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Just and fair household energy transition in rural Latin American households: are we moving forward?

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Abstract

In this paper we conduct a scoping review of current household energy use patterns and trends in rural Latin America (LA), with the objective of identifying strategies that help promote just and fair transitions in the region. We reviewed a total of 143 publications covering 13 countries within the period from 1996 to 2021. The review shows: (a) fuelwood (FW) continues to be a very important, resilient—and in many countries—the dominant cooking fuel for rural LA households, both exclusively and increasingly stacked (combined) with liquefied petroleum gas (LPG); (b) FW is mostly used in open fires and rustic stoves, with a total toll of 59 000 premature deaths. Interventions have centered on the dissemination of improved woodburning chimney cookstoves and increasing access to LPG through top-down government programs. These programs have focused mostly on single-fuel and stove combinations, and on the number of devices installed with little or no follow-up with local users. As a result, success has been limited and open fires have not been fully displaced in most programs. We conclude that renewed efforts are needed to ensure a sustainable and just household energy transition in the LA region. These efforts should promote integrated portfolios of options including improved practices (drying wood, use of pressure cooker), and the stacking of devices (stoves, water heaters, space heating) and fuels (biomass, other). Specifically, improved chimney woodburning stoves need to be integrated with and be an important component of these programs. Programs should adopt a user-centered perspective, beginning with the understanding of users' needs and priorities and tailoring solutions to their socio-environmental context. Innovation should be fostered through participatory methods, developing tests adapted to local circumstances and enforcing national standards. Implementation programs should focus on the adoption and sustained use of clean(er) devices and the displacement of traditional fires. Public policies should be more integrated and intersectoral seeking synergies between health, environmental, social development, and economic objectives.

1. Introduction

Approximately 2.6 billion people, mostly rural (90%) and poor in the world, currently use fuelwood (FW) and charcoal, as their principal energy source for cooking, water heating, space heating and other household energy needs. Globally, these two woodfuels account for 10% of primary energy or 31–50.5 EJ are used mostly in open fires and rustic traditional stoves, almost 50% of total wood harvesting and 2%

of global greenhouse gas (GHG) emissions (Masera *et al* 2015). The reliance on polluting devices to meet household energy needs is a leading cause of household air pollution (HAP), which results in millions of deaths worldwide and almost 59 000 deaths in Latin America (LA) and Caribbean alone for the year 2019 (http://ihmeuw.org/5fuo), while WHO's estimation for year 2016 shows almost 78 500 deaths for this region (WHO 2021). Exposure to HAP is a major avoidable health hazard that increases the risk of several communicable and non-communicable diseases (Lee *et al* 2020).

Assuring a just and fair household energy transition for these households is therefore imperative. By 'just and fair' energy transitions we mean a process that leaves no household behind and that everyone can relate to—with the outcome of providing universal access to clean and affordable energy services. To reach this goal it is essential that the benefits and costs of the transition are distributed equally, a participatory process that engages all stakeholders in the decision making, and recognizing multiple perspectives rooted in social, cultural, ethical and gender differences. The discussion on just, fair, and sustainable energy transitions has been stated as a global priority, being the subject of several Sustainable Development Goals (SDGs), specifically SDG 7 ('Energy for all') but also connected to SDGs 3 (Good health and well-being), 5 (Gender equality), and 15 (Life on land), among others. National and international programs that are designed to address these concerns have focused on transitioning households towards cleaner energy practices by encouraging access to improved woodburning cookstoves (ICS), and increasingly by promoting exclusive use of other fuels, such as liquefied petroleum gas (LPG), electricity, biogas, and other options. However, efforts have not been entirely successful—both in terms of the financial resources committed globally and the program's effectiveness. As a result, the targets are not expected to be realized in 2030 as planned, particularly within the world's poorest regions and populations (World Bank 2021).

In this paper we review the status of the so-called residential energy transition within rural LA households. The paper is timely and needed for several reasons. First, despite a long and rich experience of household energy programs within LA there has not been a recent review covering the whole region (see for example (Wang *et al* 2013) for Central America and Mexico). Second, LA is unique in that—while not comprising a large share of the global population—the energy-transition is much more advanced than in other regions. So, lessons from LA could be of great value to other regions. Also, biomass cooking technology has centered on the development of chimney stoves, some of which comply with WHO targets in terms of health impacts. There has also been a rich array of experiences, detailed studies on health, energy and environmental impacts of stove interventions, and public policies from which to reflect and learn to improve future actions and programs.

In the next sections we will review the current situation of household energy use in LA, discuss the main findings of existing studies on health and environmental impact of residential solid biomass use, and review the main cookstove implementation programs conducted within the region. We will then propose a series of strategic actions to cope with the present challenges.

2. Methods

We performed a scoping review to provide an overview of the available research evidence with a focus on the range of content identified. We examined the literature on the health and environmental impacts of household FW use for cooking in rural LA and the documented household energy programs. We identified relevant studies through an electronic database search (language English), adding other publications identified in reference lists and hand searches, and the authors knowledge of gray literature as part of the Red Latinoamericana y del Caribe de Cocinas Limpias (languages Spanish and English). We searched the electronic database PubMed using the following terms: fuels and devices (cooking, HAP, solid fuel, FW, stove, improved stove, stacking, LPG, gas), process and impact areas (implementation, adoption, exposure, health, emission, climate change, performance) and countries (Mexico, Guatemala, Honduras, El Salvador, Nicaragua, Belize, Panama, Costa Rica, Colombia, Venezuela, Peru, Bolivia, Ecuador, Brazil, Paraguay, Chile, Guyana, Argentina, Uruguay). We selected the papers that presented a comparison between fuels and/or devices and/or a specified intervention. The papers not including such a comparison were dropped. Most of the gray literature refers to the description of the country's household energy use profile or the implementation of household energy programs. We selected the main topic for each selected publication (implementation, performance, adoption, use, exposure, health, emissions, climate change, deforestation). The expert authors for each topic reviewed the publications (AS, BO, JAE, LAS, MS, VB, VR) and extracted the information in a previously designed data charting form. All authors reviewed the data charting form to discuss the findings after completing information when necessary. As shown in figure 1, we extracted information from 124 articles and 19 reports (supplementary information in Schilmann 2021).

Figure 1. Flow diagram of articles selected for the scoping review.

3. Current household energy use patterns

FW is still an important household energy source for cooking, water and space heating and other uses in LA. Specifically, rural communities are highly reliant on biomass, exclusively or in conjunction with LPG, to cover their main energy needs. There are no reliable statistics about the extent of FW users in LA, existing estimates range from 70–90 million exclusive users (SEGIB 2021) to 160 million users (GACC 2014) including both exclusive FW users and users that combine FW with other fuels for cooking and space heating. Rural FW users in several LA countries account for 80%–100% of their rural population, with large differences among countries—ranging from almost 100% of users for Bolivia and Nicaragua, to 55% of users for Panama and 25% of users for Costa Rica (Wang *et al* 2013). Peri-urban FW use, generally mixed with LPG, is also reported in the region ranging from 20% to almost 40% of this sector (Serrano-Medrano *et al* 2014, Ruiz-Mercado and Masera 2015, Garland *et al* 2018, Gould *et al* 2020b). FW is generally burned in traditional devices such as three-stone fires (TSFs), U-shaped stoves, and in poorly ventilated kitchens (Serrano-Medrano *et al* 2014, Garland *et al* 2018, Williams *et al* 2020a, Gould *et al* 2020b).

