The aim of this review was to compile all available information on the impacts that solid and clean fuel interventions used in homes for everyday needs have on HAP and personal exposure. The key questions for the review were as follows: 1. Are improved solid fuel stoves and cleaner fuel interventions in everyday use, compared to traditional solid fuel stoves, effective for reducing average concentrations of, or exposure to, PM and among households in LMICs? 2. By what amount (in absolute and relative terms) do the interventions reduce PM and CO, and how do post-intervention (in-use) levels compare with WHO AQGs?

Review	Title	Aim and key questions for the review
7	Factors influencing the adoption and sustained use of improved cookstoves and clean household energy	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 for 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?
8	Household coal combustion: unique features of exposure to intrinsic toxicants and health effects	The aim of this review was to identify the unique characteristics of coal, including toxic contaminants, and its health risks in household use to supplement the material in Review 4 on solid fuels (Health effects of household air pollution) on solid fuels. This review addressed the following four questions: 1. What characteristics of combustion emissions are specific to coal? 2. What are the specific adverse health effects of household coal combustion, in addition to the effects of products of incomplete combustion shared with biomass? 3. What are the health risks from toxic contaminants in coal? 4. What are the impacts of interventions to reduce risk from household use of coal, including the history and extent of bans on household coal use (with focus on China)?
9	Summary of systematic review of household kerosene use	The aim of this review was to summarize the evidence, drawing primarily on a recently published systematic review, relating to the following key questions: 1. How is kerosene used in households, including technology types used for combustion, and fuel quality? 2. What types and levels of pollutants are emitted, and what area concentrations and personal exposure levels result? 3. What is the evidence for health risks, as reported from epidemiological studies?
10	Burns and poisoning	The aim of this review was to synthesize and present the current evidence base for burns associated with the combustion of household fuels used for cooking, heating, and lighting in LMICs. A second objective was to summarize the evidence concerning poisoning related to the unintentional ingestion of liquid household fuel. The main questions addressed by this evidence review were: 1. What is the epidemiology (incidence, morbidity, mortality, sequelae) of burns and poisoning in LMICs attributable to household fuel combustion and use? 2. What are the important risk factors, including the role of household fuel use, for burns and poisoning in LMIC homes? 3. What are the impacts of technology and behavioural interventions on the risks of burns and poisoning in LMIC homes?
11	Costs and financing for adoption at scale	The aim of this review was to provide data on, and frameworks of analysis for, the financial implications of trying to improve air quality through changes in cooking technologies and fuels.

Annex 4: Recommendation 1 – Emission rate targets: assessment of the quality of the evidence and strength of the recommendation

A4.1 Assessment of the quality of the evidence

Details of the assessment of quality of evidence are provided as follows:

a) Review of health-damaging pollutant emissions from household stoves
b) Model linking emission rates with household air pollution (HAP)

A4.1.1 Health damaging pollutant emissions

Nature of evidence available

The data available from the majority of studies of stove and fuel emissions include important pollutants which are both health damaging and have an impact on climate. These data were obtained from a range of different types of test, the majority conducted in laboratory settings (including simulated kitchens), rather than in homes with normal cooking tasks. There is a wide range of types of solid fuel stove and fuel; this variability, together with variation of test protocols between studies, led to a decision not to carry out meta-analysis. Consequently, Grading of Evidence for Public Health Interventions (GEPHI) assessment has not been used, but Grading of Recommendations Assessment, Development and Evaluation (GRADE) domains were used to guide the assessment of quality.

Study design (testing protocols)

Three main test protocols have been used, the water boiling test (WBT), controlled cooking test (CCT) and the kitchen performance test (KPT), with most data available from the first two. For the laboratory-based studies, all results are presented for the WBT which increases comparability, but even so there are variations between studies in the way this has been applied (see risk of bias). The largest, well-standardized set of studies have been reported from the The United States of America Environmental Protection Agency (USEPA) stove laboratory, but so far these have been restricted to solid fuel stoves burning wood. Of the field studies, two used the CCT, while others tested stoves during normal cooking activities ranging from a single cooking event to all cooking performed in a single day.

Metrics

Emissions rates are presented for six important health and climate-relevant pollutants (particulate matter) PM, carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), total non-methane organic carbon (TNMOC) and black carbon (BC)). For PM, both total suspended particulates (TSP) and $PM_{2.5}$ have variously been reported, but these data are combined in the current review as 99% of the emitted PM by mass is less than 1 micron in diameter. Rates are presented in two ways: (i) as g/kg dry fuel (representing combustion efficiency) and (ii) as g/MJ energy delivered to pot (representing heat transfer efficiency).

Risk of bias

For emission rate measurements, the two main sources of bias lie with (i) the test protocol used, and (ii) the manner in which this protocol was applied in practice, along with quality control procedures. All results for laboratory-based tests are for the WBT. Those reported by the USEPA for wood burning stoves are well standardized and quality controlled. For others it is recognized that there are variations in respect of test procedures (water volumes, simmering temperatures, treatment of evaporative losses etc.), fuel preparation (e.g. timed feeding of precision-cut blocks of fuel vs. naturally sourced branches and twigs), analytical methods, and dilution approaches. Overall, the laboratory-based data have a much lower intrinsic risk of bias than those from field studies but, as discussed below, there is evidence that laboratory and field testing are not comparable.

Heterogeneity

For all pollutants there was a wide range of values for the most commonly tested stove/fuel subgroups (traditional and improved unvented wood stoves, improved charcoal stoves). Formal testing of statistical heterogeneity was not conducted due to methodological variations between studies.

Precision

As noted, most of the studies available used laboratory testing. Of these, 13 investigated solid fuel stoves (mostly those using wood), three studied kerosene and three gas (2 liquefied petroleum gas (LPG); 1 natural gas). For CO emissions, data were available from >100 solid fuel stoves, but only five kerosene and three gas. For PM emissions, data were available from >50 solid fuel stoves, and the same numbers of kerosene and gas stoves. Precision was good for common types of traditional and improved wood-burning stoves, but rather poorer for other types of solid fuel stoves, kerosene and gas.

Of the available field studies, two used the CCT, and seven used testing of normal cooking activities including one each for kerosene and gas. For CO emissions, data were available for >30 solid fuel stoves, one kerosene and three gas; for PM >30 for solid fuel stoves, one for kerosene and none for gas. Precision was moderate for wood-burning solid fuel stoves, but poor for other groups.

Publication bias

Given the heterogeneity of methods used to apply the test protocols between studies, and the large number of stove/fuel subgroups, formal testing of publication bias was not carried out. While the wood-burning stove tests reported by USEPA represent a complete series, and unpublished sources were included in the systematic review to minimize this bias, it is quite possible that there is other unpublished material with different results.

Comparison of laboratory and field testing

Assessment of studies comparing features of emissions from test protocol-based and normal use studies provided evidence that the WBT and CCT do not reflect well the emissions produced during normal cooking activities. There is greater variability within and between homes, the coefficient of variation ranging from 9% to 43% higher for CO_2 and CO with normal use activities. Furthermore, the CCT has been found to be fundamentally different from normal cooking, both in terms of emission rates for a given level of combustion efficiency, and also in terms of the composition of particles emitted (although the health implications of the latter are not known). These findings highlight the need for enhanced methods for, and attention given to, testing of emissions in normal use. It remains the case that emission rates tend to be higher in normal use than in laboratory-based protocol defined tests.

Summary

The main sources of data from laboratory testing (e.g. USEPA) provide reliable, high quality evidence, using standard protocols for the tests that are widely published and disseminated. However, although common test protocols were used, there are still significant variations between stove and fuel groups related to test procedures, fuel preparation, analytical methods, and dilution approaches. The reliability of laboratory results, however, is generally higher than field measures, as more sophisticated approaches to the measurements of the emissions species can be used. There are relatively limited data on field emissions and generalizations over large geographical regions are limited by our understanding of the factors that drive the variability in emissions over geographic scales. There is evidence from direct comparisons between the laboratory and the field that the laboratory tests are not representative of the emission concentrations or the range of particle properties and compositions that are seen in the field. There are still a large number of gaps in stove and fuel in-field emissions testing data, especially on low emission and advanced stoves, but also for charcoal and coal. Thus, field-based emissions during normal daily cooking activities are not well quantified. Data on emissions from LPG and natural gas in both laboratory and in-field settings are also limited. The overall assessment of the quality of the evidence by this review is **moderate** for laboratory test evidence, and **low** for field-based evidence.

A4.1.2 Emissions model

Assessment of the quality of this evidence for the purpose of these guidelines (i.e. providing guidance on emission rates that will allow the AQGs to be met), was based on two main types of validation studies, as summarized below.

Comparison of model predictions with observed kitchen concentrations

The first source of validation comes from comparing estimated concentrations of $PM_{2.5}$ and CO derived from the model with those observed in kitchen field studies.

Table A4.1 compares results for model predictions of $PM_{2.5}$ and CO concentration distributions for three types of stove/fuel (traditional solid fuel, unvented rocket-type wood stove, and gas), with mean (24-or 48-hr) and standard deviations (SD) or range of concentrations measured in homes around the world. The latter data were obtained from the systematic reviews of population levels of household air pollution (HAP) and exposure (Review 5) and of intervention impacts on HAP and exposure (Review 6). Data from the WHO South-East Asia Region compiled in Review 5 are also shown separately where available, since input data for the model (kitchen volume, air exchange rates, average duration of use per day) are derived from studies carried out in that region (India).

Table A4.1: comparison of distributions of $PM_{2.5}$ and CO from model predictions with observed means (and standard deviations or range) of concentrations of both pollutants in WHO South-East Asia Region and all regions

Stove/fuel type	$PM_{2.5}$ (µg/m³)		CO (mg/m³)	
	Model predicted	**Observed**	**Model predicted**	**Observed**
Traditional solid fuel	> 60% had concentrations in range 500–1800 Mode: 800	Mean: 826 (SD = 1038) (SEAR); 972 (SD = 876) (all regions)[a]	> 60% had concentrations in range 5–25 Mode: 12	Mean: 11.09 (SD = 8.03) (SEAR); 9.94 (SD = 7.11) (all regions)[a]
Improved (unvented) rocket-type	> 60% in range 200–1500 Mode: 500	Mean 410 (range 170–1180)[b]	> 60% in range 2–15 Mode: 5	Mean 7.56 (range 5.04–17.99)[b]
Gas	99% would meet interim target (IT)-1 (35 µg/m3)	All clean fuel; mean: 72 (SD = 41) (SEAR); 66 (SD = 37) (all regions)[a]	All would meet the 24-hour air quality guideline (7)	All clean fuel; mean: N/A (SEAR); 1.49 (SD = 0.69) (all regions)[a]

[a] Data from systematic review of levels of HAP and exposure (Review 5).

[b] Data from systematic review of intervention impacts (Review 6).

For traditional solid fuel stoves, the predicted and observed results are very similar. For the improved rocket-type stove, results are comparable for $PM_{2.5}$, but the predicted results are a little lower than those observed for CO. For gas, which is predicted to meet the IT-1 for $PM_{2.5}$ (35 μg/m^3) in 99% of homes, it was found that in practice average concentrations in homes were approximately 70 μg/m^3, with an SD of around 40 μg/m^3. For CO, gas was predicted to meet the 24-hour AQG of 7 mg/m^3 in 100% of homes, and this was borne out with an average concentration observed in homes of 1.49 (SD = 0.69) mg/m^3. The considerably higher levels of observed $PM_{2.5}$ concentration are likely to be the result of multiple stove and fuel use in these homes, along with pollutants from neighbouring households and other sources entering the study kitchens.

Comparison based on simultaneous measurement of emissions and pollutants

The second source of validation is derived from data obtained from India. Emission rates, ventilation, room volume and indoor concentrations of CO were measured simultaneously. These data indicated that the model underestimated CO room concentrations by 46%. Several factors may be contributing to this, including spatially heterogeneous distributions in the kitchen leading to measured values reflecting higher concentrations nearer the stove, rather than average concentrations for the whole room.

Summary

Overall, the validation studies suggest that for $PM_{2.5}$ concentrations, the model performs well. The high observed levels for clean fuel users do not call into question the validity of the model, but rather emphasize the need to control other, more polluting, sources in the home and neighbourhood, if AQG values are to be met. There is some evidence that the model may underestimate observed CO concentrations in some settings, but it appears to be satisfactory for the studies of traditional stoves and clean fuel. An additional consideration for validity is that the model inputs are based solely on data from India. Better regional performances may be obtained using input data collected on a regional, if not subregional basis. Plans for obtaining and applying these data are described in Section 5 of the guidelines.

Overall, the evidence provided by the model was assessed to be of **moderate** quality.

A4.2 Determination of the strength of Recommendation 1: Emission rate targets

The evidence and model-based information summarized above was considered of sufficient quality and scope to develop a recommendation based on emission rates required for meeting the WHO AQGs. The issues concerning poorer field-based emission performance and the finding of higher observed $PM_{2.5}$ values in homes when validating the model predictions for higher quality solid fuel stoves and LPG, were not seen as a threat to the model or the approach to the recommendation. These were taken as indications of a need for community-wide action and control of other combustion sources, and improvement in testing protocols. These points are incorporated in the general considerations for implementation of the recommendations in Section 4.2 of the guidelines.

