Improved Cookstoves in Central America: Health Impacts and Uptake

A desk study by Fiona Lambe (SEI) and Caroline Ochieng (SEI)

Acknowledgements

This desk study carried out by SEI and commissioned by the World Bank reviews recent research linking cleaner cookstoves to health gains at the household level, and offers insights into what type of technical solutions can have an impact in Central America. It also provides a snapshot of the sector in terms of technologies being adopted and their potential for improving household health.

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ESMAP
Energy Sector Management Assistance Program

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1. Introduction

Globally, more than three billion people continue to rely on traditional biomass to meet their household energy needs. In Central America approximately 20 million people cook in this way (more than half of the region's population) and 86% of these are located in Guatemala, Honduras, Nicaragua and El Salvador (Wang et al. 2013). Strong associations have been found between indoor air pollution and acute lower respiratory infection (Smith 2000; Ezzati et al. 2004; Lim et al. 2012) and chronic obstructive pulmonary disease (Bruce et al. 2002; WHO 2002). Other health effects of solid-fuel cooking, with varying degrees of epidemiological evidence, include asthma, tuberculosis, adverse pregnancy outcomes, pediatric sleep disorders, depression, bacterial meningitis, a variety of moderate-to-severe physical injuries associated with firewood collection, burns, and widespread minor ailments from smoke inhalation, such as eye irritation and headaches (World Bank Forthcoming).

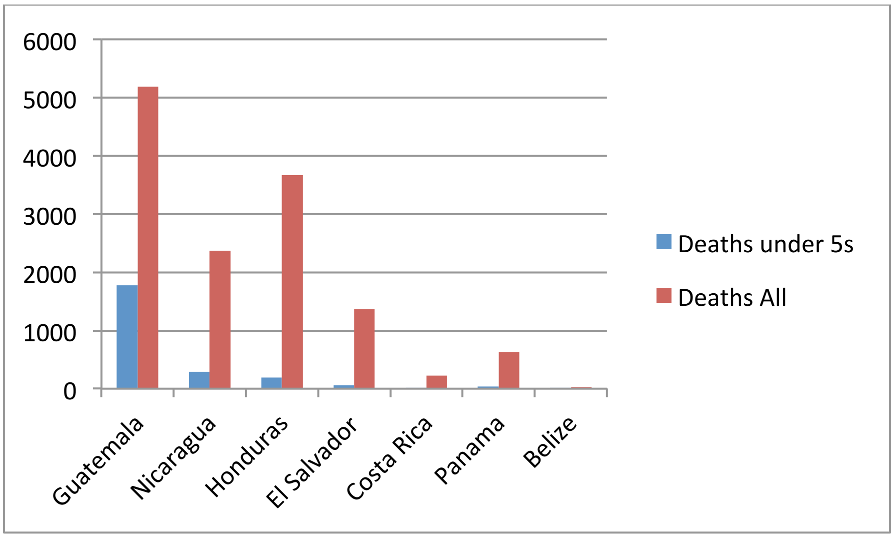

Figure 1. Annual deaths attributable to household air pollution across Central America

Every year in Central America, 37,000 people die prematurely—most of them women and children—because of exposure to household air pollution (HAP) (Wang et al. 2013). WHO estimates that in 2012, 7,500 deaths were attributable to indoor air pollution in children under 5 years of age in low- and middle-income countries of the Americas (World Health Organisation 2015) In Guatemala, the top cause of Disability Adjusted Life Years (DALYs[1]) in 2010 was lower respiratory infections (Institute for Health Metrics and Evaluation (IHME) 2014).

As in other parts of the world, while there is a long history of improved cookstove (ICS) programmes in the region, many of these initiatives have not been adopted in a sustained way, mainly because of poor performance of cookstoves in the field, the availability of free wood, the absence of quality standards in improved cookstoves, and the lack of attention to the needs of the end user and specific socio-cultural contexts (The World Bank 2011; Mobarak et al. 2012; Simon et al. 2014). Few cookstoves have been evaluated for their performance on reducing emissions (with much of the analyses done in the lab) or on air pollution exposure. And even fewer have been evaluated for their performance in realizing the numerous potential health benefits, which still remains the primary motivator for cookstove programs. Most evidence on health benefits is drawn from the RESPIRE randomized trial carried out with Plancha stove in Guatemala (Smith et al. 2011). In terms of childhood pneumonia, a critical impact of cooking with biomass, the intervention achieved only a marginal health benefit. These results have been confirmed by studies in several other regions, and

[1] Disability-adjusted life years (DALYs) quantify both premature mortality (YLLs) and disability (YLDs) within a population.

have led to strong recommendations to make clean fuel an available option as a means to tackle health problems resulting from household air pollution.

However, it is acknowledged that because transition from biomass to clean fuels, such as liquefied petroleum gas (LPG) and electricity takes time, clean cookstoves are still needed in the interim (World Bank Forthcoming; The World Bank 2011). The stoves should, however, meet performance standards and be used correctly and consistently in households for these benefits to be realized.