FW use has proved very resilient either as exclusive fuel or increasingly in combination (or *stacking*) with LPG despite the prolonged access to this latter fuel in some countries (Serrano-Medrano *et al* 2014, Ruiz-Mercado and Masera 2015, Gould *et al* 2018). Also, the scattered nature of rural settlements and the low purchasing power of most rural households has limited the penetration of LPG. Additionally, to cost and access restrictions, reliance on FW use patterns is associated with culinary, convenience, economic and cultural practices. For instance, the preparation of traditional meals based on corn like *tortillas* in Mexico, or the preparation of potato-based dishes in South American countries like Peru, Bolivia, and Ecuador (Ruiz-Mercado and Masera 2015, Gould *et al* 2018, 2020b).

Furthermore, space heating is also an important end use in rural communities located in cold regions and living space heating is the main FW use in countries such as Chile and Argentina (Schueftan *et al* 2016, Cardoso and González 2019). The use of FW to heat water for bathing and cooking food for animals, lighting of the home, drying of clothes, smoking of food, discarding of waste, keeping away insects and other animals from households, as well as when cooking for large number of people have also been widely reported in the literature (Ruiz-Mercado and Masera 2015, Gould *et al* 2018, 2020b).

The intensity, importance and studies regarding FW use within the residential sector varies among LA countries as shown in table 1 and figure 2.

4. Household energy transition programs and their impacts

4.1. Implementation programs

In LA, programs to foster the transition to cleaner and more sustainable energy for cooking have adopted various models and implementation scales. Improved woodburning cookstoves (ICS) and clean fuels have been promoted mostly to reduce FW consumption and deforestation, to mitigate GHG emissions and to reduce health risks in rural areas aiming to improve the life quality of local people (Troncoso *et al* 2007, Berrueta *et al* 2008, 2017, Ghilardi *et al* 2009, Wang *et al* 2013).

In this review we identified 30 programs from 11 countries, half of them implemented at the national or regional level, the other 11 at the local level and the remaining 3 represent research projects (table 2). Most programs have disseminated ICS of various models: on-site construction, portable or semi-portable; five have promoted the use of LPG through devices and subsidies; Haiti and Guyana have simultaneously disseminated two technologies: ICS + LPG stoves; and solar stoves + ICS respectively; Ecuador has a program of induction electric stoves (Gould *et al* 2018).

Table 1. General characteristics of household fuelwood use in selected Latin American countries.

Country	Number/percentage of users/households using fuelwood	Dominant fuel	Secondary fuel	Fuelwood consumption (kg cap^{-1} yr^{-1})	Observations
Brazil (Gioda 2019)	About 30 million people depend on firewood as a household energy source. Fuelwood is used by 17%–87% of households in the Brazilian rural sector (especially by rural families in the Northeast and indigenous communities) but it can also reach up to 38% of households in specific cities.	-LPG (National level and urban sector) -Fuelwood (Rural—Northeast and Indigenous communities)	-Fuelwood (National level) -LPG (Rural—Northeast mainly)	600–780	Additionally, a high percentage of households use LPG and firewood simultaneously (60%–90%). Fuelwood is mostly used for cooking.
Ecuador (Gould et al 2018, Gould et al 2020b)	Despite more than 98% of the households in the study reported using LPG for cooking, about 40% also reported using firewood as a secondary option to LPG[b].	-LPG (In the study region)	-Fuelwood (In the study region)	N/A	Firewood use has proved resilient despite the existence of long-term subsidies to facilitate the transition from cooking with biomass to cooking to LPG[a].
Guatemala (Pachauri et al 2018)	About 90% of the rural households, and 50% of urban households use solid biomass and stoves.	-Fuelwood (National level and rural sector)	-LPG (National level)	1033	The residential sector demands about 98% of the biomass energy consumption in the country.
Honduras (Garland et al 2018)	52% of the population use firewood mainly for cooking and heating. Firewood for cooking is more used by the rural population (89%) than by its urban counterpart (24%).	-Fuelwood (National level and rural sector)	-LPG (National level) Fuelwood (Urban sector)	1000 (rural) 500 (urban)	N/A
Mexico (Serrano-Medrano et al 2014, INEGI 2018)	About 28 million people use fuelwood as a primary or secondary fuel for cooking[a]. Country wise, 67% of rural households and 16% of urban households cook with fuelwood.	-Fuelwood (Rural sector) -LPG (National level and urban sector)	-LPG (Rural sector) -Fuelwood (National level and urban sector)	770 (550–1100)	Fuelwood accounts for almost 40% of total residential energy consumption in the country[b].
Nicaragua (Pachauri et al 2018)	97% of the rural population in Nicaragua (for cooking).	-Fuelwood (National level and Rural sector)	N/A	927	Nicaragua is one of the poorest countries in Central America.
Peru (Pollard et al 2018)	Over 80% of rural households use biomass as their primary fuel source to meet residential energy needs.	-Fuelwood (Rural sector)	LPG (Rural sector)	N/A	N/A

N/A: not available information or no additional observations from the reviewed article.

National programs for the transition to clean energy for cooking were identified in seven countries: National Program of Efficient Stoves for cooking with FW in Colombia (PAHO 2015b); National LPG Subsidy Program in Ecuador (Gould et al 2018); Social Investment Fund (SIF) in Guatemala (Bruce et al 2004); Mirador and Adhesa Project in Honduras (PAHO 2016); special climate change

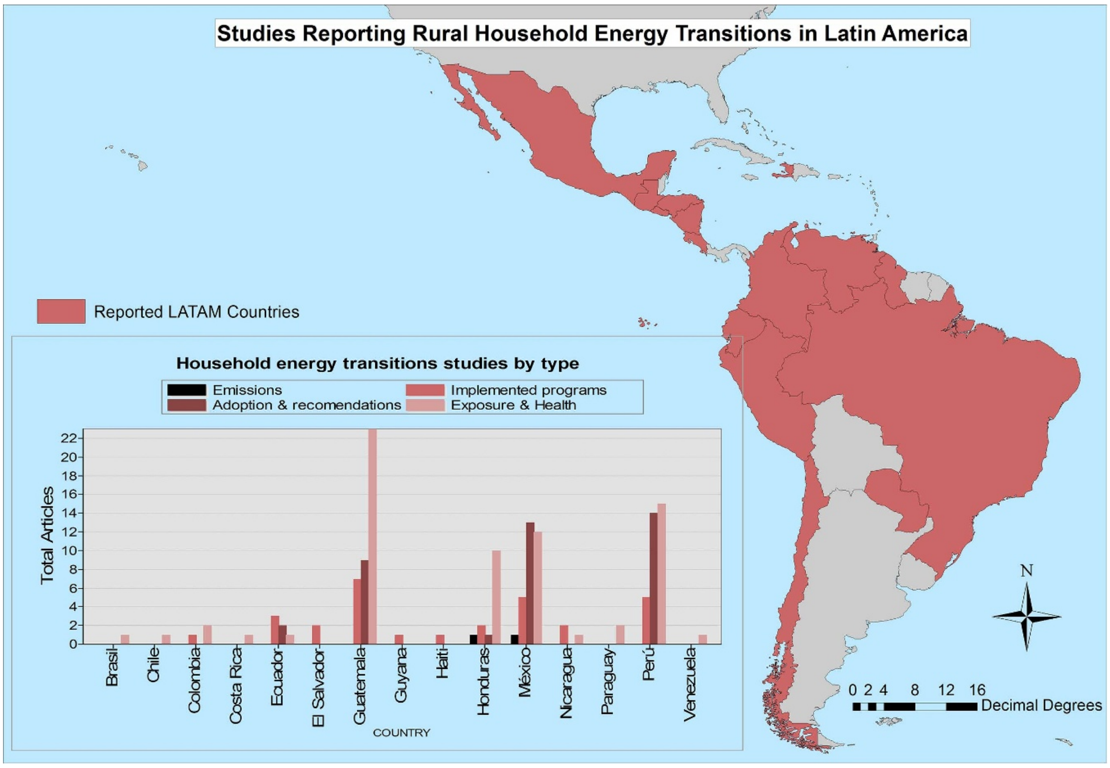

Figure 2. Studies reporting rural household energy transitions in Latin America.

plan/program of attention to priority areas in Mexico (PAHO 2012c); Mifogón in Nicaragua (PAHO 2015e); National Program Together (Fitzgerald *et al* 2012), for a Peru without smoke and the Social Inclusion Fund for energy in Peru (PAHO 2015f). Of these, five programs are implemented by the government and six are implemented by the government and NGOs.