When the GDG assessed benefits and harms, they agreed that there are very substantial health benefits to be gained from markedly reducing emissions. They also noted that more efficient fuel combustion has economic, time saving, climate and other benefits. These benefits were felt to considerably outweigh potential harms, so long as safety is considered and policy deals with the affordability, support and fuel supply issues that may arise during transition to low-emission interventions.

When considering values and preferences, the GDG noted the wide acceptance in the implementation community of emission rates as a guide to health impacts, and their inclusion in developing International Organization for Standardization (ISO) standards (see also Annex 9)*(1).* Users are known to value highly the benefits of cleaner and more efficient household energy devices, although rapid change may present cultural and other challenges that need to be handled appropriately.

When assessing feasibility the GDG considered the additional funding needed for testing and certification to ensure compliance with emission rates. This was assessed as being a relatively small component of programmatic costs, and it was agreed that the new global energy access initiatives including the UN Sustainable Energy for All programme (SE4All) will bring about greater public and private investment.

On the basis of these considerations, this recommendation is **Strong** (Table A4.2)**.**

Table A4.2: Decision table for the strength of Recommendation 1 – Emission rate targets

Factors influencing strength of recommendations	Decision
Quality of evidence	Existing WHO air quality guidelines: high
	Pollutant emissions: moderate
	Emissions model: moderate
Balance of benefits versus harms and burdens	Benefits clearly outweigh harms
Values and preferences	The use of emission rate targets as a practical tool for guiding selection of interventions is widely seen as useful; rapid shifts in technology/fuel type may be difficult for some users
Feasibility	Implementation will require increased resources, but some investment is under way, and it is feasible that the necessary resources will be available given continued political commitment
Decision on strength of recommendation	**Strong**

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Annex 5: Recommendation 2 – Policy during transition: assessment of the quality of the evidence and the strength of the recommendation

A5.1 Assessment of the quality of the evidence

The assessment of the quality of evidence was based on the following:

1. Grading of recommendations assessment, development and evaluation (GEPHI) assessment of evidence for impacts of interventions on specific disease outcomes (population, intervention, comparator, outcome (PICO-1))
2. GEPHI assessment of evidence for intervention impacts on kitchen average fine particulate matter ($PM_{2.5}$) and carbon monoxide CO
3. Assessment of evidence compiled in the integrated exposure-response (IER) functions
4. Assessment of evidence on population levels of household air pollution (HAP) and personal exposure.
5. Assessment of evidence on factors influencing adoption and sustained use of solid fuel interventions and clean fuels.

This was followed by an assessment of the consistency of evidence across the causal chain.

A5.1.1 GEPHI assessment of evidence for estimates of impacts of interventions on specific disease outcomes: PICO question 1

For full details of the systematic reviews and GEPHI assessment including scores for importance of outcomes and for grading in tables, please refer to Review 4: Health impacts of HAP available at: http://www.who.int/indoorair/guidelines/hhfc

Non-fatal acute lower respiratory infection (ALRI)

Importance of outcome: Important (6)

Design	No. of studies	Risk of bias	Inconsistency (heterogeneity)	Indirectness (external validity)	Imprecision (power)	Publication bias	Other considerations (specify)*	Number of events: intervention	Number of events: control	Relative effect and 95% CI	Quality
Randomized-controlled trials (RCTs)	1	No	No	No	Yes (-1)	No	No	149	180	0.78 (0.59, 1.06)	Moderate
Observational	20	Yes (-1)	Yes (-1)	No	No	No	No	11,331 events		0.63 (0.53, 0.75)	Very low
Intermediate score										Very low	
Final score		Despite statistical heterogeneity in the systematic review, overall consistency of effect is demonstrated through sensitivity analysis (+1)								**Moderate**	
		Evidence on effects of exposures to ambient air pollution and second-hand tobacco smoke (+1)									

* Only large effect (relative risk estimate >2) is used for upgrading if the group of studies is downgraded for any reason

Severe ALRI

Importance of outcome: Critical (9)

Design	No. of studies	Risk of bias	Inconsistency (heterogeneity)	Indirectness (external validity)	Imprecision (power)	Publication bias	Other considerations (specify)*	Number of events: intervention	Number of events: control	Relative effect and 95% CI	Quality
RCTs	1	No	No	No	No	No	Exposure-response (+1)	72	101	0.67 (0.45, 0.98)	High
Observational	3	Yes (-1)	No	No	No	No	Large effect (+1)	331 events		0.40 (0.25, 0.67)	Low
Intermediate score										Low	
Final score		Insufficient evidence to upgrade for overall consistency of effect								**Low**	
		No analogous evidence available yet of larger risk for severe pneumonia									

Fatal ALRI

Importance of outcome: Critical (9)

Design	No. of studies	Risk of bias	Inconsistency (heterogeneity)	Indirectness (external validity)	Imprecision (power)	Publication bias	Other considerations (specify)*	Number of events		Relative effect and 95% CI	Quality
								Intervention	Control		
RCTs	1	No	No	No	Yes (-1)	No	No	3	6	0.48 (0.12, 1.91)	Moderate
Observational	3	Yes (-1)	No	No	No	No	Large effect (+1)	659 events		0.34 (0.22, 0.55)	Low
Intermediate score										Low	
Final score		Insufficient evidence to upgrade for overall consistency of effect								**Low**	
		No analogous evidence available yet of larger risk for fatal pneumonia									

Low birth weight

Importance of outcome: Important (6)

Design	No. of studies	Risk of bias	Inconsistency (heterogeneity)	Indirectness (external validity)	Imprecision (power)	Publication bias	Other considerations (specify)*	Number of events		Relative effect and 95% CI	Quality
								Intervention	Control		
RCTs	1	No	No	No	Yes (-1)	No	No	13	26	0.74 (0.33, 1.66)	Moderate
Observational	6	No	No	No	No	No	No	5670 events		0.71 (0.64, 0.79)	Low
Intermediate score										Low	
Final score		The remarkable consistency across studies and settings could lead to upgrading, but this was not done as only 7 studies are available								**Moderate**	
		Good analogous evidence from other combustion sources, especially tobacco smoking									

Stillbirth

Importance of outcome: Critical (9)

Design	No. of studies	Risk of bias	Inconsistency (heterogeneity)	Indirectness (external validity)	Imprecision (power)	Publication bias	Other considerations (specify)*	Number of events		Relative effect and 95% CI	Quality
								intervention	control		
Observational	4	No	No	No	No	No	No	3345 events		0.66 (0.54, 0.81)	Low
Intermediate score										Low	
Final score											**Low**

Stunting (all observational designs)

Importance of outcome: Important (6)

Design	No. of studies	Risk of bias	Inconsistency (heterogeneity)	Indirectness (external validity)	Imprecision (power)	Publication bias	Other considerations (specify)*	Number of events		Relative effect and 95% CI	Quality
								Intervention	Control		
Stunting	2	No	No	No	No	No	No	7109 events		0.79 (0.70, 0.89)	Low
Severe stunting	2	No	Yes (-1)	No	No	No	No	8157 events		0.64 (0.43, 0.96)	Very low
Intermediate score										Low	
Final score		Insufficient evidence to upgrade for overall consistency of effect								**Moderate stunting: Low**	
		Analogous evidence from maternal smoking (including from Kyu et al. 2009) (1) for severe stunting								**Severe stunting: Low**	

All cause child mortality

Importance of outcome: Critical (9)

Design	No. of studies	Risk of bias	Inconsistency (heterogeneity)	Indirectness (external validity)	Imprecision (power)	Publication bias	Other considerations (specify)*	Number of events		Relative effect and 95% CI	Quality
								intervention	control		
Observational	5	No	Yes (-1)	No	No	Possible	No	8446 events		0.79 (0.70, 0.89)	Very low
Intermediate score										Low	
Final score	Insufficient evidence to upgrade for overall consistency of effect									**Low**	
	Insufficient evidence to upgrade for analogous evidence on risk for all cause child mortality										

Chronic obstructive pulmonary disease (COPD)

Importance of outcome: Important (6)

Design	No. of studies	Risk of bias	Inconsistency (heterogeneity)	Indirectness (external validity)	Imprecision (power)	Publication bias	Other considerations (specify)*	Number of events		Relative effect and 95% CI	Quality
								intervention	control		
Observational	25	Yes (-1)	Yes (-1)	No	No	Yes (-1)	Large effect for women (+1)	24 870 cases		Women: 0.43 (0.33, 0.58) Men: 0.53 (0.32, 0.87)	Very low
Intermediate score										Very low	
Final score	Despite statistical heterogeneity in the systematic review, overall consistency of effect was demonstrated through sensitivity analysis (+1)									**Low**	
	Evidence on effects of exposures to ambient air pollution, second-hand tobacco smoke and active smoking (+1)										

Lung cancer with exposure to household coal use

Importance of outcome: Important (9)

Design	No. of studies	Risk of bias	Inconsistency (heterogeneity)	Indirectness (external validity)	Imprecision (power)	Publication bias	Other considerations (specify)*	Number of events: intervention	Number of events: control	Relative effect and 95% CI	Quality
Observational	25	No	Yes (-1)	No	No	No	Large effect (+1)	10 142 cases		0.46 (0.35, 0.62)	Low
Intermediate score										Low	
Final score	Evidence that risk does vary by setting, possibly due in part to type of coal									Moderate	
	Evidence on effects of exposures to other sources of coal combustion pollution (+1)										

Lung cancer with exposure to household biomass use
(a) Men

Importance of outcome: Important (9)

Design	No. of studies	Risk of bias	Inconsistency (heterogeneity)	Indirectness (external validity)	Imprecision (power)	Publication bias	Other considerations (specify)[a]	Number of events: intervention	Number of events: control	Relative effect and 95% CI	Quality
Observational	3	Yes (-1)	No	No	No	No	Exposure-response (+1)	4005 events		0.82 (0.73, 0.93)	LOW
Intermediate score										Low	
Final score	Too few studies to assess consistency across settings									Moderate	
	Evidence on effects of exposures to biomass from second-hand and active smoking (+1)										

a Almost all evidence for men is from Europe and North America and this estimate may not be reliable for higher exposures with open fires/stoves in developing countries.

(b) Women:

Importance of outcome: Important (9)

Design	No. of studies	Risk of bias	Inconsistency (heterogeneity)	Indirectness (external validity)	Imprecision (power)	Publication bias	Other considerations (specify)*	Number of events		Relative effect and 95% CI	Quality
								intervention	control		
Observational	6	No	Yes (-1)	No	No	No	No	4311 events		0.63 (0.43, 0.93)	Very low
Intermediate score										Very low	
Final score	Lack of consistency for largest group across Asia and Mexico									**Low**	
	Evidence on effects of exposures to biomass from second-hand and active smoking (+1)										

Cataract with exposure to household solid fuel use

Importance of outcome: Important (9)

Design	No. of studies	Risk of bias	Inconsistency (heterogeneity)	Indirectness (external validity)	Imprecision (power)	Publication bias	Other considerations (specify)*	Number of events		Relative effect and 95% CI	Quality
								intervention	control		
Observational	7	No	Yes (-1)	No	No	No	Large effect (+1)	3170 events		0.41 (0.29, 0.57)	Low
Intermediate score										Low	
Final score	Although the studies show reasonable consistency, all were conducted in the same region									(Women only) **Moderate**	
	Evidence on effects of exposures to tobacco smoking (+1)										

A5.1.2 GEPHI assessment of the evidence for estimates of impacts of interventions on kitchen concentrations of $PM_{2.5}$ and CO: PICO question 2

For full details of systematic review and GEPHI assessment, please refer to Review 6: Intervention impacts available at: http://www.who.int/indoorair/guidelines/hhfc

Solid fuel stoves with chimneys: kitchen $PM_{2.5}$

No. of studies	Design	Risk of bias	Inconsistency	Indirectness	Lack of precision	Publication bias	Other	No. of homes		Effect (μg/m³) 95% CI	Quality
								Int	Cont		
12 (17 estimates)	Before-and-after studies	Low	$I^2 = 69\%$ (-1)	No	No	Yes (-1)	Large effect (+1)	388	N/A	−0.46 (−0.60, −0.33)	**Low**
6 (7 estimates)	Cross-sectional studies	Yes (-1)	$I^2 = 83\%$ (-1)	No	Yes (-1)	No	No	227	217	−0.53 (−0.94, +0.13)	**Very low**
Final score	Based on before-and-after studies		11/12 show reductions (+1 for consistency)							−0.46 (−0.60, −0.33)	**Moderate**[a]

[a] The final score of moderate quality is based on restriction to the before-and-after studies which were upgraded (from an initial assessment of low quality) on the criterion of consistency in direction of effect across studies carried out in a wide range of settings.

