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Acceptance and uptake of improved biomass cookstoves in Peru – Learning from system level approaches to transform large-scale cooking interventions

Nestor Nuño [a,b,1], Daniel Mäusezahl [a,b,*,1], Stella M. Hartinger [a,b,c,1], Amy R. Riley-Powell [d,e], Héctor Verastegui [c], Jennyfer Wolf [a,b], Joan Muela [f,g], Valerie A. Paz-Soldán [c,d]

[a] Swiss Tropical and Public Health Institute, Kreuzstrasse 2, 4123 Allschwil, Switzerland
[b] University of Basel, Petersplatz 1, CH-4003 Basel, Switzerland
[c] Universidad Peruana Cayetano Heredia, Av. Honorio Delgado 430, Urb. Ingeniería, S.M.P., Lima, Peru
[d] Tulane University, 1440 Canal Street, Suite 2210, New Orleans, USA
[e] Institute of Development Studies at the University of Sussex, Library Road, Brighton BN1 9RE, UK
[f] Partners for Applied Social Sciences (PASS International), Baal 58, 3980 Tessenderlo, Belgium
[g] Universitat Rovira I Virgili, Avinguda Catalunya, 35, 43005 Tarragona, Spain

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ABSTRACT

Improved biomass cookstoves (ICS) are cooking technologies that increase wellbeing and reduce household air pollution. With the goal of identifying factors influencing ICS acceptance and uptake at five system levels (intrapersonal, interpersonal, community, institutional, and policy), we carried out a qualitative study in three regions in Peru. We conducted 32 focus group discussions (243 ICS users) and 26 semi-structured interviews with key stakeholders, applying a combination of two system-level frameworks for analysis: the socio-ecological model and the ICS adoption domain.

Enabling and impeding factors at each level were closely related to each other. Decisions made by policy makers – often centralised and not considering local/regional realities – strongly influenced acceptance and barriers at lower levels. ICS acceptance and uptake tended to be low when ICS users were not involved from the start. Most ICS programmes focused on stove distribution outputs, without considering community needs, such as training on ICS building, maintenance and repair, or issues related to spare part availability, which is a strong barrier to sustained uptake of ICS.

Using a combination of models that allows one to examine facilitators and barriers at multiple levels, as well as the interactions of those levels, was useful in assessing potential improvements to intervention design, facilitating programme success, preventing unforeseen programme adaptations, and improving cost-effectiveness of interventions.

1. Introduction

Household air pollution (HAP) from incomplete biomass combustion represents an important risk to health, particularly in low- and middle-income countries (LMIC) [1]. For this reason, global and national programmes and policies have focused on the provision of improved cooking technologies to vulnerable populations [2]. In the last two decades, improved biomass cookstoves (ICS) have been the most widely distributed cooking technologies, designed to increase wellbeing by reducing HAP, cooking time, and fuel use [3].

Despite the widespread distribution of ICS, rates of continuous daily ICS uptake have remained low worldwide [4]. Different frameworks, such as the adoption process [5] and the adoption index [6], have been developed to analyse the acceptance and continuous uptake of improved

Abbreviations: HAP, household air pollution; FGD, focus group discussion; ICS, improved biomass cookstoves; KII, key informant interview; LMIC, low- and middle-income countries; LPG, liquefied petroleum gas; SEM, socio-ecological model; TCS, traditional cookstoves.

* Corresponding author at: Swiss Tropical and Public Health Institute, Kreuzstrasse 2, 4123 Allschwil, Switzerland.
E-mail address: daniel.maeusezahl@unibas.ch (D. Mäusezahl).

[1] Equal contributions of authors.

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cooking technologies such as ICS [5,6]. These frameworks are useful to illustrate the interactions between users and cooking technologies at the household level [5,6]. However, they do not explore the impact of other social, cultural, and system factors on stove acceptance and uptake.