The WHO guidelines for indoor air quality (IAQ), published in 2010, outlined the levels of IAP that should not be exceeded for health protection (World Health Organisation 2010). This was a great move from the 2005guidelines that did not consider indoor air quality outside of occupational settings. But like the previous guidelines, the 2010 guidelines did not provide practical recommendations to assist countries and implementing agencies to put these guidelines into practice. This gap has been addressed by the recent indoor air quality guidelines (World Health Organisation 2014) that focus on household fuel combustion, and therefore responds to particular needs of low income countries where the problem of indoor air pollution is concentrated, and caused by domestic sources of energy. Furthermore the approach to development of the indoor air quality guidelines has been pragmatic, taking into account the fact that not all countries can meet the stringent health guidelines. Thus the guidelines provide both interim targets (for 60% of homes meeting the targets) and aspirational targets (for 90% of homes meeting the targets).

Even where technologies that can meet the guidelines are available, getting households to adopt them is challenging since it entails a shift in behaviour which can be difficult to bring about because cooking is deeply embedded in socio-cultural contexts, and low-income households tend to be highly risk averse and therefore less prone to change behavioural patterns (World Bank 2014; Figueroa 2014). Furthermore, compared to other parts of the world, ICS technologies[2] in Central America are often prohibitively expensive for low-income households, relative to what is currently being used (Wang et al. 2013). This is because stoves need to accommodate a “plancha” (griddle) so that households can bake tortilla, a staple food in the region, which adds significantly to the material cost. There are also many market barriers to the availability, delivery and service of such products, which must be overcome if they are to be embedded in existing economies and production chains. In short, the path to improved health through the use of cleaner cookstoves involves overcoming many hurdles, but could, if successfully navigated, result in improved respiratory health (as well as other health outcomes such as reduction in eye problems and fewer burns), livelihoods and local environment.


Figure2: Tortilla baking on an improved plancha (left) and several dishes simmering (right), Honduras, Proyecto Mirador

[2] Partly because of its size and the metal materials required, improved biomass stoves in the Central American context are much more expensive than common models acceptable in Asia or Africa.

2. Objective of the desk study

This discussion brief aims to distil recent research linking cleaner cookstoves to health gains at the household level to offer insights into what type of technical solutions can have an impact in Central America.[3] It provides a snapshot of the sector in terms of technologies in use and their potential for improving household health. Specifically, we review the technology options currently available in the region in terms of the type of health benefits associated with them in light of the recently published WHO household air pollution guidelines. We then provide an overview of the ICS technologies which are achieving uptake by households, and an analysis of the factors which appear to support uptake. We discuss the challenges related to introducing such technologies in terms of the behavioural shifts needed at the household level and establishing sustainable local markets for ICS.

3. Methods, scope and approach

We carried out a desk review of cookstove initiatives in Central America to assess both technical performance and user adoption.

The WHO guideline development entailed two systematic reviews of published literature on IAQ performance of various stove types, including ones in Central America (Balakrishnan and Mehta 2012; Rehfuess et al. 2012). These reviews formed a natural starting point for our own.

The WHO review's inclusion criteria was strict, and only included studies with experimental components (randomized or quasi randomized intervention trial). We looked for any additional articles that were not included in those reviews. Our approach further differs from the WHO one in that we included all health outcomes, while the WHO review was for instance restricted to outcomes that have an impact on child survival and development; and those responsible for large burden of disease based on the 2010 GBD report. In this review we include all health outcomes. The scope of this review is Central America and only includes cookstoves that are being promoted in this region.

The literature search for data on cookstove performance in Central America entailed:

- Identification of studies covered in the WHO systematic review:
- Searches in PubMed, Web of Science, Google Scholar and other bibliographic databases for studies that could have been missed in the WHO reviews, or classified as weak for inclusion in those reviews. Search terms entailed a combination of terms such as names of the stoves (e.g. Plancha, Justa), region/countries (e.g. Central America, Guatemala, Nicaragua), fuel types (biomass, solid fuels) and health outcomes (e.g. ARI, cardiovascular disease).
- The Global Alliance for Clean Cookstoves partners database was also available for Guatemala; a self-reporting by all partners of the design of cookstoves they promote, name of stoves and efficiencies. The names of the stoves were included in the search terminologies as described in 2) above. Unfortunately a similar type of list was not available for other countries in the region.
- Data were included for three additional cookstoves that appear to be achieving significant uptake (highlighted in grey on table 5).

Two reviewers performed the literature search and data extraction. There were no disagreements in the results. In total, 15 articles met the eligibility criteria of 1) A field based study on cookstove performance in Central America; 2) Assessed the performance of an improved cookstove; 3) Reported measurements of IAQ: CO, PM or other pollutants. From the articles we extracted basic data on stove name/type, reported IAP test results (actual concentration values where available and percentage reductions where the details were not provided), reported health impact (odds ratios or risk rations for disease outcomes where reported, or % reductions in symptoms) and other reported benefits that could

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[3] The World Bank has a regional programme in Central America and commissioned SEI to conduct this focused review to support this programme.

be linked to lower exposures such as reduced fuel use. The GACC partners report provided efficiency measures for the stoves, which were extracted into Table 1 below for analysis. The literature review however focused on field performance of clean cookstoves, which is of more relevance to the health outcomes and air quality guidelines. The peer reviewed publications also focused on results based on field performance.