Of the fifteen small-scale programs, five have been implemented with the exclusive participation of NGOs (Alvarez *et al* 2004, Masera *et al* 2007, García-Frapolli *et al* 2010, Ludwinski *et al* 2011, PAHO 2015c, 2015e, Hartinger *et al* 2016); five by NGOs in collaboration with governments, international agencies and/or private companies (Alvarez *et al* 2004, PAHO 2012a, 2015a, ADRA 2013); three are research projects (Smith *et al* 2010, 2011, Thompson *et al* 2018b, Checkley *et al* 2021) and two have been implemented exclusively by the government (Troncoso *et al* 2019).

Of all the programs, 13 report carrying out training on the use of technologies prior to installation, of which 11 also report performing follow-up and maintenance (Alvarez *et al* 2004, Masera *et al* 2007, García-Frapolli *et al* 2010, Smith *et al* 2010, 2011, Ludwinski *et al* 2011, PAHO 2015a, 2015b, 2016, Hartinger *et al* 2016, Thompson *et al* 2018b, Weinstein *et al* 2020, Checkley *et al* 2021).

Local Central American entrepreneurs have been very important in stove innovation, oftentimes with external support. However, as in the whole LA region, efforts in Central America have not transcended into a scale economy or self-sustaining market for improved stoves; indeed, the region is still far from forming a large-scale commercial stove market (Wang *et al* 2013).

4.2. Stove and clean fuel adoption and stacking

While most programs have focused on the number of stoves installed, no stove program can achieve its goals unless people adopt the stoves and continue using them on a long-term basis (Ruiz-Mercado *et al* 2011). We identified 53 articles with relevant information regarding the adoption and stacking of stoves and fuels in Argentina, Brazil, Chile, Colombia, Ecuador, Guatemala, Honduras, Mexico, Peru, Paraguay, Uruguay and Venezuela (supplementary information in Schilmann 2021). Of these, 39 articles gave specific data on adoption and all of them reported stacking of fuels and technologies (table 3).

Factors that influence adoption include sociocultural aspects ($n = 19$), like traditions, symbolic aspects related to food or to local uses of FW (Mazzone *et al* 2021); addressing users' preferences and needs ($n = 11$), like perceived differences in flavor and nutrition of food prepared in different stoves (Hollada *et al* 2017); follow up after stove installation ($n = 13$), to guarantee optimum stove performance and also to actually get the benefits of stove implementation programs (Masera *et al* 2005); the previous use of other technologies or fuels ($n = 6$), for example, in the case of the Patsari Stove an important factor for adopting the stove was user's previous experience

Table 2. Improved cookstoves and clean fuel implementation programs in Latin America.

Country	Program	Type of program (implementer)	Program financer	Level of intervention	Stove type	Num. of stoves	User participation	Training	Follow up and maintenance
Bolivia (PAHO 2015a)	Cookstoves for a better life; 100 000 smoke-free households in Bolivia	Government program/Private companies/NGOs	Government/private companies/NGOs	National	ICS, *in situ* construction	82 500	Yes	Yes	Yes
Colombia (PAHO 2015b)	Programa Nacional de Estufas eficientes para cocción con leña	Government program/NGOs	Government/private companies/NGOs	National	ICS, several models	28 238	NI	Yes	Yes
Ecuador (ADRA 2013)	Energización Rural en Comunidades de Guano y Pujilí, a Través de la Implementación de Cocinas Mejoradas	Government program/private companies/NGOs	Government/private companies/NGOs	Community	ICS, plancha	800	Yes	NI	NI
Ecuador (Gould *et al* 2018)	National LPG Subsidy Program	Government program	Government Program Subsidy	National	LPG stoves/LPG	NI	NI	NI	NI
Ecuador (Gould *et al* 2018)	Energy Efficiency Program for Cooking	Government program	Government Program Subsidy	National	Induction stoves	NI	NI	NI	NI
El Salvador (PAHO 2012a)	El Salvador Ecocina	Private companies/NGOs	Private companies/ NGOs/users	National	ICS, portable	11 170	Yes	NI	NI
El Salvador (PAHO 2012a)	El Salvador Turbococina	Government program/private companies/NGOs	Government/private companies/NGOs	Community (schools)	ICS, portable	1200	Yes	Yes	NI
Guatemala (Bruce *et al* 2004)	SIF (Social Investment Fund)	Government program	Government/ international agencies	National	ICS	90 000	Yes	Yes	No
Guatemala (Alvarez *et al* 2004)	Tezulutlán	NGOs, international agency, Government	International agency	Community	ICS, *in situ* construction	4129	Yes	Yes	Yes
Guatemala (Alvarez *et al* 2004)	Intervida	NGOs	NGOs	Village	ICS, *in situ* construction	9000	Yes	Yes	Yes
Guatemala (Ludwinski *et al* 2011)	Field experiment in Guatemala	NGOs	NGOs	Village	ICS, portable	28	Yes	Yes	Yes
Guatemala (PAHO 2015c)	Onil stoves dissemination	NGOs	NGOs/government/ microcredits	National	ICS, portable	110 000	NI	NI	NI
Guatemala (El-Saghir Selim 2013, Thompson *et al* 2018a)	NACER II	Research project		Small scale	LPG stoves/LPG	50	Yes	Yes	Yes
Guatemala (World Bank 2011)	RESPIRE	Research project		Community	ICS	534		Yes	Yes
Guyana (PAHO 2012b)		Government/international agencies	International agencies	Community	Solar cooking stoves, ICS	600	NI	NI	NI

(Continued.)

Table 2. (Continued.)

Country	Program	Type of program (implementer)	Program financer	Level of intervention	Stove type	Num. of stoves	User participation	Training	Follow up and maintenance
Haiti (PAHO 2015d, Phanol and Pierre 2015)	Improved Cooking Technology Program (ICTP)	International agencies/private companies/government	Users/microcredits	National	ICS/LPG stoves	NI	NI	NI	NI
Honduras (PAHO 2016)	Proyecto Mirador	Government program/NGO	NGOs/users	National	ICS, *in situ* construction	85 000	Yes	Yes	Yes
Honduras (Clark *et al* 2010)	Adhesa	Government program/NGO	NGOs/users	National	ICS, *in situ* construction	30 000	Yes	Yes	Yes
Mexico (INSP 2016)	Programa de estufas ecológicas	Government program	Government	Provincial	ICS, several models	60 000	No	No	No
Mexico (García-Frapolli *et al* 2010, Masera *et al* 2007)	Patsari Project	NGO	NGO/users/ microcredits	Village	ICS, *in situ* construction	1500	Yes	Yes	Yes
Mexico (PAHO 2012c)	Plan Especial de Cambio Climático/Programa de empleo temporal/Programa de atención a Zonas Prioritarias	Government program/NGOs	Government	National	ICS, several models	561 000	No	No	No
Mexico (Troncoso *et al* 2019)	Ciudades Rurales de Chiapas	Government program	Government/users subsidies	Village	LPG stoves/LPG	NI	NI	NI	NI
Mexico (Troncoso *et al* 2019)	Municipality program	Government program	Government	Village	ICS	NI	NI	NI	NI
Nicaragua (Terrado and Eitel 2005, PAHO 2015e)	ESMAP	NGO	NGO/users	Village	ICS	1300	NI	NI	NI
Nicaragua (PAHO 2015e)	Mifogón Program	Government program/ NGO	NGO/users/ government	National	ICS several models	25 000	Yes	NI	No
Peru (Checkley *et al* 2021)	Intervention project	Research project	Project/users subsidies	Community	LPG stoves/LPG	180	Yes	Yes	Yes
Peru (Fitzgerald *et al* 2012)	Juntos National Program	Government program	Government	National	ICS	NI	NI	NI	NI
Peru (PAHO 2015f)	Por un Peru sin humo	Government program	Government/carbon credits	National	ICS	360 000	NI	NI	NI
Peru (PAHO 2015f)	Fondo de inclusión social energético	Government program	Government/NGOs/ users subsidies	National	LPG stoves/LPG	491 000	NI	NI	NI
Peru (Hartinger *et al* 2016)	Optima Program	NGO	Project	Community	ICS	93	Yes	Yes	Yes

NI: no information.