In a systematic review, Rehfuess and colleagues propose a framework to reconceptualise ICS uptake (henceforth referred to as 'ICS adoption domains'). They understand ICS uptake as an intersection between 31 factors, which act as enablers or barriers to ICS uptake, grouped into seven system-based domains. These domains include the following: Fuel and Technology Characteristics (henceforth referred to as 'Fuel/Technology'), Household and Setting Characteristics (henceforth referred to as 'Household/Setting'), Knowledge and Perception (henceforth referred to as 'Knowledge/Perception'), Financial, Tax and Subsidy Aspects (henceforth referred to as 'Financial'), Market Development (henceforth referred to as 'Market'), Regulation, Legislation and Standards (henceforth referred to as 'Regulation/Legislation'), and Programmatic and Policy Mechanisms (henceforth referred to as 'Programmatic/Policy') [7].

While the Rehfuess ICS adoption domains framework represents an alternative to ICS uptake approaches focused on individual dimensions, it does not explore how the different individual, social, and system mechanisms interact with each other to facilitate or impede ICS uptake (systems level approach). Other frameworks, such as the socio-ecological model (SEM), originally put forth by Urie Broenfenbrenner [8], overcome the limitations of the ICS adoption domains framework by exploring the complex interplay between individuals, social groups, and the system environment across five system levels: intrapersonal, interpersonal, community, institutional, and policy.

In Peru, 70 % of households in rural areas use biomass for cooking, compared to 7 % in urban settings [9]. Between 2009 and 2011, 56 Peruvian and international stakeholders working in ICS implementation launched the campaign "Half a million ICS for a smokeless Peru", with the collective aim to install 500,000 ICS in the country. This initiative distributed almost half of the intended stoves (235,263 ICS) in 76 % of all regions in the country, benefiting more than one million people [10]. Simultaneously, other legislative changes were enacted, enabling regional governments to invest up to 2.5 % of mining revenues in ICS implementation [11].

We aimed to examine enabling factors and barriers associated with ICS acceptance and uptake in large-scale ICS interventions. For this purpose, we conducted a qualitative study in one coastal and two high-altitude Andean Peruvian ecosystems. These geographical regions were previously part of the "Half a million ICS for a smokeless Peru" initiative. We applied a combination of the ICS adoption domains plus the SEM for analysis. This allowed us to consider the impact and relationships of the seven aforementioned ICS adoption domains within the five SEM societal levels.

2. Materials and methods

2.1. The SEM as a conceptual system-level framework

The SEM framework describes the social reality as a dynamic environment where five system levels (intrapersonal, interpersonal, community, institutional, and policy) can influence – positively or negatively – individuals' perceptions and actions. All system domains are interconnected, meaning that interactions are bidirectional and reciprocal (Fig. 1). Any change at the individual level is believed to alter upper levels and vice versa. Hence, when change affects an individual (e.g., the arrival of a new cooking technology), this change transforms the person as much as the social environment in which the person lives and interacts.

We chose the SEM as an analytical framework due to its simplicity and usefulness to illustrate the interconnectedness between different societal levels of interaction and influence. The SEM has previously been applied to assess factors associated with healthcare access or behavioural changes [12]. For the analysis of ICS interventions, we used Brieger's combination of the classical SEM with a disease-behavioural model, as it specifically focuses on the interactions (between individuals, groups of people, and institutions) that take place during the implementation of large-scale interventions [13]. Based on Brieger's model, we adapted SEM levels to ICS interventions as described in Table 1.

2.2. The system domains of ICS adoption

The ICS adoption domains comprise a framework specifically designed to assess ICS acceptance and uptake processes [7]. Based on the