For the review of user adoption[4], we included a total of 33 cookstove initiatives, focusing on countries where biomass reliance for cooking is the highest in the region (Guatemala, Honduras, Nicaragua, El Salvador) (Wang et al. 2013). Relevant improved cookstove initiatives were identified through a number of sources including the Global Alliance for Clean Cookstoves partner database [5] the Global Alliance for Clean Cookstoves Country Action Plan for Guatemala (Global Alliance for Clean Cookstoves 2014) ,through internet searches and consultations with prominent sector experts[6]. The focus was on household, rather than commercial or institutional cookstoves. The literature review included academic and grey literature on adoption, taking as a starting point recent systematic reviews on cookstove adoption (Rehfuess et al. 2013) and factors determining choice of stove and fuel (Lewis and Pattanayak 2012) . Where published data were unavailable, we attempted to gather additional information on ICS programmes via e-mail correspondence with cookstove implementers. Key factors included in the review were: number of stoves sold/disseminated; cost of stove, financing model, innovative features of the programme, success rates in adoption (both numbers of stoves installed, and reports of sustained use over time) and reported reasons for success/failure in achieving adoption.

The findings on cookstove adoption in the region were then synthesised with the data on performance for the identified technologies and compared with WHO guidelines for improved cookstoves.

4. Results

4.1 Stove performance in terms of emission reduction

Table 1 is a summary of various stove designs used in Central America and their "efficiencies" based on the GACC partners' self reports. In total 30 stove models were identified. In the GACC report, efficiency is defined as gain over open fires i.e. amount of energy produced per CO and PM emission. As can be seen from the table, there is a very mixed reporting of the efficiency levels, making it difficult to compare the performance of different stove types. For instance, a programme that reports performance as 53%/0 (ID 11) while another reports it as 45%/100% (ID 23). It is clear that the metric for the efficiency measure was not understood in some instances. Because the efficiencies are reported as percentage values, it is also not possible to compare them to WHO guidelines which are reported as concentrations values that should not be exceeded in specific time periods.

Table 1: Stove performance based on pollutant emissions

Stove ID	Stove name	Promoter	Energy type	Cost (USD)	Efficiency	Certification
1	Onil	HELPS international	Firewood	97	66%/99%	Yes
2	Nixtamal	HELPS International	Firewood	37	66%/99%	No
3	Dona Dora	Estuta Dona DOra	Firewood	193	60%/98%	No
4	Ecocina	Limited Company	Firewood	65	60%/95%	Yes

[4] Though there is no commonly accepted definition of cookstove "adoption", for this study we build on the definition proposed by Shankar et al. of adoption as *the acquisition and substantive use of a technology by the user* (Shankar et al. 2014) by adding that cookstove adoption implies daily use of ICS by the household where the stove is used for at least some of the households cooking tasks.

[5] See http://cleancookstoves.org/partners/

[6] Sector experts included regional representatives from GIZ, SNV and HIVOS

5	Ecocomal	Limited Company	Firewood	110	60%/95%	Only tests
6	Ecoplancha II	Limited Company	Firewood	114	60%/95%	Only tests
7	Ecoplancha III	Limited Company	Firewood	117	60%/95%	Only tests
8	Noya	Mannel Tay	Firewood	155	50%/99%	No
9	El Poyo Est Rella	Community Solutions	Firewood	176	50%/Unknown	No
10	Nixtamalera	Community Solutions	Firewood	32	65%/Unknown	No
11	Improved stove GNG	Good Neighbours Guatemala	Firewood	230	1st generation – 53%/0 2nd generation – 39%/0	No
12	Aler	Hands for peace-making foundation	Firewood	169	65%	No
13	La A Horradora, HM5000	Envirofit International	Firewood	340	65%/99%	Yes
14	La Frijolera, M5000	Envirofit International	Firewood	45	70%/99%	Yes
15	La Carbonera, CH5200	Envirofit International	Firewood	40	60%/80%	Yes
16	Hiteca – Plancha	Soluciories Apropiadas	Firewood	156	50%/98%	No
17	Hasa	Hasa Industry	Firewood	240	65%/95-99% (CO)	No
18	Ecostufa	Hasa Industry	Firewood	156	50%/98%	No
19	Totonicapan	Ecologi Development Fund	Firewood	100	40%	No
20	Horno Urrea	Horns Urrea SA	Firewood	Q1900	60%/98%	No
21	Estufa Maya	Maya Pedal	Firewood	120	60% to 95%	No
22	La UTZ	Tecnoutz	Firewood	129-198	75-80%/99%	
23	Estufa Mesa	Industries Nivi S.A	Gas	19-44	45%/100%	No
24	Super Cocinas MG-400	Super Cocinas Guatemala	Gas	165	No data provided	No
25	Super Cocinas MCA-315	Super Cocinas Guatemala	Gas	140	No data provided	No
26	Alterna	Alterna Biodigesters	Biogas	974	No data provided	No
27	Peace Corps Model with some modifications	ABPD	Firewood	155	70%	No
28	Estufas Don Juan	Association of women Ixchei		200	65% to 95%	No
29	Estufas Lupita	Association de Mujeres del altiplano		160	60%/95%	No
30	Justa	Arks and Rotary Club		134	50%/98%	Another model in Honduras has been validated
31	Justa 22 x 22 (Honduras)	EnDev	Firewood	105	55%	Only tests
32	Justa 2x3	Proyecto Mirador	Firewood	45	50%/79%	Yes

Note: Efficiency is reported as efficiency gain over open fires: energy/CO and particulate.