Int: intervention, Cont: control

Solid fuel stoves with chimneys: kitchen CO

No. of studies	Design	Risk of bias	Inconsistency	Indirectness	Lack of precision	Publication bias	Other	No. of homes		Effect (μg/m³) 95% CI	Quality
								Int	Cont		
1 (1 estimate)	RCTs	Low	N/A	No	No	N/A	No	36	36	−7.5 (−6.1, −8.9)	**High**
10 (14 estimates)	Before-and-after studies	Low	$I^2 = 77\%$ (-1)	No	No	Yes (-1)	Large effect (+1)	421	N/A	−5.5 (−3.7, −7.3)	**Low**
6 (7 estimates)	Cross-sectional studies	Yes (-1)	$I^2 = 88\%$	No	No	No	No	144	189	−4.7 (−1.7, −7.6)	**Very low**
Final score	Based on RCTs and before-and-after studies		11/11 show reductions (+1 consistency)							−5.7 (−3.9, −7.5)	**Moderate**

Int: intervention, Cont: control

Solid fuel stoves without chimneys: kitchen $PM_{2.5}$

No. of studies	Design	Risk of bias	Inconsistency	Indirectness	Lack of precision	Publication bias	Other	No. of homes		Effect (μg/m³) 95% CI	Quality
								Int	Cont		
4 (7 estimates)	Before-and-after studies	Low	$I^2 = 36\%$	No	No	Yes (-1)	No	169	N/A	−0.26 (−0.12, −0.39)	**Low**
Final score	Based on before-and-after studies		No additional criteria met. Only 4 studies. All studies show reductions, but only 2 estimates (from 2 studies) are statistically significant							−0.26 (−0.12, −0.39)	**Low**

Int: intervention, Cont: control

Solid fuel stoves without chimneys: kitchen CO

No. of studies	Design	Risk of bias	Inconsistency	Indirectness	Lack of precision	Publication bias	Other	No. of homes		Effect (μg/m³) 95% CI	Quality
								Int	Cont		
4 (7 estimates)	Before-and-after studies	Low	$I^2 = 0\%$	No	No	No	No	170	N/A	−3.32 (−1.86, −4.77)	**Moderate**
Final score	Based on before-and-after studies		No additional criteria met. Only 4 studies. All studies show reductions, but only 2 estimates (from 2 studies) are statistically significant							−3.32 (−1.86, −4.77)	**Moderate**

Int: intervention, Cont: control

Advanced combustion solid fuel stoves: kitchen $PM_{2.5}$

No. of studies	Design	Risk of bias	Inconsistency	Indirectness	Lack of precision	Publication bias	Other	No. of homes		Effect (μg/m³) 95% CI	Quality
								Int	Cont		
1 (3 estimates)	Before-and-after studies	Yes (-1)	$I^2 = 0\%$	No	No	N/A	No	65	N/A	−0.22 (−0.06, −0.38)	**Low**
Final score	Based on before-and-after studies		No other criteria met							−0.22 (−0.06, −0.38)	**Low**

Int: intervention, Cont: control

Advanced combustion solid fuel stoves: kitchen CO

No. of studies	Design	Risk of bias	Inconsistency	Indirectness	Lack of precision	Publication bias	Other	No. of homes		Effect (μg/m³) 95% CI	Quality
								Int	Cont		
1 (3 estimates)	Before-and-after studies	Yes (-1)	$I^2 = 0\%$	No	No	N/A	No	66	N/A	−3.16 (−0.73, −5.59)	**Low**
Final score	Based on before-and-after studies		No other criteria met							−3.16 (−0.73, −5.59)	**Low**

Ethanol: kitchen $PM_{2.5}$

No. of studies	Design	Risk of bias	Inconsistency	Indirectness	Lack of precision	Publication bias	Other	No. of homes		Effect (μg/m³) 95% CI	Quality
								Int	Cont		
2 (4 estimates)	Before-and-after studies	Low	$I^2 = 82\%$ (-1)	No	No	Possible (-1)	Large effect (+1)	85	N/A	−0.58 (−0.24, −0.92)	**Low**
Final score	Based on before-and-after studies		No other criteria met							−0.58 (−0.24, −0.92)	**Low**

Ethanol: kitchen CO

No. of studies	Design	Risk of bias	Inconsistency	Indirectness	Lack of precision	Publication bias	Other	No. of homes		Effect (μg/m³) 95% CI	Quality
								Int	Cont		
2 (4 estimates)	Before-and-after studies	Low	$I^2 = 83\%$ (-1)	No	No	No	Large effect (+1)	85	N/A	−21.9 (−16.5, −27.4)	**Moderate**
Final score	Based on before-and-after studies		No other criteria met							−27.3 (−13.1, −41.5)	**Moderate**

A5.1.3 Assessment of quality of the evidence for Integrated exposure-response (IER) functions

Given the very limited amount of directly measured exposure-response evidence and the nature of the IER models, it was not appropriate to apply GEPHI assessment. However, it was considered that GRADE domains are a useful guide for assessing the strength of this body of evidence, including possible implications of the assumptions, and its suitability for developing recommendations. In doing this, a generic assessment of the evidence from the IER models was made, (see Table A5.1), followed by more specific discussion of the evidence available for child ALRI and other quality issues for ischaemic heart disease (IHD)/stroke and COPD.

Table A5.1: Generic issues relating to the IER functions

Criterion	Assessment
Number of studies	A good number of studies are available for each outcome in the models, and for each source of exposure, with the exception of ALRI (all HAP risk estimates are based on the RESPIRE study, but see below for further discussion of consistency with systematic review of solid fuel use and ALRI), and IHD/stroke for which no studies were available at the time of model development, also discussed separately below.
Risk of bias	Studies have generally used adjusted risk estimates, although some residual confounding is possible. Age-adjustment was carried out for IHD and stroke to account for the reduction in risk with increasing age. The main source of bias may come from estimates of the true exposure, with the exception of the RESPIRE study which measured this directly, albeit using a single pollutant (CO) as a proxy. Thus, exposure levels in second-hand smoke (SHS) have been estimated and may not be accurate, and furthermore those exposed to SHS may also be exposed to ambient air pollution (AAP), and vice-versa.
Indirectness	Studies providing risk estimates have direct measures of risk of the outcomes of interest. Some indirectness may result from combining sources of $PM_{2.5}$ and the assumption that risk of $PM_{2.5}$ exposure increases with dose, independent of the source. Currently however, there is insufficient evidence to suggest this is not the case. There is some suggestion that wood smoke may be associated with a higher risk of COPD than coal, and that coal exposure may have a higher risk of lung cancer than wood. In both cases, however, the respective 95% CIs overlap, and other sources of heterogeneity may contribute.
Imprecision	The 95% CIs have been calculated for the functions, and are shown in Review 4. There is generally greater precision for exposure to active smoking compared to the other sources, reflecting the extent of epidemiological evidence and precision of the component studies. This does, however, mean that the high end of the IER functions are relatively well estimated, which in turn lends more precision to the upper end of the HAP range of exposure. The exception is child ALRI for which no risk data are available for active smoking.
Inconsistency	The alternative models were assessed by the Akaike and Bayesian information criteria, and the IER version performed best in terms of fitting the data. Review 4 reports the estimates from all contributing studies for the four adult disease conditions, and for all sources of $PM_{2.5}$. These show the degree of inconsistency, which is quite substantial in some cases, especially at the lower levels of exposure associated with AAP and SHS, although much less so for high exposure resulting from active smoking. For HAP, there were no estimates for IHD and stroke, and although more than 20 studies are available for COPD, the meta-analysis estimates did not fit well (see Review 4).
Publication bias	Publication bias was assessed in the systematic reviews. There was no indication of publication bias for the reviews of child ALRI or for lung cancer with exposure to coal and biomass. For COPD there was an indication that publication bias could be contributing to overestimation of the risk estimates, but the available reviews are not entirely consistent on this finding (see discussion in Review 4).

ALRI: As noted above, child ALRI has the most direct exposure-response data for HAP, and is a very important outcome in a vulnerable population group. Consequently, there is a good case for giving this outcome special attention when considering recommendations. In addition to the generic issues concerning quality of this evidence, there are a number of specific issues regarding the strength of evidence for the ALRI IER function. As there are no estimates from active smoking, the upper bound of the curve is dependent on HAP, which is derived from a single study. On the other hand, a strong aspect of this evidence is that the HAP data points are based on direct individual subject (child) exposure measurement, which is not available for any other source or outcome in the IERs. Some additional uncertainty arises from the possibility that the epidemiology of ALRI may differ between AAP and second-hand smoke results (all developed countries) and HAP (developing countries, also high altitude).

The consistency of the IER function with the systematic review and meta-analysis of child ALRI (reported in Section 3 of Review 4) can also be assessed. That review provided a pooled odds ratio (OR) of 0.63 (95% CI: 0.53, 0.75) for all ALRI. The exposure contrast was estimated to be around 300 $\mu g/m^3$ $PM_{2.5}$ for the exposed groups which used traditional solid fuel fires and stoves and around 50–75 $\mu g/m^3$ $PM_{2.5}$, for the 'unexposed' groups. This is consistent with what has been measured in studies of clean fuel users in developing country settings (see Reviews 5 and 6). The IER function predicts an increase in relative risk (RR) from around 1.7 to 2.9 as exposure increases from 50–75 to 300 $\mu g/m^3$ $PM_{2.5}$, with a ratio of relative risks 0.59. This indicates a good level of consistency between the IER and the available epidemiological evidence on solid fuel use and ALRI risk.

IHD/stroke: For IHD/stroke, two studies are described in Review 4. One was unadjusted and hence not useful for comparison. The other reported ORs of 2.58 (95% CI: 1.53, 4.32) for cardiovascuar disease (CVD) and 1.60 (0.80, 3.21) for stroke, when comparing ever use of solid fuels (coal, biomass) for cooking and/or heating with never use. Although actual long-term average exposures in these groups are not known, the CVD estimate appears somewhat high compared to the HAP range of the IER model (although within the 95% confidence intervals). The stroke estimate is more consistent.

COPD: The relatively poor fit of the HAP estimates for COPD may be due to exposure beginning very early in life (in utero), compared to late teenage years or early adulthood for smoking. Thus, risk could be expected to be higher for a given level of exposure due to longer duration, and possibly exposure during critical periods of life and lung development.

Summary

Direct, quantified evidence on exposure-response relationships is limited to two studies for one outcome (child ALRI), and these two sets of data could not easily be combined. Some exposure-response evidence is available for other outcomes, provided in Review 4. While this is useful for establishing causation, it is not quantified in terms of exposure. The IERs are a relatively new approach and have some important assumptions, but are mostly based on an extensive and broad evidence base. That developed for child ALRI is based on the only directly assessed individual exposure data, and shows consistency between the IER and pooled estimate for the predominantly observational epidemiological studies available.

Overall, the IER evidence was assessed as being of **moderate** quality.

A5.1.4 Assessment of evidence on population levels of HAP and personal exposure

The evidence compiled in this systematic review (Review 5) was intended to provide comprehensive descriptive information on average levels of HAP and exposure for population groups using traditional solid fuels, improved solid fuel stoves, and clean fuels. The impacts of interventions reported by studies (including observational studies of intervention projects and programmes) are reviewed separately (see Review 6). Meta-analysis was not carried out, although pooled values for pollutant concentrations were calculated using weighted averages. GRADE domains have been used as a guide for assessing the quality of the evidence.

Studies

All studies included were cross-sectional. The inclusion criteria covered: provision of adequate detail on sampling criteria, sampling methods (including specification of sampling devices, flow rates, calibration procedures etc.), analytical methods (including specification of analytical instrumentation, sensitivity and, wherever applicable, specificity of method), calibration standards and corrections for measurement errors (such as co-locating or calibrating against gravimetric samplers for light-scattering devices used for measuring PM).

Risk of bias

As the inclusion criteria for this review covered those aspects of study design and conduct that may bias results, the risk of bias was judged to be low. In order to provide comparable average levels of PM and CO, only those studies reporting 24-hour or 48-hour measurements were included. As studies have variously measured $PM_{2.5}$, PM_4 and PM_{10}, results for these different particle size cut-offs were reported (and averaged) separately.

Heterogeneity

No formal assessment of statistical heterogeneity was made. It was expected that household and personal exposure levels would vary greatly due to the variability in household energy use, housing type, seasonal factors, etc. The pattern of variability was, however, generally not suggestive of unreliable results, as values for homes using traditional stoves and solid fuels reported high (albeit variable) levels of PM and CO, and did not have unusually low values. Some of the studies of homes using clean fuels found levels higher than might be expected on the basis of emission rates, but these could be explained by multiple stove/fuel use in the study homes, and emissions from neighbours and other external sources of combustion.

Precision

The precision of estimates varied considerably by type of stove and fuel, by outcome (pollutant) measure, and level of aggregation. Precision of global results is considered here, but are lower for the regionally-stratified results also reported by the systematic review. For area kitchen levels with traditional solid fuel stoves, there were almost 20 studies with more than 600 subjects for $PM_{2.5}$ and larger numbers for CO. Adequate precision was also available for area kitchen levels with improved solid fuel stoves, and for personal exposure measurements of both PM and CO with solid fuel use among both women and children.