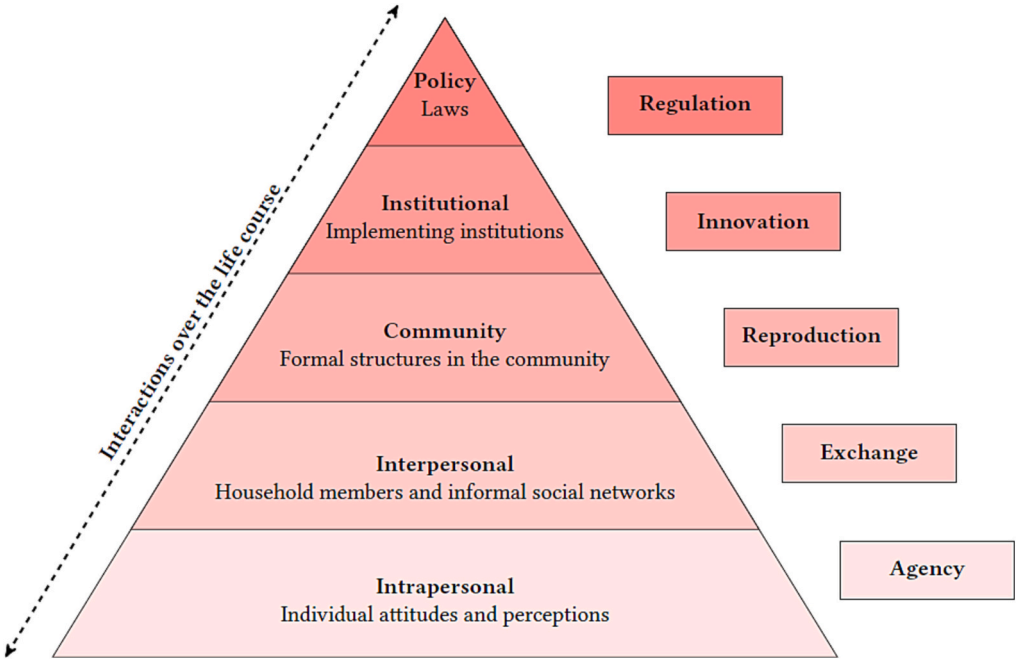

Fig. 1. Societal levels proposed by the Socio-Ecological Model.

Table 1
SEM structure for the analysis of ICS interventions.

Level	Definition	Examples
Intrapersonal	Issues relating to an individual's knowledge, beliefs, actions, decisions, and behaviours	Personal preferences for ICS elements, such as number of furnaces or type of bricks to use; values and beliefs toward ICS
Interpersonal	Exchanges and interactions between ICS users and other relevant social actors in their lives may influence their knowledge, beliefs, or actions related to an ICS. Interpersonal relationships can influence intrapersonal perceptions and vice versa	Impact of positive (supportive) and negative (demotivating) comments from family members and neighbours
Community	Laws, realities (e.g., basic services, transport), trust, and norms related to local networks, authorities, and community groups	Community groups may be catalytic in changing perceptions and attitudes. Regional realities (trust in leaders and access to spare parts) may be an asset or barrier to ICS uptake
Institutional	Institutions directing ICS programme dissemination	The goal of an institution may or may not be matched with the goals or needs of a community; hence, these can work in parallel or conflict with the other levels
Policy	Policies, strategic plans, and operational guidelines may influence the work of ICS programmes and ICS stakeholders and, consequently, the functioning of the overall programme	Policies, such as those relating to ICS certification, can serve as facilitators or barriers to ICS acceptance and uptake

Note: information concerning the SEM levels and their interconnection was extracted from Brieger [13].

same premise of the SEM, this framework describes how the different adoption domains can equally facilitate or impede ICS acceptance and uptake depending on the particularities of the context and the characteristics of the ICS intervention. We chose the ICS adoption domains framework because its application in real contexts is not yet common. The seven domains proposed by Rehfuess and colleagues [7] are organised at two system-based levels: 'Household and Community', and 'Programme and Societal' (see Fig. 2). At the Household and Community level, the first domain (Household/Setting) comprises those socio-economic, demographic, and structural contexts that affect ICS acceptance and uptake (e.g., household assets, education level) at the household level. The domain Knowledge/Perception addresses the expectations of users regarding the impact of ICS on their household and daily life. This includes HAP reduction, cleanliness, and social influence. The four domains under the Programme and Societal level focus on the design of cost-effective approaches to reduce the barriers to ICS purchase (Financial domain), the creation of ICS supply chains (Market domain) through appropriate market strategies, the promotion of legislative changes to facilitate ICS diffusion (Regulation/Legislation domain), and the coordination and interaction between different ICS stakeholders (Programmatic/Policy domain). Fuel/Technology is the only domain that pertains to both system levels. Here, user needs and preferences (e.g., stove design, fuel type) are captured, along with functional features of ICS such as heating and/or cooking (e.g., fuel savings or impacts on time).