All the stove designs utilize firewood, except for four (23 to 26), with one of them utilizing biogas. None of the stoves are stated to utilize charcoal or other forms of biomass; Of the 30 stoves, only 5 (16%) have been certified by a third party. Interestingly nearly all provide values of efficiency performance. On average, the stoves reduce CO emissions by 59% (s.d. 11.7) relative to the open fire;

and PM by 95% (s.d. 8.0) relative to the open fire. A repeat of the analysis with only certified stoves (n = 5) suggests a reduction in CO by 64%, and in PM by 94%. This sample is however too small for drawing any meaningful conclusion on the stoves' performance. No program reported stove performance level of below 50%. This means that all the stoves would meet the WHO guidelines for household fuel combustion in Table 2.

Table 2: Device and fuel emission rates required to meet WHO (annual average) air quality guidelines and interim target-1 for PM2.5 and CO (the values presented in table 3 below).

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)	

Source: (World Health Organisation 2014)

Overall, the results on the stove efficiencies should be taken with serious caution since they are based on only a few stoves the majority of them uncertified Performance of the stoves in the lab has also been shown to vary significantly from field performance (Johnson et al. 2010) The results are also based on self-reports, and there is clearly a problem in how different programmes interpreted the performance metric. The reporting could also be biased towards high performance of the stoves.

4.2 Stove performance in relation to indoor air quality standards and health

The WHO has set guidelines for indoor air quality based on existing evidence on relationship between exposure and various health outcomes. In generating the guidelines for household fuel combustion, the WHO committee did not revisit these guidelines. Table 3 is a summary of the IAQ WHO guidelines (World Health Organisation 2014)

Table 3: WHO guideline values for PM and CO

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)	–	–	–	–	–	–	–	6.0×10^{-6}	No safe level	WHO 2010 *(13)*

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/m^3)	–	100		35	10	7	–	–	–	WHO 2010 *(13)*

Source: (World Health Organisation 2014)

In the review, we identified studies conducted in Central America that have measured pollutants associated with biomass fuel use, in order to gauge whether or not the stoves achieve indoor air quality to levels that meet the WHO/IAQ ?guidelines. Table 4 is a summary of the reviewed studies.

Overall, these findings suggest significant reduction in IAP following installation of improved stoves. The health gains in respiratory conditions, and other conditions, such as low birthweight also appear significant. This is in line with the findings from the WHO systematic reviews which showed significant post-intervention reductions in both CO and PM concentration (for cookstoves with chimneys, the average reduction in PM concentrations was 63.3% and CO concentrations was 62.8%) (Rehfuess et al. 2012) As with the emission values however (Table 1), it is difficult to make a comparative analysis of these studies due to the differences in study designs, measurements (instruments, duration, pollutants), stove types (vented and unvented) and cultural differences across geographical settings within the region. Looking at the specific values for CO and PM presented in table 4, and comparing them with the guideline values in Table 3 above, we can see that even stoves with "high" performance (e.g. the plancha stove tested in the RESPIRE study) are not achieving reductions in PM to levels that meet the guidelines.

For studies that do not report health outcomes (e.g. 1, 4 and 6), a critical question is whether the reported emission reductions are representative of reductions in personal exposure, which is of more interest when assessing health impacts of improved wood stoves. In the RESPIRE study for instance (Smith et al., 2010), use of improved chimney stoves was associated with 90% reduction in indoor CO concentrations; however, reductions in personal exposure were more modest (50%) because of exposure elsewhere from open fires? Studies from other settings outside Guatemala confirm this. In Mexico for instance, Cynthia and colleagues (2008) report a 74% reduction in median 48-h $PM_{2.5}$ concentrations in kitchens but only 35% reduction in median 24-h $PM_{2.5}$ personal exposures. This is an important question when it comes to interpretation of the guidelines. The stoves might meet the emission targets as set out in the guidelines (Table 2) but might not yield significant health benefits due to several determinants of exposure at household level. These include stove tending practices, degree of maintenance practice and continued use of traditional stove along with the improved one (stove stacking). Any stats on % households using stove stacking?

It is also important to note that results for the plancha stove, whose field performance is reported in the studies, are largely generated from the RESPIRE randomized trial. Randomized trials are informative on the efficacy on interventions (e.g. cookstoves) but not on their performance outside the research setting, where there is a lack of substantial resources to follow-up households usage and adherence to improved stove use, and to carry out regular stove maintenance. This trial may therefore overestimate the performance of the stoves (Hanna et al. 2012).