There was less precision (due to lower subject numbers) in studies measuring kitchen area concentrations when clean fuels were used. Three studies (56 subjects) measured PM and only one study (9 subjects) measured CO. No personal PM or CO exposure data were available for clean fuels. All of the weighted average pooled estimates are provided with standard deviations.

Publication bias

This was not formally assessed due to the large variability expected between studies from different regions. It is possible that some unpublished studies have not been included.

Summary

This assessment found that the evidence for the majority of area and personal exposure for PM and CO was of **moderate** quality, but precision was limited (principally by small numbers of studies and subjects) for homes using clean fuels.

A5.1.5 Assessment of quality of the evidence on factors influencing the adoption and sustained use of improved solid fuel stoves and clean fuels

This evidence was based on a synthesis of quantitative, qualitative and policy studies and case studies (Review 7). It was not appropriate to use the GEPHI assessment tables to evaluate its quality so GRADE domains were used as a guide for making that assessment.

Study design

The available evidence was drawn from a wide range of study designs, namely randomized trials, before-and-after studies, cross-sectional surveys, economic and survival analyses, 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 different study designs are consistent is considered below.

Risk of bias

Quality assessments were conducted according to established criteria for each study design (described in full in Review 7). Some quantitative studies used sampling that may not have been representative, and some used only simple descriptive (unadjusted) analyses, but were considered 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 of low quality found this did not affect the findings. This assessment supported the conclusion that there was no serious risk of bias.

Indirectness

All the studies included were required to provide direct evidence on adoption and/or sustained use of improved solid fuel stoves or use of one of the four clean fuels included in the review (LPG, alcohol fuels, biogas, solar cookers).

Inconsistency

It was not possible to use measures of statistical heterogeneity to assess this body of evidence. However, 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 showed that inconsistency among studies of similar interventions in comparable settings was uncommon. It was concluded that inconsistency was not a major issue.

Imprecision

Imprecision reflects subject and event numbers. For quantitative studies, the individual sample sizes and their representativeness were summarized, with 19 out of 22 studies having a sample size of 200 or more individuals (including surveys of more than 1000 individuals). Assessment of an overall pooled effect was not appropriate due to the different interventions and outcomes. For qualitative evidence, sample size is less relevant, as meaningful information can be obtained from a smaller number of study participants. 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; 17 such studies had sample sizes of 200 or more individuals.

Publication bias

This cannot be assessed in the formal way used for quantitative systematic reviews-using funnel plots and statistical tests – but publication bias may never theless be present. While it was difficult determine whether there was a bias towards not publishing unsuccessful programmes, 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 to a lesser 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 studies included were peer-reviewed, with the rest being research reports, dissertations, conference proceedings and book chapters. About 12 of the 101 studies included seem likely to have been written and/or published by authors closely associated with the implementing programme or 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.

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. Different forms of consistency were considered as follows:

- *Consistency of evidence across different 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 design or paradigm. This is one of the strengths of this evidence base, 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 across different settings*: findings supported by studies using very distinct interventions, settings, socioeconomic and cultural contexts are likely to be more valid or of greater relevance than findings supported by studies from one or a few settings. Studies were identified across Africa, Asia and Latin America which is an additional point of strength of this evidence base.

Other GRADE criteria

There are other GRADE criteria 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.

Summary

Assessment of this set of evidence suggests that it provides 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 that for solar cooking, is weaker. It is also notable that no studies of adoption of newer improved solid fuel stove technologies (i.e. advanced combustion fan-stoves) were available.

Overall, the evidence on factors influencing adoption was assessed as being of **moderate** quality.

A5.2 Synthesis of the evidence

In the discussion of evidence review methods (see guidelines, Section 2.2.3), the value of taking an overview of the varied types of evidence informing the recommendations, and which contribute to the causal chain was described. The causal chain diagram is reproduced below for reference (Figure A5.1). Here we assess the degree of consistency among some of the key findings from the evidence reviews, and identify any less coherent aspects that indicate where research and policy attention should be focused.

A5.2.1 Consistency of HAP levels from emissions model and field measurements

The emissions model (Review 3), which forms the key evidence base for **Recommendation 1**, allows linkage between emission rates from combustion devices and predicted levels of HAP ($PM_{2.5}$ and CO) in the kitchen (or the room where the device is used).

This component of the evidence contributes to Pathway B in the causal chain, relating emission rates to ambient levels of pollutants in the kitchen. Comparison can be made between the levels of kitchen $PM_{2.5}$ and CO predicted by the model for different types of device or fuel, and those observed in the reviews of (i) population levels of HAP and exposure (Review 5), and (ii) the impacts of interventions on HAP and personal exposure (see Review 6). These two reviews both provide separate but complementary evidence for pathways D(a) and D(b).

In part, this is a means of validating the model, but an understanding of any discrepancies can help identify why, for example, the predicted level of performance of a device/fuel is not being realized in everyday use.

Figure A5.2 (reproduced from Review 3, describing the emissions model) shows predicted distributions of $PM_{2.5}$ and CO for the traditional Chula (an open traditional stove); a standard rocket-type of biomass stove (a widely used type of stove with improved combustion, but without forced draught) and for LPG. The distributions shown are based on both laboratory and field (in-home) emissions performance data.

Traditional chulha

For the traditional chulha over 60% of the distribution for the modelled 24-hour $PM_{2.5}$ concentrations was between 500 and 1800 μg/m³ with a mode of 800 μg/m³. This is very similar to the kitchen concentrations reported by studies in the WHO South-East Asia region (826 ± 1038 μg/m³) and globally for solid fuel users (972 ± 876 μg/m³) (see Review 5).

Rocket stove

Modelled 24-hour $PM_{2.5}$ concentrations derived from field-based emissions rates of the rocket stove (which should be more comparable to observed levels of air pollution than laboratory-based rates), had a mode of around 500 μg/m³, a reduction of around 300 μg/m³, or nearly 40% compared to the traditional chulha. CO emissions were reduced from a mode of around 11 mg/m3 to 5 mg/m³, or by around 55%; this concentration of CO for the rocket stove (5 mg/m³) lies below the WHO 24-hour AQG.

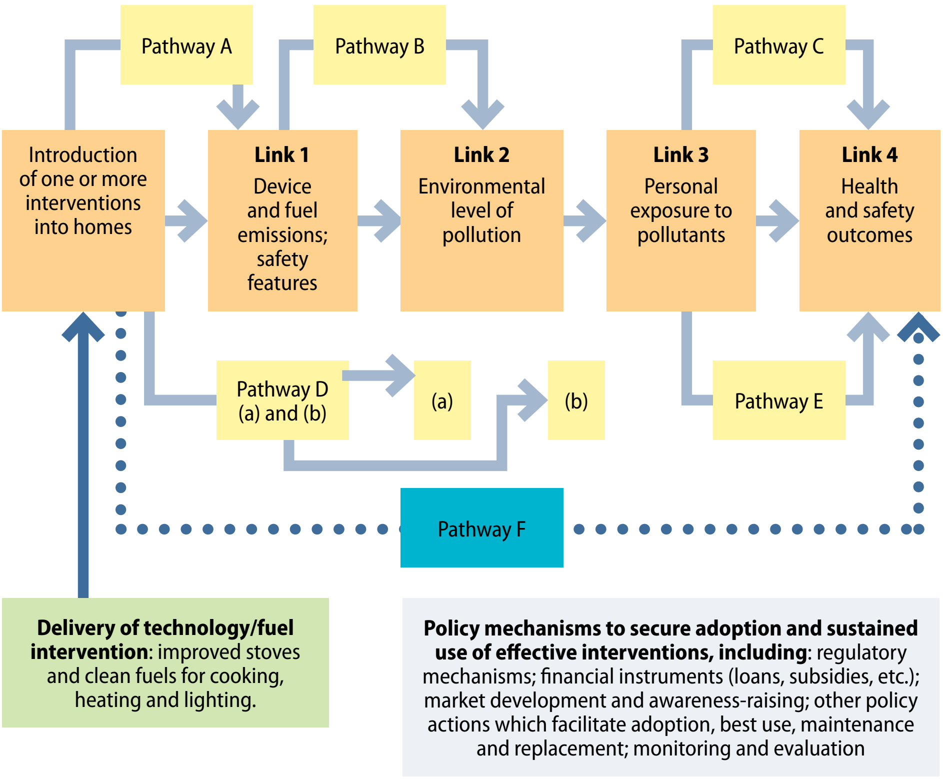
[1] Traditional Indian cooking stove

The review of intervention impacts (see Review 6) found that this type of stove reduced $PM_{2.5}$ by an average of 260 μg/m³ and CO by 3.41 ppm (3.9 mg/m³), with weighted mean percentage reductions of 48% and 39% respectively, and post-intervention means of 410 μg/m³ and 6.6 ppm (7.6 mg/m³) respectively. Given the variability in data, devices, fuel used and other factors, these results can be considered consistent. Although the post-intervention CO mean is slightly above the WHO 24-hour AQG, this distribution is positively skewed, and the majority of studies found values below this guideline value.

LP Gas

The model predicts that almost all LPG-using homes would have concentrations of $PM_{2.5}$ below the WHO interim target (IT-1) value of 35 μg/m³, and CO levels below 1 mg/m³. The review of population-based studies (see Review 5) found levels of $PM_{2.5}$ in gas (and other clean fuel-using homes) to be mainly in the range 35–80 μg/m³, with some above 100 μg/m³. Equivalent CO data were not reported.

Figure A5.1: Causal chain relating household energy technology, fuel and other interventions to health and safety outcomes via intermediate links



The review of intervention impacts (see Review 6) found few studies of clean fuels (one for LPG, four for ethanol): reductions for $PM_{2.5}$ were between 60% and 80% with post-intervention mean $PM_{2.5}$ levels between 120 and 280 μg/m³. For CO, reductions were very similar in percentage terms, with post-intervention means between 2.7 and 5.9 ppm (3.1 and 6.6 mg/m³).

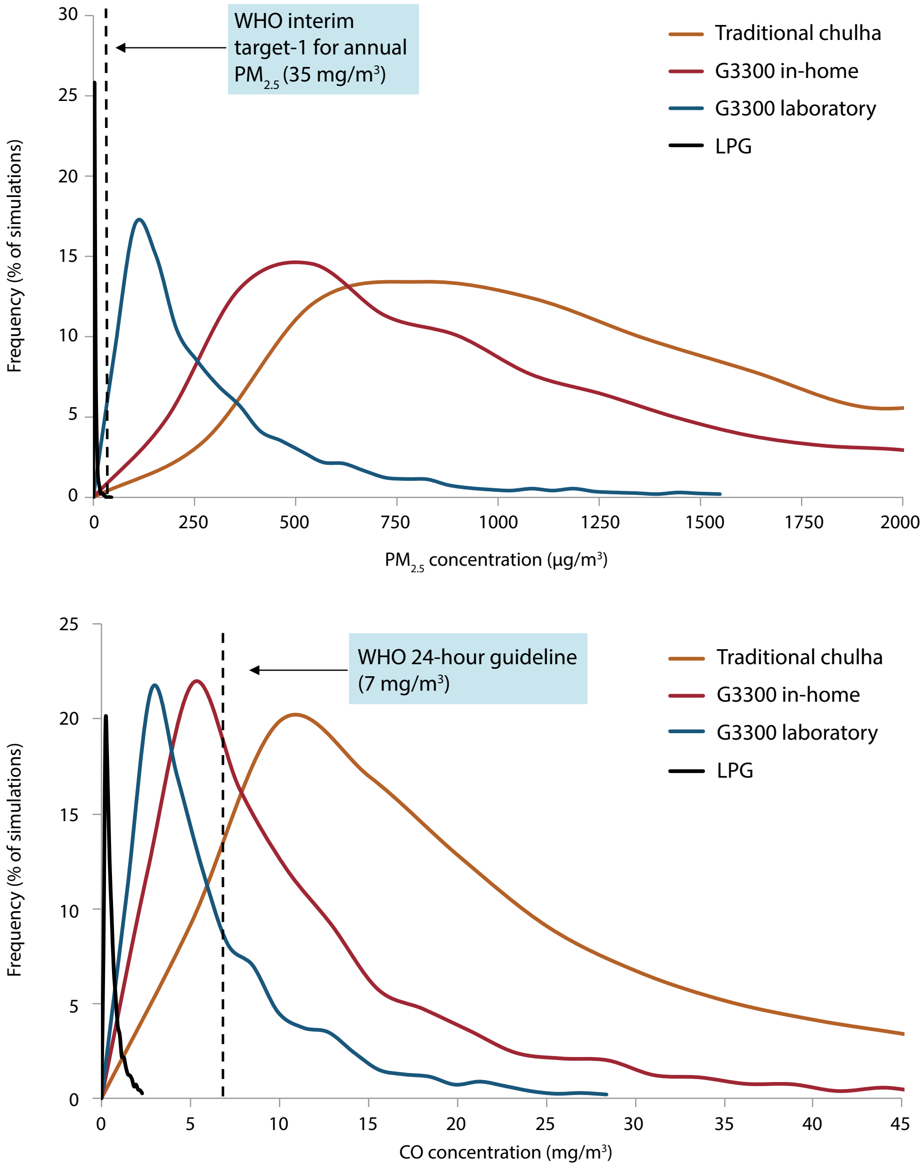
Even allowing for variability and differing circumstances, it is clear that the measured levels of PM and CO in homes using clean fuels are much higher than predicted. This does not undermine the model, but points towards other explanations. These include continued use of the traditional stove (even in stove/fuel evaluation studies), along with the new one (known as stacking), other emission sources in and around the home (kerosene lamps, waste burning), and external sources such as fuel combustion from other homes and other sources of combustion contributing to outdoor air pollution entering all homes. The review of population studies (see Review 5) found that average outdoor $PM_{2.5}$ concentration in the vicinity of solid-fuel using homes was 106 (SD = 79) μg/m³. Most of these studies were conducted in rural areas. Clearly, if ambient pollution levels are this high, it will not be possible for homes exclusively using LPG or other clean fuels to reach the levels below 35 μg/m³ as predicted by the emissions model. Any concurrent use of the traditional stove, polluting lamps and other combustion sources will further increase the pollution in and around the home.