2.3. Integrating the SEM and ICS adoption domains frameworks

Considering the complementary similarities between the SEM and ICS adoption domains frameworks, we combined both for our analysis. Fig. 2 depicts how the five levels of the SEM [13] are connected with the seven domains of the ICS adoption domains framework [7].

2.4. Study setting

The study was conducted between February and November 2014 in 20 rural communities from the Peruvian high-altitude Andean regions of Cajamarca and Cusco and the coastal region of La Libertad. Sites were selected purposively based on the following four criteria that helped to identify communities where ICS interventions have been taken place in the past and focus group discussions (FGDs) with sufficient number of ICS users would be possible: i) large ICS dissemination programmes implemented in the previous 15 years; ii) heterogeneity in geography, altitude, and type of traditional cookstoves (TCS), and cooking practices; iii) availability of ICS programme data on distributed stove locations; and iv) at least 50 % of households in each community had participated in ICS interventions.

Today, access to clean fuels and cooking technologies, rather than ICS, is a priority in many LMICs. Specifically, in 2010, the Peruvian National Energy Policy was launched to promote an energy transition in rural areas toward the use of clean cooking fuels such as liquefied petroleum gas (LPG). Additionally, in 2014, the national electrification policy sought to connect remote communities to the grid in order to ultimately switch to electric cooking. This change at the government level decreased large ICS installation rollouts and reduced investments and support for ICS diffusion over time [14]. Changing priorities in Peru's energy sector occurs in a similar way to other LMICs that prioritise access to clean fuels and cooking technologies over ICS to achieve Sustainable Development Goals [15,16]. However, we believe that the results of our 2014 study are still relevant today. Evidence indicates that the uptake of clean cooking fuels such as LPG (the most common cooking fuel distributed today) is strongly influenced by societal, cultural, and economic dynamics. A recent cross-sectional study in Cameroon showed that while LPG uptake was related to household wealth, there was no relationship between this factor and exclusive LPG use, despite the existence of a relatively well-established LPG market [17]. A qualitative study in the same setting concluded that the compatibility of clean cooking fuels with local cooking needs was an influential factor for LPG users [18]. In rural Guatemala, households with higher income did not prioritise the use of LPG and used firewood more often than LPG. Reasons included the lack of confidence in LPG suppliers and the widespread perception of firewood gathering as a social activity [19]. Similarly, in Andean Peru LPG use was negatively affected by insufficient communication with LPG contractors, time spent refilling LPG cylinders, seasonal fluctuations in LPG costs, and the perceived lower capacity of subsidised LPG cylinders compared to regular ones [20]. Likewise, rural Peruvian families asserted that LPG was not always compatible with local social norms and values, such as the custom of socialising while collecting fuel and cooking with relatives or friends [21]. For these reasons, we consider that current efforts to understand LPG acceptance and uptake would benefit from applying a systems-level approach similar to the one applied in this study.

2.5. Study design

We conducted FGDs with ICS users to investigate local conceptualisations of ICS acceptance and uptake. Alongside the FGDs, we carried out semi-structured key informant interviews (KIIs) with ICS stakeholders (e.g., ICS programme managers and directors at provincial and national levels) and local (formal and informal), provincial and regional authorities, to explore the benefits and difficulties of implementing and scaling up ICS programmes. FGDs provided information relevant to the intrapersonal, interpersonal, community, and institutional SEM domains. Results from KIIs were used to complement the lack of knowledge of ICS users concerning the institutional (e.g., barriers faced by ICS implementers) and policy SEM domains.

Households were eligible to participate if they i) had previously taken part in an ICS programme in the last 4 years; ii) used biomass as primary cooking fuel; and iii) had a household head aged 18 years or