Table 3. Stove and fuel stacking patterns within Latin American households.

Country	References	Type of study	Type of stacking	Percentage of households stacking fuels and stoves (%)	Explanatory comments
Brazil	(Gioda 2019, Mazzone *et al* 2021)	QL/QN	TSF/ICS/LPG Electrical	60%–90%	A high percentage of households use LPG and fuelwood simultaneously (60%–90%). The introduction of 'ready-meals' and processed food also contributes to the increased usage of LPG over firewood.
Chile	(Shupler *et al* 2020)	QN	ICS/LPG	36%	Fuelwood was the primary fuel in 91% of rural households surveyed, and its main use is for space heating. Stacking with LPG was present in 36% of cases. Manufactured chimney stoves were most prevalent.
Colombia	(Shupler *et al* 2020)	QN	TSF/LPG	39%	In the rural case study surveyed, fuelwood was the primary fuel in 65% of households, and LPG in 35%. Stacking was present in 39% of households. Open fires were the main traditional cooking device.
Ecuador	(Gould *et al* 2018, Shankar *et al* 2020, Gould *et al* 2020a, Gould *et al* 2020b)	QN	TSF/LPG ICS/electrical	36%–81%	LPG is the main rural cooking fuel and TSF (and to a lesser extent induction stoves) are used for specific purposes. In the studies reviewed stacking was found in 36%–81% of households.
Guatemala	(Albalak *et al* 2001, Bruce *et al* 2004, Schei *et al* 2004, Mccracken *et al* 2011, Thompson *et al* 2018a)	QL/QN	TSF/ICS/LPG TSF/ICS TSF/ICS/LPG/electrical	10%–30%	Fuelwood is the main cooking fuel in rural areas. The studies reviewed reported higher acceptance of ICS than LPG; TSF are used for more intensive tasks, followed by ICS. LPG used for quick tasks. Stacking ranged from 10% to 30% of households depending on the study and consisted in different combinations of fuels and technologies.
Honduras	(Young *et al* 2019)	QN	TSF/ICS/LPG	42%	Fuelwood is the main cooking fuel; stacking was present in 42% of households surveyed (18% TSF/LPG and 24% ICS/TSF).
Mexico	(Masera *et al* 2005, Zuk *et al* 2007, Armendariz *et al* 2008, Romieu *et al* 2009, Pine *et al* 2011, Schilmann *et al* 2015, Ruiz-Mercado and Masera 2015, INSP 2016, Catalán-Vázquez *et al* 2018, Schilmann *et al* 2019, Troncoso *et al* 2019, Estévez-García *et al* 2020)	QL/QN	TSF/ICS/LPG/ microwaves	10%–80%	Fuelwood is the dominant rural cooking fuel, with increasing penetration of LPG (10%–80% of rural households depending on the region). Most people cook with open or semi-closed fires. Making tortillas—including the preparation of nixtamal—represents up to 50% of total household fuelwood use. There is an increasing—but still limited—adoption of ICS. LPG complements rather than substituting fuelwood and is used mostly for the less intensive cooking tasks. Stacking between TSF/ICS; ICS/LPG, LPG/TSF or even the three stoves together is very common; TSF are rarely completely abandoned. There is an increasing use of microwaves for warming food in the wealthiest households.

(Continued.)

Table 3. (Continued.)

Country	References	Type of study	Type of stacking	Percentage of households stacking fuels and stoves (%)	Explanatory comments
Paraguay	(Troncoso *et al* 2018, Tagle *et al* 2019)	QL/QN	TSF/metal braziers for charcoal/LPG/ electric—hot plate	n.a.	The use of woodfuels, particularly charcoal, for cooking is very common in rural Paraguay, with estimates ranging from 40% to 74% of rural households depending on the study. Both fuelwood and charcoal are used on open kitchens and on rustic devices without chimneys (84% of households). Stacking with LPG is common, while electricity is seldom used as the main cooking fuel.
Peru	(Pollard *et al* 2014, Hartinger *et al* 2016, Wolf *et al* 2017, Pollard *et al* 2018, Díaz-Vásquez *et al* 2020, Shankar *et al* 2020, Williams *et al* 2020a, Williams *et al* 2020b, Checkley *et al* 2021)	QL/QN	TSF/ICS/LPG	20%–100%	Fuelwood is the dominant cooking fuel in Peru. Penetration of LPG has been increasing, particularly due to government programs that have provided different types of subsidies to this fuel. Stacking is common, ranging from 20% to 100% of households, depending on the case study. In intervention studies devoted to promoting LPG and ICS it was observed that all households stacked LPG with TSF; 85% stacked clean stoves; and more than 50% stacked ICS with TSF after the intervention. ICS were found to be preferred and more intensively used than LPG.
Venezuela	(Kraai *et al* 2013)	QN/QL	TSF/LPG	30%	In the case study of a Native American village in Venezuela, fuelwood was reported as the main cooking fuel. 30% of households stacked TSF/LPG; 20% cooked with LPG alone.

with elevated stoves (Romieu *et al* 2009); and functional aspects of the technology ($n = 14$), i.e. including 'add-on' benefits to the stove that could produce small amounts of electricity to charge cell phones, sanitize water, or power compact fluorescent lights (CFL) (Bielecki and Wingenbach 2014) (table 4). A third of studies show economic variables ($n = 13$) as important predictors of adoption. These studies emphasize that economic reasons—like fuel or stove price, household incomes—are one of the main reasons for using traditional open fires (Thompson *et al* 2011) and therefore, economic incentives are recommended to facilitate the adoption of efficient stoves (Masera *et al* 2005). Regarding LPG, it is found that income is not a good predictor of adoption but rather of sustained use (INSP 2016) and that the high cost of LPG is one of the main barriers to its adoption (Wang *et al* 2013, Troncoso *et al* 2019). Table 4 lists other factors that are also associated with stove adoption.

Recommendations to encourage stove adoption include: that program participants should contribute with a payment or in-kind contribution (ADRA 2013, Gómez *et al* 2014), that the benefits from cleaner cooking should be clearly explained to women and men or other members of the household (Hollada *et al* 2017, Thompson *et al* 2018a, 2018b), that the approaches should be comprehensive rather than individual (Masera *et al* 2005, Bielecki and Wingenbach 2014, Rhodes *et al* 2014, Hartinger *et al* 2016) and that user participation is fundamental (Córdova and Castro 2012, ADRA 2013, Mazzone *et al* 2021).

As Mazzone *et al* (2021) states: 'The ethical and symmetrical energy transition requires decentralized strategies to understand, consider and include the cultural capital of local communities and their direct participation in the decision-making processes of the energy transition.'

4.3. Global environmental impacts

While important in specific areas or 'hot spots' in terms of forest degradation, household FW use in the region is mostly renewable and, in principle, solid biomass resources can be managed sustainably, particularly if actions are taken to reduce FW demand in

Table 4. Factors related to adoption and use of clean energy options in Latin American households.