Vented stoves

The emissions model allows for ventilation (with a flue or chimney) by assuming (based on empirical data from several studies and countries) that the fraction of total emissions entering the room lies between 1% and 50% with a mean of 25% and standard deviation of 10%. On average, therefore, it is expected that emissions entering the room from vented stoves are 75% lower than with unvented stoves. The review of intervention impacts (see Review 6) found that solid fuel stoves with chimneys (for which there were 23 and 22 estimates for $PM_{2.5}$ and CO respectively) did indeed achieve a greater reduction of $PM_{2.5}$ and CO than unvented stoves. This reduction was 63% for both pollutants, with post-intervention means of 370 μg/m³ and 4.2 ppm (4.8 mg/m³) for $PM_{2.5}$ and CO respectively.

Although vented stoves achieved larger reductions in emissions as predicted, the improvements were nowhere near as large as might be expected and post-intervention levels remained high. It should be noted, however, that several of the chimney-stove studies reported the largest reductions in emission levels of all stoves and fuels studied in the review (see Review 6). Three such studies reported $PM_{2.5}$ levels of between 50 and 80 μg/m³ post-intervention, which are more consistent with the larger reductions predicted by the model. These findings do not undermine the model but point towards reasons why this much better performance is not being achieved more widely. As discussed above, other sources in the home and AAP are likely to be responsible. In the case of vented stoves, the fraction not entering the room is simply moved to the outside of the home, contributing directly to the often high levels of outdoor pollution, as reported in Review 5.

Figure A5.2: distributions of modelled 24-hour $PM_{2.5}$ and CO concentrations for India (Source: Review 3)



A5.2.2 Consistency of estimates of health risks and intervention impacts

In the absence of multiple randomized controlled trials (RCTs), estimates of the impacts of different devices or fuel types on a range of health outcomes, and crucially relating these to levels of exposure, have been derived from compiling three related sources of evidence (in this discussion, pathways refer to those illustrated in the causal chain model (Figure A5.1):

1. Systematic reviews of epidemiological studies, almost all observational, which report on the risk of disease outcomes among those using higher pollution devices or fuels? (e.g. solid fuel stoves, kerosene cookers or lamps) and those using clean fuels or some other proxy for lower exposure (very few having measured exposure). These studies provide evidence for **Pathway C**, with devices or fuel types typically providing a proxy for the pollution level.
2. A small number of studies reporting on interventions, including two RCTs and three cohort studies, which provide direct information on the impacts of interventions on health outcomes, and contribute evidence for **Pathway F**. One of these RCTs, that reported by Hanna et al. *(2),* achieved no exposure reduction due to unsuitability of the intervention and provides lessons more for adoption rather than on health impact.
3. Exposure-response evidence, derived from two epidemiological studies (one a RCT) *(3),* and a set of recently developed integrated exposure-response (IER) functions which have modelled relationships between $PM_{2.5}$, exposure and risk of five important health outcomes (child ALRI, IHD, stroke, COPD and lung cancer) using findings for outdoor air pollution, second-hand smoke, HAP (where available) and active smoking (not in the case of child ALRI). The IERs provide evidence on the relationship between exposure levels and health outcomes, **Pathway E**.

This evidence can, in turn, be related to the findings discussed above on actual levels of air pollution and exposure in homes using different types of device and fuel. This provides information about the levels in the homes of people in the low exposure category of epidemiological studies: although these are described as using clean fuels, in practice it is found that levels in their homes are in the range 35–80 $\mu g/m^3$ $PM_{2.5}$ and if living in areas where solid fuels are used, outdoor levels may be as high as 100 $\mu g/m^3$ $PM_{2.5}$, as reported in Review 5. This clearly has implications for risk estimates, when the WHO annual AQG value (which indicates the level associated with no or minimal excess risk) is 10 $\mu g/m^3$ $PM_{2.5}$.

Systematic review of health risks of HAP

A substantial range of health outcomes have been studied, including most of those which have been found to be causally related to tobacco smoking. Risk estimates for those important outcomes, for which GEPHI assessment found the evidence to be mostly of moderate quality (in a few cases low), suggest that reduction of exposure to the estimated 35–80 μg/m³ $PM_{2.5}$ range would result in risk being reduced by between 20% and 50%, depending on the outcome, and possibly more for some outcomes including severe child ALRI, lung cancer with coal use, and COPD in women.

Studies reporting on health impacts of interventions

A summary of studies reporting on the health impacts of interventions (experimental and observational) is provided in Table A5.1 (reproduced from Review 4), and discussion of the most important of these follows.

Table A5.1: Summary of studies reporting on health impacts of household fuel combustion interventions

Disease outcome	Study and design	Main features and findings	Reference
Acute respiratory infections	RESPIRE study, Guatemala, RCT	534 homes randomized to use a plancha chimney stove compared to open fire. Kitchen HAP levels were reduced by 90%, and exposure in women and children by around 60% and 50% respectively. In children <19 months, plancha group had 22% not statistically significant and 33% (*p*<0.05) reductions in all and severe pneumonia, respectively.	Smith et al. 2011 *(3)*
	Chinese National Improved Stove Programme r etrospective cohort study	In a large cohort of over 42 000 farmers, compared to traditional open fires, long-term use of improved stoves in a coal-using region of Xuanwei was associated with reductions of around 50% in risk of adult ALRI mortality.	Shen et al. 2009 *(4)*
	Massachusetts Institute of Technology study, India, RCT	Comparison of an improved mud-stove design with chimney among 2651 homes in 44 villages in Orissa. Reduced emissions in laboratory tests were not translated into exposure reductions in practice, and no health benefits were reported. Households had low valuation of the stoves and did not use them regularly.	Hanna et al. 2012 *(2)*

Disease outcome	Study and design	Main features and findings	Reference
Adult respiratory health/COPD	Patsari stove trial, Mexico, RCT	668 homes were randomized to use a Patsari chimney stove compared to an open fire. Due to poor adherence to allocated stove use, authors presented most results for users vs. non-users. Improved stove users reported reduced respiratory symptoms, and a lower rate of decline in lung function, over 1 year.	Romieu et al. 2009 *(5)*
	RESPIRE study, Guatemala, RCT	Among 504 women, those randomized to use the plancha stove reported reduced respiratory symptoms, but there was no impact on lung function up to 18 months.	Smith-Sivertsen 2009 *(6)*
	Chinese NISP retrospective cohort study	In a cohort of over 20 000 subjects in the coal-using region of Xianwei, those with long-term use of improved chimney stoves showed substantial reductions in COPD, with 42% and 25% reductions in men and women respectively. Results became unequivocal after 10 years of stove use.	Chapman et al. 2005 *(7)*
Birth weight	RESPIRE study, Guatemala, RCT	Among 174 mothers and newborns for whom birth weight was measured within 24 hours, use of the plancha chimney stove (not per randomization) was associated with an adjusted 89 gm (NS) increase in birth weight, and a 26% reduction (NS) in risk of low birth weight.	Thompson et al *(8)*
Lung cancer	Chinese NISP cohort study	In a cohort of over 20 000 subjects in the coal-using region of Xianwei, subjects with long-term use of improved chimney stoves showed substantial reductions in lung cancer, 41% and 46% for men and women respectively. As with COPD, results became unequivocal after 10 years of stove use.	Lan et al. 2002 *(9)*

The single RCT (RESPIRE) with a well-accepted improved stove was carried out in rural Guatemala, and studied the impact of a chimney stove on child ALRI up to 18 months of age. Detailed, repeated measurement of kitchen pollution and child exposure was included; this allowed both intention-to-treat (ITT – improved stove versus open fire) and exposure-response analyses to be conducted. The ITT analysis found that the intervention group had a 90% reduction in kitchen air pollution, and a 50% reduction in child exposure (to an equivalent of around 125 μg/m³ $PM_{2.5}$) which was associated with a relative risk (RR) of 0.78 (95% CI: 0.59, 1.06) for all physician diagnosed pneumonia and an RR of 0.67 (95% CI: 0.45, 0.98) for severe pneumonia. While these risk reductions (22% and 33%

respectively) are less than seen in the observational study pooled estimates (37% for all pneumonia and 60% for severe pneumonia), these findings are consistent if the intervention group mean child exposure level is taken into account as this is considerably higher than the HAP concentrations estimated for the observational studies. The exposure-response evidence adds further detail to this question, as it provides an estimate of how much this difference in risk would be expected to be.

The other important studies with health outcome definitions that can be compared with the epidemiological study systematic reviews and the IER functions are a set of three cohort studies investigating the impact of long-term (10 years or more) use of an improved chimney stove as part of the Chinese national improved stove programme. The studies were all conducted in the coal-using area of Xuanwei, and examined impacts on COPD, lung cancer and adult mortality from ALRI. The findings showed reductions in risk of between 40% and 50% for all three outcomes (other than for COPD for women where the risk reduction was 25%). These studies did not include HAP or exposure measurements (apart from a very small, separate investigation in the same area), so the reductions and intervention-group levels can best be inferred from the results of the intervention impacts review (see Review 6). This found large reductions (63%) but post-intervention levels of more than 300 μg/m^3 $PM_{2.5}$. The one study of a chimney stove evaluation in China included in that review found baseline level of 270 μg/m^3 PM_4 and a 43.3% reduction in kitchen concentration to 150 μg/m^3 with the intervention, but this was not conducted in Xuanwei, and was for biomass rather than coal. Nevertheless, these findings imply that substantial risk reductions were seen in association with 40–60% reductions in kitchen $PM_{2.5}$ and that levels in the intervention groups were probably at least 150 μg/m^3. Interpretation of should be cautious, however, as no personal exposure data are available from these settings.

Integrated exposure-response functions

The IER functions, described in Review 4, provide estimates of how risk varies with exposure for five important health outcomes, child ALRI, IHD, stroke, COPD and lung cancer. The IER curves for IHD and stroke do not include any empirical risk estimates for HAP, as no studies were available at the time the curves were developed (and only one study with adjusted risk estimates is available now). The curve for child ALRI is reproduced here to assist with discussion (Figure A5.3); for other outcomes, please refer to Review 4.

Child ALRI: The most notable feature of the curve for ALRI is that it is relatively steep at low exposure levels (even below the IT-1 annual average value of 35 μg/m^3 $PM_{2.5}$), and flattens off at around 200 μg/m3, continuing to rise steadily across the rest of the exposure range and, unlike for other outcomes, is not bounded at the upper end by active smoking risk data. With this curve, it can be seen why the risk reduction in ITT analysis of the RESPIRE study, with intervention group exposure in excess of 100 μg/m³ $PM_{2.5}$, would be less than that seen in the meta-analysis of epidemiological studies which compared traditional solid fuel use to (estimated) levels in the range 35–80 μg/m³ $PM_{2.5}$.

Lung cancer: The IER curve for lung cancer is much closer to being linear, rising to very high levels of risk with active smoking. This linearity across the HAP exposure range would explain why the 40–60% reductions in exposure (estimated) for the Chinese NISP stoves in Xuanwei would result in 40–50% reductions in lung cancer risk.

COPD: The IER curve for COPD is less clearly defined as the HAP risk estimates do not fit well with the function derived for the other sources of exposure. The reason for this is unclear, but could be related to lifelong exposure (during pregnancy and from birth) to HAP having a greater effect (dose for dose) on the airways and lungs than, for example, smoking which usually does not start until the late teenage years at least. The curve suggests a function which is more linear than for ALRI, but perhaps not as linear as for lung cancer. If confirmed, this would also be consistent with the 25–50% reductions in risk seen in the Xuanwei cohort study.

Discussion

This review of the consistency of key evidence contributing to the causal chain model has shown a good degree of consistency for the health risk and intervention impact findings, but more mixed results for the findings on consistency between HAP levels based on predictions from the model and measured levels. Specifically in respect of the latter, it is the findings for the lower emission devices and fuels that differ from what is observed, but the reasons are likely to lie with contributions from other sources, both inside and outside the home. These issues have very important implications for implementation, and these are captured in the general considerations accompanying the recommendations.