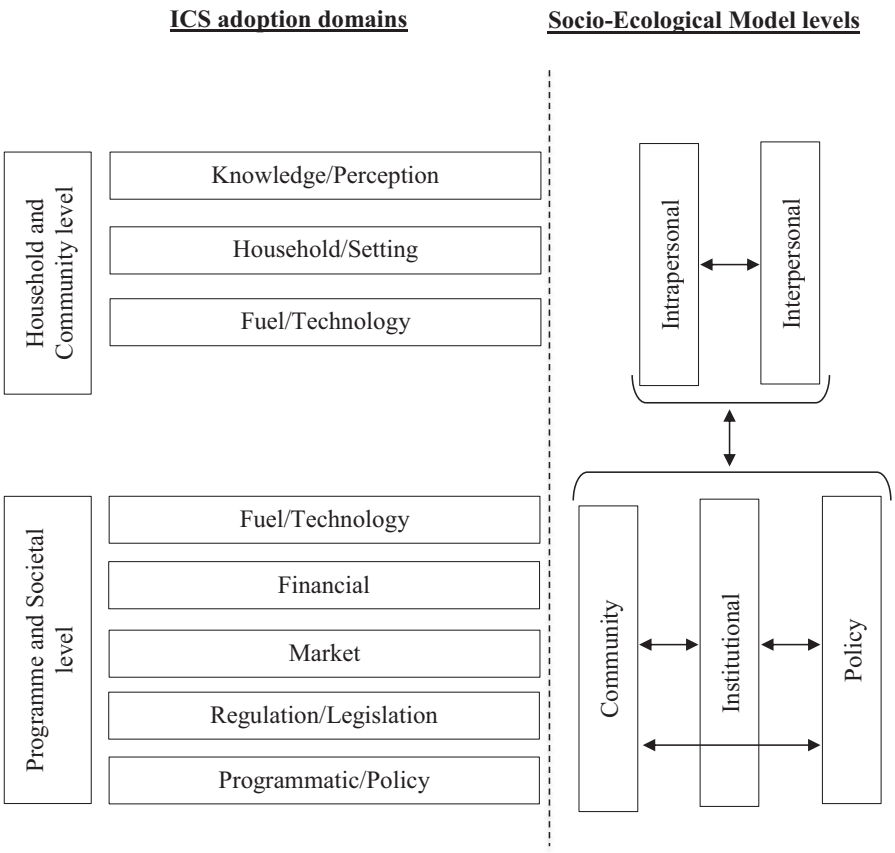

Fig. 2. Relationship between the Socio-Ecological Model (SEM) and ICS adoption domains frameworks.

older. We invited men and women to participate in the same FGDs to ensure a gendered perspective on the implementation, uptake, and benefits of ICS within the different regions.

For the KIIs, we used the chain-referral sampling technique to identify and contact participants who were either involved in or knowledgeable about the implementation of ICS initiatives. This sampling technique consists of initial contact with a small group of people relevant to the research topic and then draws on their networks to establish new contacts. KII participants were intentionally considered eligible to participate if they were above 18 years old and spoke Spanish.

We arranged both FGDs and KIIs two days before their completion with the assistance of experienced field staff from Cajamarca and the local community and provincial authorities. The guides for the FGDs and KIIs comprised the following topics: i) acceptance of ICS interventions (intrapersonal level); ii) enablers and barriers to ICS uptake (intrapersonal and interpersonal levels); iii) main actors at family, community, and institution levels that support, discourage or reject ICS acceptance and uptake (interpersonal, community, and institutional levels); iv) ICS condition, satisfaction, and maintenance mechanisms (interpersonal, community, institutional, and policy levels); and v) policies and organisations that support ICS dissemination on a large scale (policy level). Questions in both FGDs and KIIs were aligned with the factors described in the ICS adoption domain framework [7]. During the analysis, we classified each factor as a barrier or enabler according to participants' descriptions. We audio recorded the FGDs and KIIs with the participants' consent. Two field staff members took detailed notes during FGDs to facilitate transcription. Notes were also compared for consistency by a field supervisor. The sample size for FGDs and KIIs was determined by thematic saturation (i.e., recruitment stopped when no new relevant data emerged on the research topic) and we sought the participation of individuals from different settings to ensure a range of experiences with different programmes and communities.

2.6. Data analysis

All FGDs and KIIs were transcribed verbatim in Spanish with Express Scribe transcription software (NCH Software, Canberra, Australia) [22]. Two social scientists analysed the data concurrently during data collection manually, i.e., without using a computer software, according to the guidelines described in Dawson et al. [23]. We used a combination of both deductive and inductive methodologies (grounded theory) for the analysis. We read, edited, and coded information according to the defined topics of interest. New themes that emerged through the process were included in the codebook and subsequent analysis. The thematic codes of every fifth FGD and KII were compared between both coders to ensure consistency. The agreement was reached based on the classical principles of qualitative research (i.e., active dialogues and multiple comparisons of analytical notes).