Main factors	Examples	Countries (references)
Sociocultural factors	Traditions and symbolic aspects related to fire, food, and local uses of fuelwood, dominant gender roles (e.g. who decides about the purchase of new fuel/stove).	Latin America (Córdova and Castro 2012); Central America (Wang *et al* 2013); Brazil (Mazzone *et al* 2021); Ecuador (ADRA 2013); Guatemala (Schei *et al* 2004, Bielecki and Wingenbach 2014, Thompson *et al* 2018a, Williams *et al* 2020b); Mexico (Pine *et al* 2011, Ruiz-Mercado and Masera 2015, INSP 2016, Catalán-Vázquez *et al* 2018, Schilmann *et al* 2019, Estévez-García *et al* 2020); Peru (Hartinger *et al* 2013, Rhodes *et al* 2014, Hollada *et al* 2017, Wolf *et al* 2017, Williams *et al* 2020b)
User preferences and needs	Perceived differences in taste and nutrition associated to food prepared in different stoves; ranking of fuel savings, vs savings in cooking time vs smoke reduction in the kitchen; ease in lighting the fire or repair the stove.	Latin America (Córdova and Castro 2012); Central America (Wang *et al* 2013); Guatemala (Bielecki and Wingenbach 2014, Williams *et al* 2020a); Mexico (Masera *et al* 2005a, Ruiz-Mercado *et al* 2011, Ruiz-Mercado and Masera 2015, Catalán-Vázquez *et al* 2018); Peru (Rhodes *et al* 2014, Hollada *et al* 2017, Williams *et al* 2020b)
Follow up after stove installation	Visits to users to assuring adequate stove performance, answering users doubts or identifying problems not realized during stove installation.	Latin America (Córdova and Castro 2012); Ecuador (ADRA 2013, Gould *et al* 2020b); Guatemala (Bielecki and Wingenbach 2014, Williams *et al* 2020b); Mexico (Masera *et al* 2005, Ruiz-Mercado *et al* 2011, Smith *et al* 2011, Ruiz-Mercado and Masera 2015, Catalán-Vázquez *et al* 2018); Peru (Wolf *et al* 2017, Díaz-Vásquez *et al* 2020, Williams *et al* 2020b)
Previous use of other fuels and technologies	Families using TSF and LPG adopted ICS more easily than families using only TSF; also, women used to cook on elevated TSF adopted ICS more easily than those cooking kneeling on the floor.	Mexico (Romieu *et al* 2009, Pine *et al* 2011, Ruiz-Mercado and Masera 2015, Catalán-Vázquez *et al* 2018); Peru (Hollada *et al* 2017, Wolf *et al* 2017)
Functional aspects of the technology	Versatility of the proposed stove to satisfy the different user's needs; ability to provide additional benefits (e.g. stoves that could produce small amounts of electricity to charge cell phones, stoves that can provide hot water using residual heat).	Chile (Gómez *et al* 2014); Guatemala (Albalak *et al* 2001, Bruce *et al* 2004, Schei *et al* 2004, Bielecki and Wingenbach 2014, Thompson *et al* 2018a, Williams *et al* 2020b); Mexico (Ruiz-Mercado and Masera 2015, INSP 2016, Catalán-Vázquez *et al* 2018, Estévez-García *et al* 2020); Peru (Rhodes *et al* 2014, Wolf *et al* 2017, Williams *et al* 2020b)
Economic variables	Fuel and stove price relative to household incomes, subsidies to stove/fuels; financial incentives or facilities to purchase stoves (the relative weight of each factor depends on the type of stove and local circumstances).	Chile (Gómez *et al* 2014); Ecuador (ADRA 2013, Gould *et al* 2020b); Guatemala (Thompson *et al* 2011, Rajkumar *et al* 2018, Williams *et al* 2020a); Mexico (Masera *et al* 2005, Troncoso *et al* 2019); Peru (Hartinger *et al* 2013, Hollada *et al* 2017, Wolf *et al* 2017, Williams *et al* 2020a, Williams *et al* 2020b)
Focalized messages for different population groups (women/men/other family members)	Stove adoption increased when messages about health benefits of clean stoves were clearly stated and understood by all family members.	Guatemala (Thompson *et al* 2018a, Thompson *et al* 2018b); Mexico (INSP 2016); Peru (Hollada *et al* 2017)
Comprehensive approaches	Programs including multiple stove and fuel options, including options to cover the diverse uses of open fires (cooking, water heating, space heating), or improved cooking practices (e.g. using pressure cookers).	Brazil (Mazzone *et al* 2021); Guatemala (Bielecki and Wingenbach 2014); Mexico (Masera *et al* 2005, Estévez-García *et al* 2020); Peru (Rhodes *et al* 2014, Hartinger *et al* 2016)
Participation	Involvement of users—specifically local women—in the different phases of stove dissemination programs, from the design, implementation to follow up.	Latin America (Córdova and Castro 2012); Brazil (Mazzone *et al* 2021); Ecuador (ADRA 2013); Mexico (INSP 2016, Estévez-García *et al* 2020)

Table 5a. CO and $PM_{2.5}$ total emission factors during water boiling test (WBT), controlled burning cycle (CBC), controlled cooking test (CCT) and uncontrolled cooking test (UCT).

		Total emission factor		
Test type	Description	$PM_{2.5}$ ($g\ kg^{-1}$) fuelwood	CO ($g\ kg^{-1}$) fuelwood	Reference
CCT	Patsari simulated kitchen ($n = 6$)	1.7 ± 0.1	47.0 ± 2.1	[1]
CCT	U-type simulated kitchen ($n = 6$)	3.0 ± 0.3	62.0 ± 14.6	[1]
CBC	Patsari simulated kitchen ($n = 5$)	1.6 ± 0.4	46.7 ± 3.1	[1]
CBC	U-type simulated kitchen ($n = 5$)	6.0 ± 0.8	70.0 ± 5.2	[1]
WBT	Open fire simulated kitchen ($n = 6$)	5.4 ± 0.4	39.7 ± 1.9	[2]
WBT	Mud–cement Patsari simulated kitchen ($n = 6$)	5.3 ± 0.9	81.7 ± 9.5	[2]
WBT	Open fire in-home ($n = 7$)	4.1 ± 0.9	25.7 ± 4.4	[2]
WBT	Mud–cement Patsari in-home ($n = 7$)	3.1 ± 0.5	58.3 ± 7.1	[2]
WBT	Brick Patsari in-home ($n = 4$)	2.3 ± 1.4	16.3 ± 8.2	[2]
UCT	Open fire in-home ($n = 8$)	9.7 ± 1.2	81.7 ± 4.9	[2]
UCT	Mud–cement Patsari in-home ($n = 9$)	5.9 ± 0.8	65.3 ± 3.9	[2]
UCT	Brick Patsari in-home ($n = 4$)	1.8 ± 1.0	18.7 ± 12.8	[2]
UCT	Chimney cookstoves ($n = 27$)	4.5^*	76.0^*	[3]
UCT	Traditional cookstoves ($n = 13$)	8.2^*	118.0^*	[3]

The devices were tested in Mexico and Honduras, Medina *et al* (2017) [1], Johnson *et al* (2008) [2], Roden *et al* (2009) [3]. Notes: the results apply only to plancha-type stoves used in Mexico and Central America. Variability is expressed as ±SD. * Variability is not available.

the most critical areas. Bailis *et al* (2015) performed a spatial explicit assessment of pan-tropical woodfuel supply and demand to estimate the extent in which woodfuel demand surpasses regrowth (Bailis *et al* 2015). They estimated that in LA between 19% and 31% of woodfuel harvested was unsustainable, a figure which was later confirmed by national studies such as in Serrano-Medrano *et al* (2019). Woodfuel is mostly locally available, and it is extracted not only from the surrounding forest but from shrubs, agriculture, pruning residues, dead wood and from commercial wood harvesting residues. Very rarely this extraction is done by totally clearing the forest areas such as most commercial timber practices.