While the evidence on health risks and intervention impacts appears to be quite coherent, there are gaps and weaknesses in the evidence, including the lack of intervention trials, the virtual lack of empirical data on HAP exposure and IHD/stroke and the uncertainty concerning the COPD IER, which require attention from the research community.

Three randomized clinical trials are currently under way, all of which are studying the impacts of improved stoves (both standard natural draught rocket-type as well as fan-assisted) on birth outcomes (pre-term birth, birth weight) and ALRI. The trial locations together with the lead investigating institution, principal investigator and trial registration numbers are provided in Table A5.3. Two of these (Ghana, Nepal) also plan to include a clean fuel option in the trial.

Figure A5.3: The relationship between level of $PM_{2.5}$ exposure (μg/m³) and relative risk (95% CI) of child ALRI based on the integrated exposure-response (IER) function for exposure over the range 0–600 μg/m³

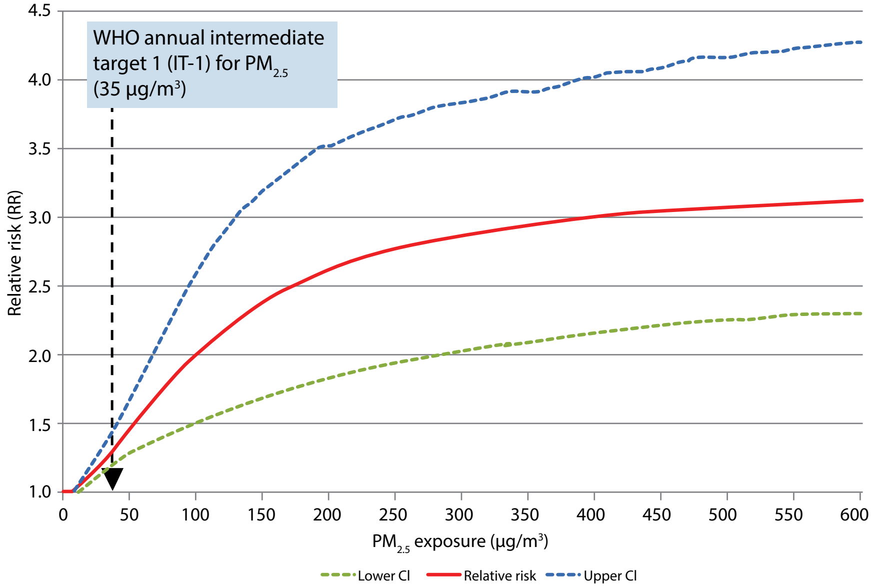


Table A5.3: Randomized clinical trials testing the impacts of reducing HAP exposure currently in progress

Trial location	Main investigating institution (PI)	Trial registration number
Ghana	Columbia University (Kinney P.)	NCT01335490
Nepal	Johns Hopkins (Tielsch J.)	NCT00786877
Malawi	Liverpool School of Tropical Medicine (Mortimer K.)	ISRCTN59448623

A5.3 Determination of the strength of Recommendation 2: policy during transition

From the evidence reviewed on impacts of interventions in everyday use, it was concluded that few, if any, are achieving levels of $PM_{2.5}$ (the key pollutant for which health risk is best evaluated) in the home at or even close to the IT-1 (35 μg/m³), and none are meeting the AQG. This was also found for clean fuels such as gas, but the reasons for this probably lie with the common practice of mixed use of traditional and clean fuels, and with pollution from neighbours and other sources.

The health risk evidence, and in particular the IER functions, show that $PM_{2.5}$ needs to be reduced to low levels, at least at or below the IT-1, if the majority of cases of disease attributable to HAP exposure are to be prevented.

These findings imply that policy on interventions should support the adoption of clean fuels for all purposes (cooking, heating, lighting and other applications) across communities and as rapidly as is feasible, and address other sources of air pollution, if AQGs are to be met. Recognizing, however, the reality that this shift from reliance on traditional solid fuels and stoves to exclusive use of clean devices and fuels will take time, the health risk evidence makes it clear that – during this transitional period – the lowest emission devices suitable for the households and communities concerned should be prioritized.

In the absence of a substantial, robust set of RCTs demonstrating the impact (or otherwise) of alternative interventions on HAP, exposure and important health outcomes, the development of these guidelines has included methods that combine evidence contributing to a causal chain. These methods, termed grading of evidence for public health interventions (GEPHI), include a step of assessing the consistency of the various components of the evidence. The degree of consistency is particularly important to the conclusions informing this recommendation, as it draws on separate sets of evidence for intervention impacts on $PM_{2.5}$, and on the relationship between $PM_{2.5}$ and health risk, but with very few studies showing the direct impact of interventions on health outcomes. An assessment of the consistency of this evidence is provided in Section A5.2, and briefly summarized here.

Overall, there is a good level of consistency for the health risk and intervention impact findings, but more mixed results regarding consistency between HAP levels based on predictions from the emissions model and measured levels from homes. Specifically in respect of the latter, it is the findings for the lower emission solid fuel devices and LPG that differ from what is observed, but the reasons for this probably lie with contributions from other combustion sources, both inside and outside the home. As noted above, these issues have important implications for implementation, which are included in the **general considerations** accompanying the recommendations.

When assessing benefits and harms, the GDG recognized that a rapid transition to low emission technologies and fuels will bring health and other benefits more quickly, with positive impacts for development. Potential harms can arise from poorly designed or inappropriate interventions, introduction of LPG without adequate provision for safety and regulation, and through energy poverty if supply and affordability are not addressed. On balance, the benefits are very substantial, and policies that recognize and address these potential harms can minimize their impact.

When considering values and preferences relating to a rapid transition, the GDG noted these vary, and an approach which takes into account the needs, socioeconomic circumstances, geography and other aspects of households and communities is required. This will help overcome concerns among those responsible for implementation about cultural, affordability, supply and related issues.

When considering feasibility, the GDG noted that there will be additional costs for bringing about this transition, but these have been shown (in analysis by the International Energy Agency) to be small relative to the total investment in the energy sector to 2030. It is expected that new investment will be mobilized through the UN's Sustainable Energy for All initiative, and related efforts to increase access to electricity and clean, efficient and safe household energy for cooking and heating.

On the basis of this assessment, the recommendation is **Strong** (Table A5.4).

Table A5.4 Decision table for the strength of Recommendation 2: Policy during transition

Factors influencing strength of recommendations	Decision
Quality of evidence	Health: Moderate
	HAP and exposure levels: Moderate
	Intervention impacts: Moderate
	Factors influencing adoption: Moderate
Balance of benefits versus harms and burdens	Benefits clearly outweigh harms
Values and preferences	There is variability. Greater awareness of, and debate around, the issues may increase positive values and preferences
Resource use	Increased investment will be required, but the economic case linked to current global initiatives on energy access makes this feasible
Decision on strength of recommendation	**Strong**

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Annex 6: Recommendation 3 – Household use of coal: assessment of the quality of the evidence and setting the strength of the recommendation

A6.1 Assessment of the quality of the evidence

Three areas of evidence were assessed for quality:
- carcinogenicity of emissions from household use of coal
- health risks from incomplete combustion of coal
- toxic contaminants

A6.1.1 Carcinogenicity

Carcinogenicity of household use of coal was reviewed by the International Agency for Research on Cancer (IARC, *(1),* using standard assessment methodology involving review of exposure data, studies of cancer in humans, studies of cancer in experimental animals, and mechanistic and other relevant data. It was concluded that for household use of coal:
- There is *sufficient evidence* in humans for the carcinogenicity of household combustion of coal. Household combustion of coal causes cancer of the lung.
- There is *sufficient evidence* in experimental animals for the carcinogenicity of emissions from combustion of coal.
- There is *sufficient evidence* in experimental animals for the carcinogenicity of extracts from coal-derived soot.

It is noted that the type of coal used by households in most, if not all, of the epidemiological studies in this assessment, was raw (unprocessed)[1] coal. The overall evaluation concluded that indoor emissions from household combustion of coal are *carcinogenic to humans (Group 1)*. This evidence was assessed as being of **high** quality. While this evidence confirms that emissions from household coal

[1] Unprocessed coal refers to forms of this fuel that have not been treated by chemical, physical, or thermal means to reduce contaminants. Unless otherwise specified, this applies throughout the discussion of this recommendation, as the great majority of the available evidence reviewed draws on studies in which households used unprocessed coal. Where reference is made to one of the few studies on the use of coal which has been processed to reduce toxic emissions, this is stated.

combustion are carcinogenic, this does not provide risk estimates for the use of coal compared to the use of an alternative clean fuel.

A6.1.2 Health risks from incomplete combustion of coal

The systematic reviews reported in Review 4 examined evidence for household air pollution (HAP) emitted by solid fuel use causing a range of disease outcomes, along with estimates of disease risk and intervention impacts. Most studies investigated biomass fuel use, however, or did not differentiate between solid fuels clearly. Risk estimates linked to coal use were only available for risk of lung cancer and COPD, although there were too few studies on chronic obstructive pulmonary disease (COPD) to permit grading of the evidence for this outcome. As per the IARC assessment, most (if not all) of the epidemiological evidence relates to household use of unprocessed coal. Table A6.1 reports grading of evidence for public health interventions (GEPHI) assessment for coal use and lung cancer, which provided an intervention effect estimate of 0.46 (95% confidence interval (CI): 0.35, 0.62) and was assessed as being of **moderate** quality. The integrated exposure-response (IER) function for risk of lung cancer, although not specific to coal exposure, indicates that risk from exposure to fine particulate matter ($PM_{2.5}$) remains elevated right down to the counterfactual level of 7.5 $\mu g/m^3$ of $PM_{2.5}$. This evidence was assessed as being of **moderate** quality.

A6.1.3 Toxic contaminants

- Review 8 identified studies reporting on health effects of five toxic contaminants in coal, arsenic, fluorine, selenium, mercury and lead. These studies provide evidence on toxin content of coals, combustion and emissions chemistry, exposure routes (i.e. food, air, water), air pollution and exposure levels, and health impacts. Of the contaminants, the risks and effects of arsenic and fluorine are the two most comprehensively investigated and reported. Most of the evidence on the effects of contaminants derives from studies in China.

The assessment of evidence for health risks from toxic contaminants of coal was based on an overall evaluation of the available studies covering all of the aspects noted above. The data obtained on the content of toxic contaminants in coal, the fact that these are not destroyed on combustion, measurements of toxins in air and food (which are the main routes of exposure), and some dose measurements (e.g. in blood) strongly indicate that use of contaminated coals in the home puts members of the household at risk.

All the epidemiological studies examining toxin-specific health outcomes were observational. Most of these compared the prevalence of health outcomes caused by the contaminants (i.e. arsenicosis, dental and skeletal fluorosis, etc.) in areas or homes using contaminated coal with those in areas using fuel with lower levels of contamination. There were no studies directly investigating health effects of mercury or lead associated with household coal use. However, there was some indirect evidence available for lead. For example, a study performed after leaded gasoline was phased out in China, found that child blood lead levels strongly correlated with coal consumption but not gasoline consumption.

In summary, the available evidence shows that toxins are widely distributed in coal and present important health risks where coal is used in the home. While the evidence shows that use of coal with toxic contaminants leads to serious adverse health effects, most of this evidence has been derived from studies conducted in affected areas of China.

Experimental studies provide evidence that exposure can be reduced, but not eliminated, by processing the coal, using chimney stoves and behavioural interventions (for example to encourage drying of food outside the home, rather than indoors where it would be more heavily contaminated). These studies have demonstrated reductions in emissions and/or urinary levels of some of these toxins, but have not included evaluation of health impacts.

Summary

Taking all of this evidence together, including the specificity of effect linking coal containing toxins, emissions of the toxins, high measured levels in air, food etc. (routes of exposure) and disease outcomes specific to the toxins, this evidence was assessed as being of **moderate** quality. It is noted, however, that this assessment applies to evidence relating primarily to raw coal, except where the studies concerned state that the coal has been processed to reduce toxic effects.

Table A6.1: Grading (GEPHI) assessment of evidence on risk of lung cancer with exposure to household coal use

For full details of the systematic reviews and GEPHI assessments (including scoring for importance of outcomes and grading in table), please refer to Review 4: Health impacts of HAP available at: http://www.who.int/indoorair/guidelines/hhfc

Importance of outcome: Important (9)

Design	No. of studies	Risk of bias	Inconsistency (heterogeneity)	Indirectness (external validity)	Imprecision (power)	Publication bias	Other considerations (specify)	Number of events		Relative effect and 95% CI	Quality
								intervention	control		
Observational	25	No	Yes (-1)	No	No	No	Large effect (+1)	10 142 cases		0.46 (0.35, 0.62)	Low
Intermediate score										Low	
Final score		Evidence that risk does vary by setting, possibly due in part to type of coal								**Moderate**	
		Evidence on effects of exposures to other sources of coal combustion pollution (+1)									

A6.2 Determination of the strength of Recommendation 3: household use of coal

The available evidence shows that emissions from coal are carcinogenic, putting those exposed to them at risk of lung cancer, and can cause poisoning due to a range of toxins found in different types of coal. It is technically difficult to burn coal cleanly in the home and toxins are not destroyed on combustion. These two facts, combined with evidence that even very low levels of $PM_{2.5}$ exposure are associated with an increased risk of cancer, indicate that the health risks of coal combustion in the home cannot be easily avoided. This assessment is based primarily on studies of the use of raw (unprocessed) coal in the home, with the exception of a small number of studies concerned specifically with the impacts of processed coals.