Table 4: Examples of studies conducted in Central America that have assessed cookstoves performance in IAP reduction

Study ID	Study	Country	Stove type	Results on HAP	Results on health	Other outcomes
1	Ludwinski et al. 2011	Guatemala	Plancha		48.6% reduction in respiratory problems in women, 63.3% reduction in	59.1% reduced wood consump

					children	tion
2	Smith et al. 2011	Guatemala	Plancha	50% exposure reduction (2.2 ppm CO to 1.1 ppm CO)	22% reduction in pneumonia. NS. 1/3 reduction in severe pneumonia cases. Significant.	
3	Naeher et al. 1999	Guatemala	Plancha	528µg/m3 for open fire, 96µg/m3 for plancha, 57µg/m3 for gas.	None reported	
4	Smith-Siversten et al. 2008	Guatemala	Plancha	61.6% reduction in CO. 4.24 ppm median CO before, 1.63 ppm after.	Significant reduction in wheeze (RR o.42), respiratory symptoms (OR 0.7). NS on lung function	
5	Thompson et al. 2011	Guatemala	Plancha	39% reduction in mean exposure to CO	Intervention group infants had 89g more weight than the control group. Adjusted OR for low birth weight was 0.74 compared to controls.	
8	McCracken et al. 2011	Guatemala	Plancha	Personal PM2.5 from 266 µg/m3 to 102 µg/m3 (64% reduction) for chimney stove compared to open fire; and 187 and 112 (40% reduction) in the before-after.	Reduced occurance of ST-segment depression; 0.26 (95% CI, 0.08-0.90)	
9	Naeher et al. 2000	Guatemala	Plancha	kitchen PM2.5 levels were 56 mg/m3 under background conditions, 528 mg/m3 for open fire conditions, 96 mg/m3 for *plancha* conditions, and 57 mg/ m3 for gas stove conditions. Corresponding PM10/TSP levels were 173/174, 717/836, 210/276, 186/218 mg/m3. Corresponding CO levels were 0.2, 5.9, 1.4, 1.2 ppm.		
10	Albalak et al. 2001	Guatemala	Plancha	24-hour PM3.5 = 1560 µg/m3 for open fire; 280 for plancha and 850 for open fire plus LPG. 45% reduction for open fire + LPG, and 85% reduction for plancha.		
11	Bruce et al. 2004	Guatemala	Plancha	The 24-h kitchen CO was lowest for homes with self-purchased planchas: mean (95% CI) CO of 3.09 ppm (1.87–4.30) vs. 12.4 ppm (10.2–14.5) for open fires. The same ranking was found for child CO exposure, but with proportionately smaller differentials (Po0.0001). The 24-h kitchen PM3.5 in the sub-sample showed similar differences (n¼24, Po0.05). The predicted child PM for all 203 children (based on a regression model from the sub-sample) was 375 mg/m3 (270–480) for self-purchased		

				planchas and 536 mg/m3 (488–584) for open fires.		
12	McCracken et al., 2009	Guatemala	Plancha	Daily average PM2.5 exposures were 264 and 102 µg/m3 in the control and intervention groups, respectively.	the improved stove intervention was associated with 3.7 mm Hg lower SBP [95% confidence interval (CI), –8.1 to 0.6] and 3.0 mm Hg lower DBP (95% CI, –5.7 to –0.4) compared with controls.	
13	Boy et al. 2002	Guatemala	Plancha	Children born to mothers habitually cooking on open fires (*n* = 861) had the lowest mean birth weight of 2,819 g [95% confidence interval (CI), 2,790–2,848]; those using a chimney stove (*n* = 490) had an intermediate mean of 2,863 g (95% CI, 2,824–2,902); and those using the cleanest fuels (electricity or gas, *n* = 365) had the highest mean of 2,948 g (95% CI, 2,898–2,998) ($p < 0.0001$). The percentage of low birth weights (< 500 g) in these three groups was 19.9% (open fire), 16.8% (chimney stove), and 16.0% (electricity/ gas), (trend $p = 0.08$).		
14	Diaz, 2008	Guatemala			52.8% of women reported improvement in health, compared to 23.8% of control women (p < 0.001). Among 84 women who reported reduced kitchen smoke as an important change, 88% linked this to improvement in their own health, particularly for non-respiratory symptoms (e.g. eye discomfort, headache); 57% linked reduced smoke to improvement in their children's health, particularly sore eyes	
15	Northcross et al. 2010	Guatemala		Estimated 48 h mean personal PM2.5 concentrations for mothers, infants, and children in open-fire homes were 0.27 +/- 0.02, 0.20 +/- 0.02, and 0.16		

				+/- 0.02 mg m(-3) respectively. In chimney-stove homes, mothers and children experienced PM2.5 personal concentrations of 0.22 +/- 0.03 and 0.14 +/- 0.03 mg m(-3), respectively.		

4.3 Which improved cookstoves are being adopted?

Of the 33 programmes reviewed, we identified six that appear to be achieving success in terms of household adoption as we define it. The numbers of stoves installed by these initiatives varies between several hundred to 100 000 but in all cases there was evidence of sustained use by households[7]. These programmes are working with six different ICS technologies. See Table 5 below. Note, we include those interventions where there is some evidence of adoption, either third-party studies or self-documented (internal evaluation reports, sales data, etc.). All six technologies meet the WHO cookstove performance guidelines for emission reduction (see Table 1 above). In terms of health impacts, the Onil stove in Guatemala and the justa 2x3 is the only one that has been rigorously tested in the field and independently certified (see Table 4 above for reported health gains).