Regarding global environmental impacts, we identified only eight articles with detailed information on greenhouse and other air pollutants emissions for chimney cookstoves and open fires in LA. Mexico and Honduras are the countries where field and laboratory measurements on pollutant emissions have been carried out, including measurements of carbon monoxide (CO) and particulate matter (PM), and more recently measurements of black carbon and methane (Padilla-Barrera *et al* 2019). Johnson *et al* (2008, 2009), estimated a 25% reduction in products from incomplete combustion comparing improved cookstoves with the traditional open fire, and also estimated that methane emitted from open fires contributes to 45% of CO_2e emissions (excluding CO_2). Plancha-type stoves commonly used in Mexico and Central America have been estimated to lead to a reduction of 44%–55% in CO and $PM_{2.5}$ emissions in controlled water boiling tests, and 65% in a typical cooking cycle test for the Mexican Highlands, with regards to TSF (EkouevI and Tuntivate 2012, Medina *et al* 2015, 2017). In addition to a reduction in total emissions, plancha-type chimney stoves ventilate on average $95 \pm 3\%$ of $PM_{2.5}$ and $99 \pm 1\%$ of CO emissions (Ruiz-García *et al* 2018). Unfortunately, at the moment, there are no more studies about fugitive emissions from chimney cookstoves used in LA, which are essential to determine the actual contribution of these stoves to indoor air pollution. Scenarios modeling the country-scale implementation of ICS and LPG programs within Mexican rural areas have shown a potential GHG emissions mitigation ranging from 30% to 35% of business as usual (BAU) emissions from open fires by the year 2030 (Serrano-Medrano *et al* 2018).

Table 5a summarizes CO and $PM_{2.5}$ total emission factors for cookstoves estimated in Central America and Mexico. Table 5b shows that emission rates from ICS can meet the WHO Air Quality Guidelines for both pollutants. So far, only Mexico has included the measurement of fugitive and chimney CO and $PM_{2.5}$ emissions from cookstoves within the national stove testing standard. The lack of specialized testing equipment within the existing regional Stove Test Centers is one of the reasons why local country standards and regulations have not included the measurement of GHG gases and short-lived climate pollutants.

4.4. Exposure and health impacts

We reviewed 71 articles with information on exposure and/or health outcomes carried out in 13 countries in LA as shown in figure 2 (supplementary information in Schilmann (2021)). Guatemala had the highest number of studies ($n = 23$), followed by Peru ($n = 15$), Mexico ($n = 13$), Honduras ($n = 10$), Colombia and Paraguay ($n = 2$), and Bolivia, Brazil,

Table 5b. CO and $PM_{2.5}$ fugitive emission rates during water boiling test (WBT).

Test type	Stove	Fugitive emissions $PM_{2.5}$ ($mg\ min^{-1}$)	CO ($mg\ min^{-1}$)	Reference
WBT	Onil in lab ($n = 15$)	2.1 ± 0.3	12 ± 3.1	[4]
WBT	Ecostufa in lab ($n = 15$)	3.5 ± 0.5	5 ± 1.3	[4]
WBT	Mera-Mera in lab ($n = 15$)	2.4 ± 0.4	20 ± 5.2	[4]
WBT	Patsari in lab ($n = 15$)	3.9 ± 0.5	11 ± 2.8	[4]
WBT	Cookstoves chimney-type ($n = 60$)	3 ± 0.2	12 ± 1.5	[4]
All	Unvented intermediate emission rate target for meeting AQG (24 h, CO) and AQGs (IT-1, $PM_{2.5}$)	1.75	350	[5]
All	Vented intermediate emission rate target for meeting AQG (24 h, CO) and AQGs (IT-1, $PM_{2.5}$)	7.15	1450	[5]
WBT	Target for fugitive emission rate	2.7	133	[6]

The devices were tested in Mexico, Ruiz-García *et al* (2018) [4], WHO (2014) [5], ISO (2018) [6]. Notes: the results apply only to plancha-type stoves used in Mexico and Central America. Variability is expressed as ±SD. * Variability is not available.

Ecuador, Chile, Costa Rica, Nicaragua, and Venezuela had one publication each.

Different improved cookstove models and technologies were evaluated in LA, predominantly wood burning stoves such as Plancha, Patsari, and Justa. In addition, there were ten studies carried out on the use of LPG stoves and one on the use of electric induction stoves.

As shown in Table 6, a total of 62 studies reported direct ($n = 46$) and microenvironmental ($n = 38$) exposure measurements of different air pollutants. Direct exposure measurements were carried out using personal monitors and quantifying biomarkers in urine, blood, or exhaled air. In the microenvironment mainly PM of different sizes ($n = 44$), and CO ($n = 28$) were measured in a fixed point in the household (mainly the kitchen). In addition, the measurements of other pollutants such as black carbon, polycyclic aromatic hydrocarbons, volatile organic compounds (VOCs), and NO_2 were reported.

HAP exposure studies recognizing that ICS showed significant reductions in pollutant exposure compared to open fires were first published in Mexico (Brauer *et al* 1996) and Guatemala (Naeher *et al* 2000b, Albalak *et al* 2001), In most post-intervention measurements ($n = 56$), the ICS showed significant reductions in PM, CO, and other pollutant levels compared to open fires. However, these concentrations were above the WHO air quality guidelines (AQGs), and the reductions in indoor concentrations were lower when the ICS is in poor condition (Clark *et al* 2013b).

The health of children was assessed only in 13 papers evaluating different respiratory outcomes ($n = 8$), lung function ($n = 2$) and perinatal outcomes ($n = 3$). Two thirds ($n = 9$) of these studies reported that ICS had a significant effect on the health outcomes. Guatemala was the country with the highest number of children studies.

The health of women was assessed in 32 papers evaluating respiratory symptoms (asthma, cough, phlegm, chest wheezing, and dyspnea $n = 14$) and lung function ($n = 7$). Twenty studies reported other health outcomes: blood pressure, exhaled CO, carboxyhemoglobin, eye irritation, headache, backache, diabetes, metabolic syndrome, ST-segment depression, vascular inflammation regulators, and urinary oxidative stress DNA biomarkers.

These papers present results under different study designs including randomized controlled trials ($n = 12$), observational studies (follow up and cross-sectional $n = 42$), before-and-after studies ($n = 17$), and program impact evaluation ($n = 1$). The randomized controlled trials are the experimental epidemiological designs to evaluate the effectiveness of an intervention but can be biased if there is a differential adherence to the intervention, as has been described in sections 3 and 4.2. There are randomized controlled trial reports assessing the impact of ICS conducted in Guatemala, Honduras, Mexico, and Peru. The studies were carried out among women, children, or both population groups.

In Guatemala, the Randomized Exposure Study of Pollution Indoors and Respiratory Effects (RESPIRE) followed by the Chronic Respiratory Effects of Early Childhood Exposure to Respirable Particulate Matter Study, under the leadership of Kirk Smith, showed the benefits of the Plancha ICS on exposure (Northcross *et al* 2010), children (Heinzerling *et al* 2016) and women (Díaz *et al* 2007a, Diaz *et al* 2007b, Mccracken *et al* 2007, 2011) health outcomes, and also presented some negative results for pneumonia in children (Smith *et al* 2011), low birth weight (Thompson *et al* 2011, 2014) and women lung function (Guarnieri *et al* 2015).

In Mexico, the comprehensive evaluation of the Patsari ICS Project showed exposure reductions (Masera *et al* 2007, Zuk *et al* 2007, Armendariz *et al*

Table 6. Summary of exposure and health impacts for ICS studies in Latin America.