When the guidelines development group (GDG) assessed harms and benefits, they agreed that replacement of raw coal with cleaner alternatives will bring substantial health benefits including a reduction in lung cancer and possibly other cancers, prevention of toxin-related effects, and protection against carbon monoxide (CO) toxicity. However, for communities which are highly dependent on coal, there is a danger of fuel poverty if adequate planning is not made for this transition. Further work is required to fully assess the benefits and harms of processed coals.

When considering values and preferences associated with this transition, the GDG noted that these are expected to vary. Agencies responsible for public health, and many households, are expected to welcome the change to cleaner (and potentially more convenient) fuels, provided the alternatives are affordable and available. Other groups, including those involved with production and distribution of coal may not welcome this change.

When assessing feasibility, the GDG noted this will depend on the investment required to ensure affordability and supply of cleaner fuels for households. These costs may be substantial in areas where alternative fuels for cooking and heating are limited. Policy-makers need to recognize these issues and plan to make cleaner fuels a viable alternative in areas currently highly dependent on unprocessed coal.

Based on this assessment, the recommendation is **Strong** (Table A6.2).

Table A6.2 Decision table for strength of Recommendation 3: Household use of coal

Factors influencing strength of recommendations	Decision
Quality of evidence	Carcinogenicity (IARC): High
	Risk of lung cancer: Moderate
	Toxic contaminants: Moderate
Balance of benefits versus harms and burdens	Benefits clearly outweigh harms
Values and preferences	Variation in perspectives is expected and policy will need to address these
Resource use	Some increased investment required; clear policy should make implementation more feasible
Decision on strength of recommendation	**Strong**

Reference

1. IARC Monographs on the Evaluation of carcinogenic risk of chemicals to humans. Volume 95. Household use of solid fuels and high-temperature frying. Evaluation of Carcinogenic Risks to Humans. Lyon: International Agency for Research on Cancer; 2010.

Annex 7. Recommendation 4 – household use of kerosene: assessment of the quality of the evidence and setting of the strength of the recommendation

A7.1 Assessment of the quality of the evidence

The areas of evidence assessed were:

1. health risks from kerosene use (emissions)
2. risks of burns, scalds and poisoning

A7.1.1 Health risks from kerosene use (emissions)

The systematic review on the health risks of kerosene use (see Review 9) compiled evidence on fuel grade and devices used for cooking, heating and lighting, emissions of health damaging pollutants, area concentrations of pollutants in homes, and that from epidemiological studies on a range of health outcomes. Assessment of the quality of the available evidence took account of all this information to assess consistency of the epidemiological findings with what is known about the type and levels of emissions from various kerosene-using devices in common usage.

A reasonable number of studies are available for heating and cooking with kerosene, but only two for lighting. These provide evidence that micro-environmental levels of $PM_{2.5}$ and other health damaging pollutants can exceed WHO air quality guideline (AQG) levels with the combustion of kerosene. For simple wick devices, $PM_{2.5}$ levels were in the range 20–400 µg/m^3 when kerosene was used for lighting and 340 µg/m3 to more than 1000 µg/m^3 when used for cooking. Such levels could lead to a substantially increased risk of multiple adverse health outcomes.

A total of 24 epidemiological studies reporting on the risk of kerosene use, mainly for cooking, with a few related to heating and lighting, were identified. Disease outcomes included lung and salivary gland cancer, respiratory symptoms/spirometry, asthma and allergic conditions, acute lower respiratory infection (ALRI), tuberculosis (TB) and cataract. Due to considerable heterogeneity in study methods, quality and findings, as well as small numbers of studies for some of the outcomes, meta-analysis was not attempted, and grading of evidence for public health interventions (GEPHI) assessment not applied. Grading of evidence for public health interventions (GRADE) domains have been used as a guide for assessing quality.

Study designs

The studies were observational, most cross-sectional, with the remainder using case–control designs. The majority were carried out in developing countries, with a few in more developed countries. Exposure comparisons were described according to fuel type, comparing kerosene with a range of other fuels, which included wood, other biomass and coal in some studies. A comparison was not specified in five of the studies. Outcome measurement was variable, ranging from clinical diagnoses and spirometry, to reported symptoms.

Risk of bias

Ten of the studies did not adjust for confounding factors during their analysis. This, combined with the potential for exposure misclassification due to comparison of kerosene use with other polluting fuels (or unspecified comparison), suggests a potentially high risk of bias in a substantial number of the studies. These sources of possible bias apply across sets of studies reporting on most of the study outcomes. For example, none of the three studies of lung cancer report adjusted odds ratios.

Indirectness

The review combined indirect evidence (on pollutant emissions, micro-environmental (area) concentrations and human exposures) with direct evidence on risks for a range of adverse health outcomes. Thus, direct evidence (albeit of low quality) is available, and there is consistency between emissions of, and exposure to, health damaging pollutants and the risk of disease.

Precision

Most studies had sufficient numbers of cases (case–control) and subjects (cross-sectional) for reasonable precision to be available for all of the outcomes. Pooled estimates were not available as meta-analysis was not conducted.

Heterogeneity

The heterogeneity of key aspects of study design has been noted above. No formal assessment of statistical heterogeneity was carried out, but considerable variation in results for exposure to kerosene use was noted, both within and between studies, often with non-overlapping 95% confidence intervals (CIs).

Publication bias

No formal assessment of publication bias was conducted as outcomes were heterogeneous for some outcomes, and numbers of studies were too few for other outcomes. Unpublished studies were not included, but the search did include Chinese language publications (although none was eligible).

Summary

There was extensive evidence that emissions from kerosene use for cooking, heating and lighting lead to levels of health-damaging pollutants which exceed WHO AQGs, considerably so for use of wick-type devices. Available data for area concentrations of emissions from kerosene burned for lighting were more limited than those for other uses. The epidemiological evidence appeared vulnerable to bias and demonstrated considerable heterogeneity in findings for several outcomes, so was assessed as being of low quality. Overall, however, this evaluation found that the high levels of emissions of health damaging pollutants would be consistent with studies reporting elevated disease risks. Thus, further research using study designs to overcome the limitations of many of the existing studies, should be conducted. It was also noted that four studies published after completion of the systematic review found significantly increased risks of several adverse health outcomes.

A7.1.2 Risks of burns, scalds and poisoning

The systematic review of burns and poisoning (see Review 10) was carried out to assess the levels of risk associated with the use of various household energy devices and fuels. The review included two types of evidence:

- descriptive studies of risk factors for burns and poisoning, including the devices and fuels used in the home, that might provide evidence relevant to the recommendations made to improve air quality, and;
- experimental studies measuring impacts of behavioural and technology interventions on burns and poisoning risks.

Risk factors

Many studies described risk factors for burns and poisoning, but few were population-based. Most studied cases in health facilities, thus providing relatively little information on levels and characteristics of risk in the community. Those cases reaching facilities are likely to be socioeconomically and geographically unrepresentative and possibly also not representative of the spectrum of injury. The finding that household fuel use (especially for cooking), particularly kerosene use, was among the most important causes of burn injuries, does provide an indication of the importance of the household setting, and of the role of kerosene in particular. The lack of data on burns from solid fuel stoves may be due to there being few community-based studies on these. Kerosene was responsible for most household fuel poisonings. This was judged to be a reliable finding as kerosene is the most widely used liquid fuel.

Interventions

The variety of interventions and outcomes made the experimental studies unsuitable for meta-analysis. There were only two studies investigating cooking-related burns. One was a randomized controlled trial (RCT) and the other a quasi-experimental study assessing the impacts of improved stoves and fuels on burns, and both were of high quality. Two other studies, also both well-designed and conducted, investigated the effects of awareness-raising on safety risk scores and behaviours. There were no experimental studies investigating prevention of residential heating burns in low- and middle-income countries (LMICs). Only one intervention study investigated lighting. The review authors concluded that the empirical evidence on specific preventive measures and the associated reduction in risk in LMICs is weak. For kerosene poisoning, one RCT and two quasi-experimental studies investigating a disparate range of interventions (educational materials, container proofing and home visits) and outcomes (knowledge and practice scores and incidence rates) were reported. No firm conclusions can be drawn due to this heterogeneity.

Summary

This assessment found that, while there is substantial evidence that household fuel use (and especially kerosene) is an important cause of burns and poisoning in LMICs, the relationship of solid fuels and other fuels (including liquefied petroleum gas (LPG)) to injuries is poorly described, primarily due to a lack of population-based studies. Given the specificity of the linkage between fuel use and injury from burns and poisoning, however, the evidence that household fuels present an important safety risk (a key aim of this systematic review) was assessed as being of **moderate** quality, with concern about kerosene noted. Although some high quality experimental studies have been reported, these are still few in number and too variable in respect of interventions and outcomes to be pooled. Evidence on the level of risk reduction that can be achieved using various preventive strategies was assessed as being of **low** quality.

A7.2 Determination of the strength of Recommendation 4: household use of kerosene

The available evidence indicated that levels of health damaging pollutants emitted during household kerosene use were sufficient to expect important health risks, and the safety concerns were also noted. The epidemiological evidence, however, was assessed as scarce and too inconsistent to allow firm conclusions about respiratory and other disease outcome risks. Therefore the priority should be to strengthen the evidence base, while discouraging kerosene use where cleaner and safer alternatives could be promoted.

When assessing the benefits and harms, the GDG expected that avoidance of kerosene use will lead to a reduction in the disease outcomes thought to be linked to its use, and (with greater certainty) a reduction in the risks of burns, fires and child poisoning. Kerosene is currently widely available, can be obtained in small quantities and is easily stored (albeit often not safely), hence the harm of removing an affordable, available fuel may be incurred if alternatives are not also affordable and easily available. Relatively inexpensive lighting alternatives such as solar lamps, for example, appear to offer comprehensive health and safety benefits (avoiding emissions, burns and poisoning risks), greater convenience, and potential medium-term cost savings.

When considering values and preferences, the GDG noted these may vary. It is expected that users will value switching to a cleaner and safer fuel if it is affordable and reliably available. The recent large-scale conversion from kerosene to LPG use for cooking in more than 40 million homes in Indonesia shows that this can be achieved at scale. However, inadequate safety regulation led to accidents with LPG and negative perceptions initially. The extent to which this experience can be generalized is unclear.

When assessing feasibility, the GDG noted that some investment will be required to replace kerosene with cleaner and safer alternatives but, since many countries subsidize kerosene, the balance sheet may be in favour of change. This was the prime motivation for the Indonesian programme, which reportedly reduced costs for both government and households due to LPG being more efficient in terms of energy per unit cost.

On the basis of this assessment, given the low quality of the epidemiological evidence, it was judged that the recommendation be **Conditional** while additional health research is conducted (Table A7.1).

Nevertheless, the concerns about emissions and safety led to the conclusion that household use of kerosene should be discouraged.

Table A7.1 Decision table for strength of Recommendation 4: household use of kerosene

Factors influencing strength of recommendation	Decision
Quality of evidence	Health risks from kerosene: Low
	Safety risks from kerosene use: Moderate
Balance of benefits versus harms and burdens	Benefits clearly outweigh harms
Values and preferences	Limited evidence suggests no major variations
Resource use	Replacement is feasible with political commitment, and may be cost-saving
Decision on strength of recommendation	**Conditional**

Annex 8: Policy considerations for the best-practice recommendation on climate co-benefits

When assessing the harms and benefits, the guideline(s) development group (GDG) agreed that taking a synergistic approach to policy based on this evidence should yield multiple benefits. These include increased commitment and financial resources, increased attention to securing health benefits in energy policy, and using energy policy to control short-lived climate pollutants. This is also an opportunity to link carbon-finance to health as well as environmental benefits. Potential harms may arise in the climate arena if interventions are inappropriate and poorly planned. Including a health impact assessment when climate policy is considered should help to avoid these adverse consequences. It is also important to consider the whole fuel/energy cycle, including emissions from electrical power generation, to ensure a comprehensive assessment of potential benefits and harms.

When considering values and preferences, the GDG noted that there is wide consensus on the value of pursuing synergistic policies that can deliver climate, health and other (e.g. local environmental and economic development) benefits. This approach is central to the strategies of the UN Sustainable Energy for All initiative (SE4All), the UN Foundation Global Alliance for Clean Cookstoves (GACC), and the Climate and Clean Air Coalition (CCAC). In addition to the UNEP (2011) assessment *(1),* and the linked paper by Shindell et al. (2012) *(2)* other studies have reported potentially large health co-benefits from policies targeting emissions of climate pollutants from household fuel combustion, see for example Anenberg et al. (2012) *(3)* and Wilkinson et al. (2009) *(4).*

When considering feasibility, the GDG agreed that synergistic policy is potentially cost-saving, and the global initiatives referred to above show that there is broad-based commitment to it. The household energy-climate impact link is already providing carbon finance for household energy programme implementation, and could be further enhanced by inclusion of indicators of health risk reduction.