Table 5. Key features of ICS being adopted in Central America

Stove name and type	Country	Number of stoves disseminated and time period	Studies/Evaluations on uptake	Reported reasons for success in adoption
Onil "mobile" rocket stove, metal plancha with chimney	Guatemala	90 000 (13 years)	Ruiz-Mercado et al. (2013); von Ritter Figueres (2012), Bielecki and Wingenbach (2013) Graven (2012)	• thorough training on use and maintenance • post installation follow up with households • community involvement in installation • having community "champions" engaged in promotion • Easy maintenance: chimney easy to clean • Meets the needs of cooks: can cook over flame
Dona Dora Insulated metal chamber, plancha with chimney	Guatemala	1215 (3 years)	None published; extensive information gathered in e-mail correspondence (sales figures overtime and business model)	• User-centred design, saves fuel • Post-installation follow up with households • Appropriate consumer finance model
Justa Fixed stove, brick base, metal plancha, chimney	Guatemala	800 (10 years)	Internal programme evaluation report, e-mail correspondence	• stove designed to meet users' needs (e.g.) • Fuel efficient (stove use is higher and stoves better maintained in areas where fuelwood is in short supply)
Justa 22x22	Honduras	15 000 (10 years)	Ostrom (2010)	• Word of mouth marketing • Presence of local distributers • Availability of spare parts

[7] Means of verification on adoption ranged from third party impact evaluations, internal programme evaluations, project data bases used for carbon finance monitoring and direct correspondence with project implementers. Where no data could be found, initiatives were excluded.

				such as combustion chambers, chimneys, planchas, etc. • Willingness of the stove owners to invest in the maintenance and repair of their stoves. • after sales services
Justa 2x3	Honduras	100 000 (12 years)	Ramirez et al (2013); Ramirez et al (2012);	• Programme is demand driven: stoves are only installed where at least 12 households have made a request • Stove designed to meet user needs (e.g.) the addition of a maintenance tool, the "Cinca" makes it easier for users to clean and maintain • Demonstrated fuel savings and emission reductions • Community training on stove use and maintenance • After sales service is provided if needed • Cost of installation shared by household
Ecocina Fully mobile,	Honduras	7691(7 years)	Internal evaluation reports	• End user training on stove use and maintenance¨ • Households have to pay a portion of the cost • Follow up one month after installation to ensure correct use • User needs central to the design
	Nicaragua	383(7 years)		
	Guatemala	9,682 (7 years)		
	El Salvador	15,321 (7 years)		

5. Factors affecting adoption/non adoption

The most commonly adopted ICS stove model is the plancha cookstove with chimney. Only one "fully mobile" rocket stove, the Ecocina was found to be achieving some level of adoption in the region. The common factors reported as being important determinants of adoption across all initiatives include training of users prior to installation, involvement of households and the wider community in installation and user training, cost sharing with households, the availability of after sales services and spare parts if needed. Furthermore, almost all of the initiatives report that taking a user-centred approach to designing the cookstove was essential for ensuring uptake by the households. Overall, adoption rates reported in initiatives were between 69% and 100% though most initiatives are not monitoring sustained use over time Some of the plancha initiatives reported regional variation in adoption rates due for example to availability of fuelwood (adoption rates are higher where fuelwood is scarce) and where households were closer to the sea, plancha chimneys tended to rust causing stoves to malfunction.

Some of the reasons for lower adoption rates were related to the technology e.g. stoves can't be used for space heating and social gathering which is important in some communities; opening to the chamber is perceived as being too small by some users; the stove is too heavy to carry if it needs to be transported for repair (this relates to the installed planchas); in some cases the stoves don't allow enough workspace for the cook, and there is some evidence of lack of availability in replacement parts. One internal evaluation of an ICS programme in Guatemala showed that cookstove adoption tended to be lower and stoves less well maintained where fuelwood supply is less constrained which confirms that fuel efficiency is a key motivating factor for using the stove correctly and consistently.

Our findings on the factors supporting adoption in Central America broadly reflect the wider literature on cookstove adoption and market transformation. For example two systematic reviews of enablers and barriers uptake of improved cookstoves find that offering technologies that meet users' needs (e.g. ability to cook local dishes and burn locally available fuels) and save fuel, user training and support and effective financing for households appear to be critical factors (Rehfuess et al. 2013) Like in other parts of the world, households in central America "stack" their stoves, typically using different stoves for different dishes so the introduction on an improved cookstove doesn't necessarily mean the abandonment of a traditional stove. Indeed, one study which monitored the use of improved cookstoves over time in Guatemala finds that it is reasonable to expect 90% stove days- that is, that stoves are used for some cooking tasks 90% of days monitored (Ruiz-Mercado et al. 2011) Furthermore, a recent study of the drivers of behaviour change related to cookstove uptake found that the three most effective drivers to be reward (e.g. savings in fuel cost); social support (community involvement and influence of peers) and shaping knowledge (marketing and information) (Goodwin et al. 2015). In all of the initiatives achieving adoption, at least two and often three of these behavioural drivers are being applied.

Particular Challenges: Market transformation of the cookstove sector is difficult given high poverty levels and the high cost of the stoves in the region. Because of this, compared to other parts of the world, there is a high incidence of stoves subsidised or given away in Central America. Some partners cited this as being problematic as it distorts the market, making it difficult for them to compete with subsidised stoves. This is supported in the literature which shows that heavy end user subsidies can act as a disincentive to other market actors and devalue the cookstove at the household level (Rehfuess et al. 2013). However, in Central America it seems there is generally a need for end user financing in all but the wealthiest families (Evitt 2015). The projects that are achieving scale in terms of stoves sold/installed are those using innovative models for reaching end users, combined with a steady stream of core finance e.g. carbon revenues such as Proyecto Mirador and the Justa 2x3 stove.