Outcome	Countries (references)	n (%) studies report a significant difference in the outcome
Exposure		
(a) Micro-environmental		
PM (TSP, PM_{10}, $PM_{3.5}$, $PM_{2.5}$), CO	Chile (Shupler et al 2020), Colombia (Shupler et al 2020, Martínez Vallejo et al 2021), Costa Rica (Park and Lee 2003), Guatemala (Naeher et al 2000a, Albalak et al 2001, Naeher et al 2001, Bruce et al 2004, Neufeld et al 2004, Northcross et al 2010, Smith et al 2010), Honduras (Clark et al 2009, Clark et al 2010, Benka-Coker et al 2018, Rajkumar et al 2018, Rajkumar et al 2019, Young et al 2019, Benka-Coker et al 2020, Benka-Coker et al 2021), Mexico (Brauer et al 1996, Riojas-Rodríguez et al 2001, Masera et al 2007, Zuk et al 2007, Armendariz et al 2008, Estévez-García et al 2020), Nicaragua (Clark et al 2013a), Paraguay (Tagle et al 2019), Peru (Li et al 2011, Fitzgerald et al 2012, Eppler et al 2013, Hartinger et al 2013, Commodore et al 2013a, Commodore et al 2013b, Pollard et al 2014, Helen et al 2015, Checkley et al 2021, Fandiño-Del-Rio et al 2020)	34 (87%)
Other (BC, BTX, NO_2)	Colombia (Martínez Vallejo et al 2021), Honduras (Walker et al 2020), Peru (Helen et al 2015, Checkley et al 2021, Fandiño-Del-Rio et al 2020, Kephart et al 2021)	6 (100%)
(b) Direct		
PM (TSP, PM_{10}, $PM_{3.5}$, $PM_{2.5}$), CO	Bolivia (Alexander et al 2014), Brazil (da Silva et al 2012), Chile (Shupler et al 2020), Colombia (Shupler et al 2020), Ecuador (Gould et al 2020b), Guatemala (Naeher et al 2000b, Bruce et al 2004, Neufeld et al 2004, Mccracken et al 2007, Northcross et al 2010, Smith et al 2010, Mccracken et al 2011, Thompson et al 2011, Guarnieri et al 2014, Thompson et al 2014, Guarnieri et al 2015, Heinzerling et al 2016, Grajeda et al 2020, Weinstein et al 2020), Honduras (Clark et al 2009, Clark et al 2010, Benka-Coker et al 2018, Rajkumar et al 2018,, Rajkumar et al 2019, Young et al 2019, Walker et al 2020, Benka-Coker et al 2020), Mexico (Riojas-Rodriguez et al 2011), Nicaragua (Clark et al 2013b), Peru (Li et al 2011, Eppler et al 2013, Commodore et al 2013a, Commodore et al 2013b, Helen et al 2015, Checkley et al 2021, Fandiño-Del-Rio et al 2020)	41 (91%)
Other (BC, eCO, %HbCO, PAHs, VOCs, BTX, NO_2)	Guatemala (Diaz et al 2007b, Guarnieri et al 2014, Guarnieri et al 2015, Lucarelli et al 2018, Weinstein et al 2020), Mexico (Torres-Dosal et al 2008, Riojas-Rodriguez et al 2011, Pruneda-Álvarez et al 2012, Ruiz-Vera et al 2019), Peru (Li et al 2011, Adetona et al 2013, Helen et al 2015, Li et al 2016, Checkley et al 2021, Fandiño-Del-Rio et al 2020, Kephart et al 2021)	12 (100%)
Children health		
(a) *Respiratory and other symptoms* (asthma symptoms, pneumonia, acute upper and lower-respiratory infections, symptoms related to sleep apnea)	Guatemala (Schei et al 2004, Harris et al 2011, Smith et al 2011), Mexico (Riojas-Rodriguez et al 2011, Schilmann et al 2015), Paraguay (Troncoso et al 2018), Peru (Castañeda et al 2013, Accinelli et al 2014)	6 (67%)
(b) *Lung function* (spirometry and peak expiratory flow rates)	Guatemala (Heinzerling et al 2016), Honduras (Rennert et al 2015)	2 (100%)
(c) *Other* (low birth weight, perinatal death and stillbirth)	Guatemala (Thompson et al 2011, Thompson et al 2014, Patel et al 2015)	1 (33%)
Women health		
(a) Respiratory and other symptoms	Brazil (da Silva et al 2012), Guatemala (Díaz et al 2007a, Harris et al 2011, Lucarelli et al 2018), Honduras (Clark et al 2009), Mexico (Romieu et al 2009, Riojas-Rodriguez et al 2011), Paraguay (Troncoso et al 2018), Venezuela (Kraai et al 2013)	12 (86%)

(Continued.)

Table 6. (Continued.)

Outcome	Countries (references)	*n* (%) studies report a significant difference in the outcome
(b) Lung function (spirometry, PEF)	Brazil (da Silva *et al* 2012), Guatemala (Guarnieri *et al* 2015), Honduras (Clark *et al* 2009, Rennert *et al* 2015), Mexico (Romieu *et al* 2009), Peru (Checkley *et al* 2021)	4 (57%)
(c) Other (quality life scores, hemoglobin, blood pressure, self-rated health, ST-segment depression, gene expression airway inflammation; vascular inflammation regulators, urinary stress markers, eNO, eCO, eHbCO, SpO_2 SpHbCO)	Bolivia (Alexander *et al* 2014), Guatemala (Neufeld *et al* 2004, Mccracken *et al* 2007, Díaz *et al* 2008, Ludwinski *et al* 2011, Mccracken *et al* 2011, Guarnieri *et al* 2015), Mexico (Torres-Dosal *et al* 2008, Ruiz-Vera *et al* 2019), Nicaragua (Clark *et al* 2013a), Peru (Eppler *et al* 2013, Commodore *et al* 2013b, Pollard *et al* 2014, Li *et al* 2016)	18 (75%)

Description: BC: black carbon; BTEX: benzene, toluene, ethylbenzene and xylene; CO: carbon monoxide; %COHb: blood carboxyhemoglobin; CO_2: carbon dioxide; eCO: exhaled carbon monoxide; eNO: exhaled nitric oxide; eHbCO: carboxyhemoglobin measured from exhaled breath; LPG: liquefied petroleum gas; NO_x: nitrogen oxides; PAHs: polycyclic aromatic hydrocarbons; PM: particulate matter; RSP: respirable suspended particles; SpO_2: oxygen saturation; SpHbCO: carboxyhemoglobin measured from pulse co-oximetry.

2008), and benefits for children and women in a randomized controlled trial analyzed considering the reported use of the cooking device (Romieu *et al* 2009, Schilmann *et al* 2015).

In Honduras, exposure reductions were reported for a stepped-wedge randomized trial evaluating the Justa ICS (Benka-Coker *et al* 2020). In Perú, two recently LPG stoves randomized trials (Checkley *et al* 2021, Kephart *et al* 2021) assessed exposure and health outcomes after the intervention.

5. Discussion: what have we learned?

Facilitating universal access to environmentally clean and healthy residential energy, requires considering the needs of the local population and providing comprehensive options (GACC 2014). Evidence from our review shows that, to be successful, policies and programs for improving access to clean cooking must be adapted to local economies, household fuel use patterns, traditions and users' needs and preferences (Pine *et al* 2011, Ruiz-Mercado *et al* 2011, Ramirez *et al* 2014, Catalán-Vázquez *et al* 2018, Shankar *et al* 2020). Finding the right combinations locally has been documented to accelerate scaling and thus contributing to making a difference globally (Urmee and Gyamfi 2014). The experience in LA shows that FW users respond well when ICS and other options meet the needs of a specific circumstance: when FW is purchased and is becoming increasingly expensive; when health issues are clearly understood by the whole family; when incentives are provided to lower the upfront costs of stoves; when ICS are tailored to local cooking practices, resulting in tangible fuel and time savings; and when they do not involve major changes in the dimensions of FW and cooking habits and appeal to the 'modernity' aspirations of users (Wang *et al* 2013). Results from studies carried out in India also indicate that stove adoption requires the availability of spare-parts for stove repair and maintenance, clearly communicating stove health, economic and environmental benefits to local users, and, in many circumstances, some financial incentives (Bhojvaid *et al* 2014, Pattanayak *et al* 2019).