We carried out 32 FGDs with 243 participants: 16 in Cajamarca (N = 79), 10 in Cusco (N = 105), and 6 in La Libertad (N = 59). The large majority of participants were women. Only 14 men (5 % of the total participants) attended the FGDs. We also carried out 26 KIIs: 16 in Cajamarca, 4 in Cusco, and 6 in La Libertad (Supplementary File 1). Participants represented 12 different ICS programmes that were part of the "Half a million ICS for a smokeless Peru" initiative: 5 in Cajamarca, 4 in Cusco, and 3 in La Libertad.

2.7. Ethics

The study was approved by the institutional review board of the University Peruana Cayetano Heredia in Lima (Ref. 385-42-13), Peru. All participants signed an informed consent before participation and provided verbal consent for being audio recorded. All personal references and identifiers were changed and participants are referred to by pseudonyms to protect their identity.

2.8. Funding

The study was supported by the United Nations Foundation (UNF-13-497). The funder had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

3. Results

We present the enablers and barriers to ICS acceptance and uptake organised by the SEM levels and ICS adoption domains described previously. We did not stratify our analysis by ICS programme since there were no noticeable differences in their design and implementation strategies.

3.1. Intrapersonal level

At the intrapersonal level, the main enablers and barriers to ICS acceptance and uptake fell within the domains of Fuel/Technology and Knowledge/Perception (Table 2).

Regarding the Fuel/Technology domain, we found that ICS design could be either an enabler or a barrier to ICS acceptance and uptake. When ICS designs met local cooking needs (e.g., number of furnaces and suitable furnaces for pot sizes), participants valued ICS positively. ICS models with adaptable furnace rings were much sought-after in all three regions. In general, most ICS programmes installed models with 2–3 furnaces (Fig. 3). Participants reported the third furnace was useful to warm up water for washing dishes and bathing children. Particularly in Cusco (the coldest of the three sites), warming the kitchen environment was noted as an advantage of ICS.

Having time and being able to leave the ICS unattended was another appealing feature for FGD participants in all sites. Participants reported being able to multitask while cooking, unlike with other cooking technologies such as LPG stoves, which required continuous supervision (e.g., adjusting flame, turning LPG stoves off, constant supervision of cooking), which impeded women to do their chores in the field and cook simultaneously. Participants in all sites considered ICS cooked equally or faster than TCS, allowing them to cook the majority of their staple foods. They reported reverting to TCS for special family events or to prepare certain meals such as *mote* (peeled corn) or *cachangas* (traditional bread). Participants considered that these meals could not be prepared with ICS because pot sizes were larger than furnaces – even with models with adaptable rings. Additionally, participants noted that lighting the fire was easier with ICS due to their closed combustion chambers.

Table 2
Enablers and barriers to ICS acceptance and uptake in the intrapersonal SEM level.

Domain	Enablers	Barriers
Fuel/ Technology	- ICS are designs adapted to cooking needs - Time and fuel savings[a] - Resistant construction materials (e.g., iron rods, cement)	- Low durability and quality materials - ICS designs not adapted to local needs - ICS cannot be used for family celebrations. - Poorly built ICS - Local construction materials
Knowledge/ Perception	- Health improvements[b] - HAP reduction[b] - Safety - Kitchen cleanliness (no soot) - The taste of food (no ash) - Previous knowledge of ICS interventions - Facilitate ash collection	

[a] Not among participants who collected firewood.
[b] In Cajamarca and La Libertad.

Fig. 3. Example of a 3-furnaces' stove in the rural Peru.

> Elia: "We use our *tulpia* [three-stone cooking fire] when we peel our *mote* [corn], we cannot do it in the stoves […]. You need to take your *paila* [traditional pot] out and prepare a *tulpia*.
> Sonia: "I cannot cook my *cachangas* [bread] on my stove".
> Elia: "But you can fry the *cachangas*".
> Sonia: "Yes, it happens when *cachangas* are fried. Otherwise, I need my *tulpia*".
>
> – FGD in Cajamarca.