6. Data gaps

An important finding of this review is that there are no comprehensive studies on household adoption of ICS over time in the region. In this respect evaluation lags behind, say compared to the evaluation emerging from Kenya. The data on adoption is scattered and largely comprised of self-reported evaluations by project implementers or third party academic research focusing on specific drivers of adoption e.g. social perceptions e.g. (Bielecki and Wingenbach 2014) or dissemination of information e.g. (Ramirez et al. 2014). Without such studies, it is impossible for the sector to understand what works in sustained adoption to cleaner cook stoves, which could have serious consequences for future interventions.

7. Study limitations

- The field studies are mainly from Guatemala, which limits generalizability of the findings.
- Due to resource limitations, it was not possible to carry out a full systematic review. It is therefore possible that we missed some field studies reported in the grey literature
- Only a few stoves in table 1 had been evaluated for performance by a third party. The self-reported performance data are therefore not fully reliable.

8. Conclusions

We conducted a desk-based review of improved cookstove interventions in Central America, focusing on the countries with highest biomass use. We reviewed the literature on performance of various stove types used in the region; looking at efficiencies, IAQ and health benefits. We also examined the evidence on adoption of ICS in the region and identified some key factors supporting household uptake of ICS. Based on self-reports on efficiencies, most of the stoves demonstrate high performance; reducing fuel use and PM/CO emissions by at least 50%. For the few that had undergone field based evaluation, we found that they reduced significantly indoor air pollution concentrations, even though reductions in personal exposure are marginal. This would explain why the health benefits were also not highly significant. We also found that some ICS are being adopted over sustained periods of time, and that key factors which appear to support their adoption include taking a user-focused approach to stove technology design, training and follow up with users, community involvement in cookstove dissemination and the availability of spare parts. This study adds to the literature on the performance and uptake of ICS and draws attention to the need for further research in this area.

9. Recommendations

- There is need for standardized measures for measuring and reporting stove performance, including, where possible, the use of remote sensors for measuring use. Capacity of stove promoters should be strengthened in use of this equipment and in interpreting efficiency values. This is important so that they understand the figures they report, but also to inform stoves are promoted to users (e.g. based on the values one can tell if a stove can achieve health benefit or save fuel, or both, and inform the users appropriately when marketing the stoves to them).

- Similar standardized measures are needed when assessing field performance of the stoves. The studies identified in this review utilized mixed approaches in monitoring durations (8 hour, 24 hour, 48 hour) and assessed different pollutants (PM2.5, PM3, PM4 and PM10) making it difficult to compare findings across different studies. The effort of developing standardized measures is already ongoing through the ISO stove standardization process. The WHO, World Bank and others should play a central role in championing these efforts, to enable countries to monitor their performance in meeting the WHO guidelines.

- Very few stoves had been certified by an independent party (5%), and those that were certified utilized different certification bodies. It would be important to have a national standardization body for the stoves, as is currently ongoing in Kenya, East Africa, and make it a requirement for all stoves to undergo the process before introduction into the market.

- There is need for more longitudinal evidence on the field performance of cookstoves in Central America. Except for the HELPS Plancha, which has undergone a lot of field tests as part of the RESPIRE trial, there is limited information on field performance of the other stoves. This is a key research recommendation emanating from this review.

- More academic research is also needed on household adoption of cookstoves, both in terms of understanding decision making around purchase of ICS, but also in the key factors underpinning the sustained and correct use of the stoves, and in user needs, which as indicated in Table 5 as a mechanism for adoption.

References

Balakrishnan, K. and Mehta, S. (2012). WHO Indoor Air Quality Guidelines: Household Fuel Combustion, Review 5: Population Levels of Household Air Pollution and Exposures. 5. World Health Organization, Geneva, Switzerland. http://www.who.int/indoorair/guidelines/hhfc/Review_5.pdf?ua=1.

Bielecki, C. and Wingenbach, G. (2014). Rethinking improved cookstove diffusion programs: A case study of social perceptions and cooking choices in rural Guatemala. Energy Policy, 66. 350–58.

Bruce, N., Perez-Padilla, R. and Albalak, R. (2002). The Health Effects of Indoor Air Pollution Exposure in Developing Countries. WHO/SDE/OEH/02.05. World Health Organization. http://whqlibdoc.who.int/hq/2002/WHO_SDE_OEH_02.05.pdf.

Evitt, D. (2015). Market barriers to uptake of improved cookstoves in Central America.

Ezzati, M., Lopez, A. D., Rodgers, A. and Murray, C. J. L., eds. (2004). Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors. World Health Organization, Geneva. http://www.who.int/healthinfo/global_burden_disease/cra/en/.

Figueroa, A. (2014). Mind the Energy Efficiency Gap! DIE, Bonn, Germany.