Also, cookstove programs in almost all cases promote only one stove model. This approach prevents learning and improvement through competition and denies consumers choice. A focus on community participation and local capacity building, particularly among women, improved cookstove program outcomes and created buy-in of beneficiaries. Most cookstove programs to date have lacked 'systematic community feedback, monitoring and evaluation'.

Household energy projects and ICS programs show that households' decisions to adopt or not a stove includes their perception of stove durability and the mid-and long-term needs of maintenance, repair, or replacement to support sustained use (EkouevI and Tuntivate 2012). A follow-up study carried out in Mexico to evaluate sustained use almost a decade after an ICS program, showed that Patsari ICS had a 50% survival time of four years. After this time, more than half of the stoves installed during the initial trial failed to be used, surpassing their useful lifespan and its well-functioning, failed to reduce the exposure to HAP and consequently people went back to using the traditional stove (Wolf *et al* 2017, Schilmann *et al* 2019).

As in other World regions, access to clean fuels in rural LA mostly leads to a diverse pattern of fuel and device stacking, where traditional open fires are seldom entirely replaced. Also, as LPG is not always an affordable fuel for the rural poor, chimney ICS together with improved cooking practices constitute a more realistic and effective approach for communities with low purchasing power. Also, high subsidies to LPG distort markets, preventing consumer feedback from reaching manufacturers and retailers, and thwarting efforts at sustainable commercialization. It is remarkable that only few studies have assessed best ways of disseminating stoves, and none have explicitly addressed the possibility of 'clean stacking options'. We argue that good implementation strategies should embark on context evaluations—identifying the needs and habits of the target groups—and co-creating ICS. This means that there is no one-size-fits-all approach. Furthermore, public awareness needs to be created, demonstrations about correct use of the ICS should be given and maintenance should be assured as shown in other regions (Thakur *et al* 2019).

While there is very limited data regarding GHG and aerosol emissions from residential solid biomass use in the LA region, our review shows that replacing an open fire with a well-designed chimney ICS may reduce from three to five times overall aerosol emissions and from 95% to 99% fugitive emissions (Johnson *et al* 2009, Ruiz-García *et al* 2018). The use of chimney ICS for cooking could also represent a solution to mitigate short-lived climate pollutants like methane and black carbon. Large GHG emissions savings could be obtained by replacing TSF with chimney ICS in rural areas of LA, and additional health benefits if ICS are stacked with LPG (Serrano-Medrano *et al* 2018, Medina *et al* 2019). Environmental and health implications depend on the specific stacking options in each region (Medina *et al* 2019). Locally assessed emissions factors and the development of new standard lab tests that better represent in-field stove performance for specific regional contexts will help to estimate more accurately the regional and country annual CO_2-e and fuel savings that could be achieved with different interventions (Johnson *et al* 2009, Medina *et al* 2017, Serrano-Medrano *et al* 2018).

Results from our review indicate that chimney ICS have shown to be effective in reducing HAP and improving health in research settings but achieving these benefits on a large scale has been challenging. The range of health benefits that have been achieved in the region through clean cooking programs, includes acute problems such as headaches and conjunctivitis mainly in women, to other benefits such as improvements in lung function. In children, a decrease in the frequency and duration of respiratory symptoms, the main cause of demand for medical attention, has been demonstrated, although the pneumonia risk reduction has not been demonstrated. Other less evaluated impacts are cardiovascular outcomes and other chronic diseases such as cancer because long-term studies are required. The documented benefits are undoubtedly linked to the decrease in the concentrations of different toxins well represented by respirable particles in addition to gases.

Although there are not many cohort studies carried out in the region, there is a significant amount of pre and post intervention studies. These studies increasingly have a sufficient follow up time to assess the magnitude of the impacts. It is desirable that more studies of this type be carried out to quantify the benefits more accurately when they exist. Regarding poor communities that rely heavily on solid biomass we find that chimney ICS interventions contribute significantly to the construction of healthier environments, to increase the quality of life and to reduce the time that especially children and women remain ill (García-Frapolli *et al* 2010).

6. Conclusions and recommendations

FW is still the dominant rural cooking household fuel within most LA countries, and by far, continues to be used on open fires and rustic stoves. While in the last 20 years there has been an increasing penetration of LPG—very important in countries like Ecuador, Brazil, and to a lesser extent Mexico and Peru—FW use has only been partly displaced because of stacking. Also, there is still a large rural population who does not have the economic means to access LPG or electricity, even on a partial basis. We have also shown that some of the new ICS chimney stove models disseminated in the region could provide tangible health and environmental benefits, as the stoves result in large GHG savings and $PM_{2.5}$ indoor concentrations with regards to TSF. Under these circumstances, regional programs and policies to promote clean and sustainable cooking should include modern solid biomass devices, such as chimney ICS, within their portfolio of options.

To be successful, programs promoting clean cooking should move from just installing or selling stoves to favoring adoption and the understanding of families' priorities rather than just focusing on behavior changes. It is essential to promote participatory innovation cycles that depart from the study of traditional practices and technologies, co-develop pilot models, disseminate the different options including follow up with users, and monitor the program. Use of trials, quality certification, consultations with stove users, and the training of stove builders can help ensure stove quality and durability (Barstow *et al* 2016, INSP 2016).

NGOs and communities should play important roles in promoting stoves at the local level, including building capacity, facilitating distribution and installation, and contributing to subsidies at the household level. Smaller subsidies can be devised to keep stoves affordable while promoting commercialization.

Goals for ICS dissemination need to be clearly stated and national ICS plans launched and designed as part of the overall regional mandate; it is necessary to provide an enabling institutional environment, to support the development of new and advanced products, and to increase efficiency and scale for ICS dissemination. Governments should prioritize household biomass use on their agenda and designate a national coordinating authority that has oversight of energy, health, environment, and gender issues related to household biomass use. It is also important for the region to remove trade barriers related to ICS dissemination and to develop regional ICS standards together with testing and M&E protocols. A country-based regional campaign is necessary to make sure the general population knows why ICS and clean fuels are important, including fuel savings, health, and quality of life for women and children, as well as environmental sustainability (Wang *et al* 2013).

Clean cooking options should help freeing time, opening educational, economic, and social opportunities in which men and women can have equal access for the control and enjoyment of benefits. The involvement of women can increase the effectiveness of the project and help increase the adoption of products and services, while in turn impacting their own livelihoods (GACC 2014). Women help catalyze the market as clean cookstove entrepreneurs, they can drive large-scale distribution as well as the distribution of quality after-sales services which in turn will contribute to the creation of a thriving global market. Also, women can take advantage of their existing networks to encourage the adoption of these new technologies and use their own experiences to promote solutions.

The studies reviewed show that health benefits derived from the use of chimney ICS are clear. However, keeping these benefits on a long-term basis is directly linked to the sustainability of the interventions. Achieving WHO recommendations on healthy air, depends not only on the stove, but also on the social acceptance of the intervention and the technical characteristics and maintenance of the device. Despite all the evidence built and despite efforts in specific countries, the involvement of the health sector both in research and clean cooking interventions remain insufficient. Taking into account the large benefits of clean cooking, it would be expected that health ministries more actively support the development of programs for the promotion, intervention, and evaluation of clean cooking programs.

Finally, clean cooking programs must go hand in hand and be integrated into larger projects aimed at reducing poverty and inequalities in rural areas, since these last are the driving force that prevents universal access to clean household energy.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/IGDP9B.

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