Wood saving was considered another enabler to ICS acceptance and uptake, as FGD participants associated it with both economic and time-saving benefits: "It's true [fuel savings], now I use fewer trunks of wood and I only need to collect firewood every eight days". – Sonia. FGD in Cajamarca. However, FGD participants in all sites pointed out that fuel savings were directly related to how well the ICS were constructed: "We do not use the stove, it consumes too much firewood. They made the combustion chamber too large so the fire expands. That is the reason why it consumes too much firewood". – Lupita. FGD in Cajamarca. Anecdotally, fuel saving was not perceived as an advantage of ICS for those FGD participants who were able to access free firewood by collecting it in fields and woods.

Across sites, ICS models made with iron rods, burned bricks, and cement were preferred over those made of local materials, such as adobe or mud bricks. Participants in all sites categorised the latter as weak and useless for constructing ICS, as they required regular maintenance:

> Martin: "We use white mud to repair the stoves".

Moderator: "And how often do you need to repair them?"
Martin: "Every year or year and a half. The stove stays as new until it breaks down again".

– FGD in Cajamarca.

In those cases where ICS were broken, FGD participants continued using ICS stoves, despite the increased smoke. Only a few participants reported returning to TCS:

Telma: "My stove has some broken bricks. The front part also has a large crack".
Moderator: "But, do you keep cooking on the stove, or do you use your *tulpia*?"
Telma: "Of course, I keep cooking on my stove. I was almost drowning in smoke when I used the *tulpia* to cook outside".

– FGD in Cajamarca.

Regarding the Knowledge/Perception domain, participants in FGDs from Cajamarca and La Libertad reported health improvements (e.g., reduced headaches, eyes pains, and coughing) linked to HAP reduction:

Maria: "The smoke hurt our eyes, but now it is different!"
Milena: "Before, our eyes were red, we cried too much".

–FGD in La Libertad.

However, in Cusco, FGD participants did not consider that ICS notably diminished HAP. This perception may result from the fact that traditional mud stoves in the region already had closed combustion chambers. Participants in all sites also emphasised ICS were more secure and robust than TCS, making kitchen environments safer and reducing the risk of burns for children. However, this perception was also linked to ICS design and construction. In some communities, FGD participants reported negative experiences, including one community in La Libertad where the heat produced by the ICS chimney burned down some houses:

Leidy: "Many houses were burned down because the chimney was hot while cooking".
Luisa: "[…] the roofs were thatched and, with the heat, the roof caught fire. The fire destroyed everything in the house".

– FGD in La Libertad.

FGD participants in all sites agreed that ICS improved the cleanliness of the kitchen environment:

Marisa: "I like the new stove because the smoke is not inside the house anymore".
Lucía: "Yes, I agree".
Matilde: "The smoke has escaped from the chimney and the kitchen is clean".
Laura: "The pots only burn on the bottom. Before, they got completely darkened".

– FGD in La Libertad.

Other advantages included clothes not smelling and meals not containing ash: "My clothes no longer smell so much of smoke. My husband likes it. He is more often with me in the kitchen". – Lucia. FGD in Cajamarca.

In addition, participants highlighted that, compared to TCS, the ICS helped them to collect ash due to their closed combustion chambers. In some communities, ash was used as a pesticide, for peeling cereals or legumes, or sold for additional household income.

In the FGDs, participants who had previously participated in other ICS programmes could more easily discuss and compare the benefits of different ICS models and programmes. They expressed more enthusiasm for ICS initiatives.

3.2. Interpersonal level

At the interpersonal level, the main enablers and barriers to ICS acceptance and uptake fell within the domains of Household/Setting and Knowledge/Perception (Table 3).

In the Household/Setting domain, FGD participants who did not own their home were more reluctant to accept the installation of an ICS. This was to avoid arguments with the owner of the property.

Concerning the Knowledge/Perception domain, FGD participants in all sites reported that in homes where an ICS was installed male family members spent more time in the kitchen and some participated in cooking activities due to the absence of smoke:

Maria: "[…] nowadays our husbands do not run out of the kitchen anymore because of the smoke".
Moderator: "And do they cook?"
Maria: "Of course!"
Margarita: "They prepare meals even when it is not time to cook!"