Global Alliance for Clean Cookstoves (2014). Guatemala Country Action Plan for Clean Cookstoves and Fuels: Annexes. Global Alliance for Clean Cookstoves, Washington DC. http://cleancookstoves.org/binary-data/RESOURCE/file/000/000/248-1.pdf.

Goodwin, N., O'Farrell, Sarah Ellen, Jagoe, K. and Rouse, J. (2015). Use of Behavior Change Techniques in Clean Cooking Interventions: A Review of the Evidence and Scorecard of Effectiveness. Journal of Health Communication, (Vol. 20).

Hanna, R., Duflo, E. and Greenstone, M. (2012). Up in Smoke: The Influence of Household Behavior on the Long-Run Impact of Improved Cooking Stoves. 18033. National Bureau of Economic Research. http://www.nber.org/papers/w18033.

Institute for Health Metrics and Evaluation (IHME) (2014). GBD Database. IHME, University of Washington, Seattle, WA. Available from http://www.healthdata.org/search-gbd-data?s=Tension-type%20headache.

Johnson, M., EDWARDS, R., BERRUETA, V. and MASERA, O. (2010). New Approaches to Performance Testing of Improved Cookstoves. Environmental Science & Technology, 44(1). 368–74.

Lewis, J. J. and Pattanayak, S. K. (2012). Who Adopts Improved Fuels and Cookstoves? A Systematic Review. Environmental Health Perspectives, 120(5). 637–45. DOI:10.1289/ehp.1104194.

Lim, S. S., Vos, T., Flaxman, A. D., Danaei, G., Shibuya, K., et al. (2012). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. The Lancet, 380(9859). 2224–60. DOI:10.1016/S0140-6736(12)61766-8.

Mobarak, A. M., Dwivedi, P., Bailis, R., Hildemann, L. and Miller, G. (2012). Low demand for nontraditional cookstove technologies. Proceedings of the National Academy of Sciences of the United States of America, 109(27). 10815.

Ramirez, S., Dwivedi, P., Ghilardi, A. and Bailis, R. (2014). Diffusion of non-traditional cookstoves across western Honduras: A social network analysis. Energy Policy, 66. 379–89.

Rehfuess, E. A., Puzzolo, E., Stanistreet, D., Pope, D. and Bruce, N. G. (2013). Enablers and Barriers to Large-Scale Uptake of Improved Solid Fuel Stoves: A Systematic Review. Environmental Health Perspectives, . DOI:10.1289/ehp.1306639.

Rehfuess, E., Bruce, N. and Pope, D. (2012). WHO Indoor Air Quality Guidelines: Household Fuel Combustion Review 6: Impacts of Interventions on Household Air Pollution Concentrations and Personal Exposure. 6. World Health Organization, Geneva. http://www.who.int/indoorair/guidelines/hhfc/Evidence_Review_6.pdf?ua=1.

Ruiz-Mercado, I., Masera, O., Zamora, H. and Smith, K. R. (2011). Adoption and sustained use of improved cookstoves. Energy Policy, 39(12). 7557–66. DOI:10.1016/j.enpol.2011.03.028.

Shankar, A., Johnson, M., Kay, E. and Pannu, R. (2014). Maximizing the benefits of improved cookstoves: moving from acquisition to correct and consistent use. Global Health, Science and Practice, (Vol. 2 (3)). 268–74.

Simon, G. L., Bailis, R., Baumgartner, J., Hyman, J. and Laurent, A. (2014). Current debates and future research needs in the clean cookstove sector. Energy for Sustainable Development, 20. 49–57.

Smith, K. R. (2000). National Burden of Disease in India from Indoor Air Pollution. Proceedings of the National Academy of Sciences, 97(24). 13286–93. DOI:10.1073/pnas.97.24.13286.

Smith, K. R., McCracken, J. P., Weber, M. W., Hubbard, A., Jenny, A., et al. (2011). Articles: Effect of reduction in household air pollution on childhood pneumonia in Guatemala (RESPIRE): a randomised controlled trial. The Lancet, 378. 1717–26.

The World Bank (2011). Household Cookstoves, Environment, Health, and Climate Change: A New Look at an Old Problem. The International Bank for Reconstruction and Development, Washington, DC, US. http://climatechange.worldbank.org/content/cookstoves-report.

Wang, X., Franco, J., Masera, O., Troncosco, K. and Rivera, M. (2013). What Have We Learned about Household Biomass Cooking in Central America? Washington DC.

WHO (2002). Reducing Risks, Promoting Healthy Life: The World Health Report. Geneva.

WHO (2014). WHO Guidelines for Indoor Air Quality: Household Fuel Combustion. World Health Organisation, Geneva, Switzerland. http://apps.who.int/iris/bitstream/10665/141496/1/9789241548885_eng.pdf?ua=1.

World Bank (Forthcoming). Clean and Improved Cooking in Sub Saharan Africa: A Landscape Report. The World Bank, Washington D.C.

World Bank (2014). World Development Report 2015: Mind, Society, and Behavior. World Bank Publications.

World Health Organisation (2010). WHO Guidelines for Indoor Air Quality: Selected Pollutants. World Health Organisation, Bonn, Germany. http://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf?ua=1.

World Health Organisation (2015). Global Health Observatory Repository: Data by Country. World Health Organisation, Geneva. : http://apps.who.int/gho/data/node. country.