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Annex 9: International standards and testing facilities

A9.1 Introduction

Standards that clearly define levels for technology performance, quality, and impact assessment provide common terminology for communicating, understanding, and improving performance of clean cooking solutions. Setting standards is an effective way of implementing health-based guidelines through providing specific technology-based targets for certification, regulation, and labelling. Consumers rely on standards to make informed choices, while designers and manufacturers use standards to affirm their product quality and/or are encouraged to innovate to meet standards. Policy-makers, donors, programmes and investors can use standards as a credible basis for comparing stove performance and quality.

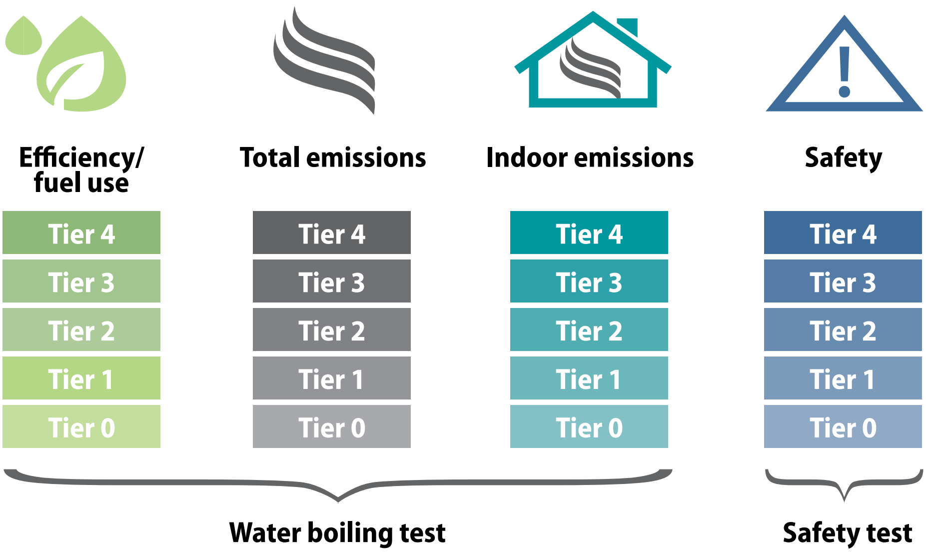
Standards can also help to translate ambitious evidence-based guidelines into specific targets that reflect additional stakeholder priorities and that allow for the guidelines to be achieved over time. Standards processes are inclusive and consensus-based, permitting buy-in from multiple stakeholder groups. They should be achievable by the private sector, address consumer needs, while also driving the sector towards goals like the WHO guidelines. Cooking practices and cuisines vary globally, but it is valuable to have international harmonization to facilitate the sharing of information about stove and other device performance. Thus, an international standards process allows countries to collaborate on standards that are relevant for their national contexts, requiring minimal adaptation before national adoption.

The Global Alliance for Clean Cookstoves (GACC) has been facilitating development of international standards, ensuring participation of all types of stakeholders in multiple countries. The Alliance has partnered with the International Organization for Standardization (ISO), a nongovernment agency which supports national standards organizations.

ISO provides multiple consensus-based and transparent processes, enabling clean cooking sector experts to draft and approve standards. International Workshop Agreements (IWAs) are a streamlined ISO consensus process that can be a first step towards formal ISO standards. To achieve real inclusiveness, consensus, and incorporation of multi-stakeholder input, the formal ISO standards development process can take at least three years. National standards organizations that are members of ISO have channels for participating in international standards development, allowing the clean cooking sector to leverage these existing paths. Once international standards are developed, many countries have policies to prioritize adoption of standards developed by the ISO.

A9.2 Development of the International Workshop

Figure A9.1: The four multi-tiered dimensions of the current IWA on cookstove standards



Agreement (IWA)

In February 2011, at the Partnership for Clean Indoor Air (PCIA) Biennial Forum in Lima, Peru, the Lima Consensus was developed as a framework for tiered standards for key indicators. The community worked throughout the next year to develop a tiered set of exposure, efficiency, and safety standards for clean cookstoves. This culminated in the International Workshop Agreement (IWA 11:2012 Guidelines for evaluating cookstove performance) a year later, in February 2012.[1] At this International Workshop, which was jointly convened in The Hague by the GACC and PCIA, more than 90 stakeholders from 23 countries reached a consensus on the tiers and indicators. The IWA represents a significant step forward in global efforts to develop standards to scale up clean cookstoves and fuels. There were also six resolutions that identified areas for further discussion and effort.

[1] See http://www.iso.org/iso/catalogue_detail?csnumber=61975

These were related to protocol development, harmonization, and expanding of indicators. It was also agreed that future development of standards should reflect these new WHO indoor air quality guidelines. The sector has been collaborating to address these resolutions and identify any additional steps needed to address remaining gaps.

The IWA provides a framework for rating cookstoves using four indicators: efficiency, total emissions, indoor emissions, and safety. Each of these indicators is quantified and mapped to yield five tiers of performance (see Figure A9.1).

The IWA is designed with three main goals in mind. The first goal is that the tiers of performance should allow the sector to acknowledge progress (from a baseline of Tier 0) while setting aspirational goals (Tier 4). For the indoor emissions indicator, the emissions rate that qualifies stoves for Tier 4 is based on that which will result in meeting existing WHO indoor air quality guidelines for fine particulate matter ($PM_{2.5}$) (annual average interim target (IT)-1 of 35 μg/m^3) *(1)* and CO (24-hr average of 7 mg/m^3) *(2)* using an earlier version of the single-zone model described in Review 3.

The second goal of the IWA is to allow organizations and countries to select indicators and tiers based on local priorities, adding flexibility to enable the framework to be used globally.

Finally, the third goal is to adopt a structure that allows for the harmonization of different test protocols that are in use in different countries.

To date, tiers of performance have been mapped to the water boiling test version 4.1.2,[1] and efforts to establish tiers of performance for other protocols are ongoing. Several countries and organizations have begun using the IWA as the basis for establishing national and organizational standards.

A9.3 Updating the IWA: towards international standards

To update these initial IWA guidelines and establish them as international standards, the sector has been working through ISO processes. ISO Technical Committee (TC) 285, the body that will develop and approve these standards, was approved in June 2013. Kenya, through the Kenya Bureau of Standards (KEBS), and the The United States of America of America, through the American National Standards Institute (ANSI), are serving as co-secretariats of the committee. As of July 2014, the committee comprised 20 participating countries, 14 observing countries and 7 international external liaisons organizations, including WHO. Standards-relevant activities and drafting of standards will be done through working groups of experts formed within the committee, with drafts presented for approval through ISO TC 285. Discussions through TC 285 may include updates

[1] As of July 2014, the current version is 4.2.2.

to the IWA based on new findings, including the findings in this WHO guidelines document, protocol development and harmonization, and use of additional methodologies or indicators.

A9.4 Testing facilities and protocol development

Testing is essential for technology development. It allows communication of stove performance to implementers, donors, government programmes and users, and evaluation of technologies against standards, including their potential to achieve these guidelines. Third-party testing is especially important to ensure results are unbiased. Testing may be done in laboratory environments under controlled conditions or under realistic conditions in homes where parameters may be harder to control. While laboratory and field testing results do not always correlate well, both are necessary to evaluate whether technologies under consideration may achieve indoor air quality guidelines. Because achieving indoor air quality guidelines depends on technology performance and use, evaluating both factors is necessary.

Most testing results to date (see Stove Performance Inventory Report 2012[1] and Clean Cooking Catalog http://catalog.cleancookstoves.org) have come from laboratories in developed countries. More laboratory and field testing capacity is needed, especially in developing countries where the use of solid fuels for cooking and the resulting household air pollution (HAP) are major concerns. Developing capacity by setting up regional testing and knowledge centres (RTKCs) is ongoing through grants and training workshops. The aim is to establish sustainable institutions that can provide high quality testing services and catalyse regional activities. These centres are working together as a consortium to standardize methods and establish best practices and common data formats to share testing results. Remaining challenges include data management and quality assurance testing to ensure better standardized results.

There has been significant progress in protocol development and standardization, especially through the ongoing TC 285 international standards process. Work is in progress to address controlled laboratory testing gaps for specific stove types (i.e. griddle stoves, batch-fed stoves), and for the assessment of durability and uncertainty in test measurements. Also in development are protocols for evaluating robustness of technologies to a variety of usage conditions, and to improve protocols so that they better reflect actual use in homes. Many field testing protocols exist, but more standardization of methodologies, as well as more guidance, are needed, particularly guidance that addresses in-home performance,

[1] See http://www.cleancookstoves.org/resources_files/stove-performance-inventory-pdf.pdf

use, acceptance, and displacement of traditional technologies in an integrated framework.

Carbon finance has stimulated a great deal of activity in the clean cooking sector, and the assessment of impact uses similar methodologies for evaluating technologies. There are also emerging opportunities to include health impacts in climate-based investment. This new phase of standards development should seek harmonization of methodologies, whether these are for carbon impact assessment, national testing and certification designed for health improvement, or other purposes.

Capacity building for testing and protocol development should be complemented by systems and resources to share test data with the sector, with consumers, investors, donors, and programmes. There is widespread consensus on the need for comprehensive and transparent resources indicating how current technologies and fuels perform in the laboratory and the field. The Clean Cooking Catalog (see Stove Performance Inventory Report 201215 and Clean Cooking Catalog http://catalog.cleancookstoves.org) is an online global database providing stove and fuel information such as stove features, specifications, emissions levels, efficiency, and safety derived from laboratory and field testing. The Catalog provides an opportunity for manufacturers to share information about their products, and for testing organizations to share independent performance data related to stoves and fuels. This online platform can easily be updated with new data submitted by manufacturers and testing organizations.

A9.5 Regulation and certification

There are a number of mechanisms that can be used to implement and enforce standards and communicate technology quality and performance to users.

Adoption of standards reflecting these guidelines can be used to regulate technologies imported or manufactured locally. Because the standards framework is based on tiered indicators, the standards can become stricter over time, as more and more technologies become available. As standards are updated, there may be other methodologies or indicators that are relevant. For example, methodologies and indicators that reflect in-home performance can be used to provide improved assessments of adoption and potential to achieve indoor air quality guidelines and targets. Governments may also consider regulations for ambient air quality based on existing air quality guidelines, and extending monitoring and enforcement beyond the main urban areas to include rural communities. However, there remain challenges for apportioning the contribution of ambient and indoor air quality to different sources, particularly in urban areas with many different sources of air pollution.

Certification processes are needed to ensure credible and standardized reporting and labelling. It is important to work with those national organizations with the mandate and experience to carry out product certification, in order to implement standards and certify technologies for their potential to meet indoor air quality targets. Certification can apply to products to evaluate performance and quality, as well as to the evaluation of testing centres' ability to produce quality results.

Labels are a means of communicating technology performance and quality to users. The effectiveness of labels depends on how well information is presented, whether there are associated consumer awareness campaigns, and whether the labelling system is enforced to minimize counterfeiting. Studies are needed to evaluate appropriate label designs and whether and how they affect consumer decisions.

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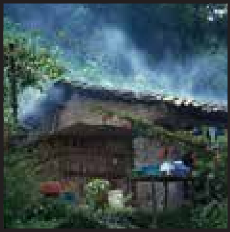
WHO GUIDELINES FOR INDOOR AIR QUALITY

HOUSEHOLD FUEL COMBUSTION

Well into the 21st century, almost 3 billion of the world's poorest people still rely on solid fuels (wood, animal dung, charcoal, crop wastes and coal) burned in inefficient and highly polluting stoves for cooking and heating, resulting in some 4 million premature deaths among children and adults. Together with widespread use of kerosene stoves and lamps, these household energy practices also cause many deaths and serious injuries from scalds, burns and poisoning. Use of solid fuel stoves for heating in more developed countries is also common and contributes significantly to air pollution exposure. Air pollution from household fuel combustion is the most important global environmental health risk today.

Building on existing WHO indoor air quality guidelines for specific pollutants, these guidelines bring together the most recent evidence on fuel use, emission and exposure levels, health risks, intervention impacts and policy considerations, to provide practical recommendations to reduce this health burden. Implementation of these recommendations will also help secure additional benefits to society, development and the environment – including climate benefits that will result from wider access to clean, safe and efficient household energy.

The guidelines are targeted at public health policy-makers and specialists working with the energy, environment and other sectors to develop and implement policy to reduce the adverse health impacts of household fuel combustion. This publication is linked to ongoing work by WHO and its partners to provide technical support for implementation of the recommendations, monitoring progress and evaluating programme impacts.



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