– FGD in Cajamarca.

ICS acceptance was also influenced by the perceptions of family members. The opinion of key family members (especially male household heads) was a decisive factor for initial ICS acceptance. In some cases, FGD women described men as being reluctant at first due to having strangers in their homes to construct the ICS but, eventually, the men overcame this barrier:

Milena: "We all wanted the stove; it was really beautiful".
Laura: "Some women even envy us because they do not have a stove".
Moderator: "And what did the husbands say?"
Milena: "Some said no, we don't want anyone [a stranger] to work in the household [installing the ICS]".
Laura: "Some of them [the husbands] are now asking for the stove".

– FGD in Cajamarca.

The mistrust of institutions was a barrier in this domain. FGD participants in all sites described mistrust and negative rumours about foreigners (*gringos*) and mining companies taking their natural resources in exchange for ICS, despite programmes being implemented by many local non-governmental organisations (NGOs) and state bodies: "Some of them wanted [to participate in the ICS programme] but others did not! It was because they said the *gringos* would take their children away". – Maria. FGD in La Libertad.

Likewise, FGD participants in all sites reported a lack of transparency and rumours of corruption regarding how families were selected for ICS interventions. According to ICS programme directors, the majority of ICS programmes selected families based on specific criteria, such as having small children and/or limited economic resources. However, FGD participants mentioned that wealthy community members were sometimes included, either circumventing the selection criteria or finding other ways to benefit. In areas where multiple ICS programmes had been active, FGD participants reported distrust toward new institutions or feared not meeting the programmes' requirements. This was reflected in the rejection (and sometimes destruction) of ICS. Occasionally, families who were excluded from ICS programmes

Table 3
Enablers and barriers to ICS acceptance and uptake in the interpersonal SEM level.

Domain	Enablers	Barriers
Household/ Setting		- Lack of household ownership
Knowledge/ Perception	- Men perceive ICS benefits - Relatives and family positively influence ICS participation - Men's participation generates networks for ICS repair	- Negative rumours and reputation of institutions - Programme inclusion criteria - Negative attitudes toward ICS support and repair - Perceptions of nepotism in the programmes' inclusion criteria - Lack of ICS repair skills

influenced neighbours to stop using the ICS: "I was really upset because some families, not all of them obviously, went to the extreme of destroying the ICS due to the terrible reputation that [name of the institution] had". – Martin, ICS programme manager. KII in La Libertad.

Conversely, across all sites we found that the active participation of male family members in ICS interventions was linked to ICS acceptance as well as positive maintenance and repair attitudes. Unlike the few FGD participants who felt maintenance and repair was the ICS programmes' responsibility, most FGD participants considered reparations were their responsibility and carried out maintenance/repair activities with their own money, using clay, cement, or adobe. The majority of these participants indicated that they would not ask for a loan to purchase a new ICS. Instead, they would be willing to save money to buy a new one. However, female FGD participants in this group argued that men were not always proactive about ICS repair and that sometimes this was also due to a lack of skills and/or low motivation:

> Laura: "Well, sometimes husbands are lazy. Despite our help, they are not interested in making bricks. In the end, we [women] have to do everything ourselves".
> Patricia: "Yes, men are sometimes like that".
>
> – FGD in La Libertad.

FGD participants who felt it was the ICS programmes' responsibility to do maintenance/repair did not want to invest any money or time in ICS maintenance. They said they would not ask for a loan to get a new ICS. They would rather wait until another ICS programme came to their communities: "I waited for the projects' people to arrive so they could repair my stove, but they never came back. It does not make sense that they do not repair the stoves. They always break down". – Lupita. FGD in Cajamarca. At the time of the study, none of the FGD participants from any of the groups had replaced their ICS.

3.3. Community level

At the community level, the main enablers and barriers to ICS acceptance and uptake fell within the domains of Market, Financial, and Programmatic/Policy (Table 4).

Barriers in the Market domain included limited access to shops, vendors, or companies to purchase ICS spare parts. In addition, the lack of ICS financing mechanisms and the inaccessibility to loans due to families' lack of stable incomes were repeatedly noted (Financial domain).

In the Programmatic/Policy domain, we identified that formal and informal community leaders (e.g., health promoters or health personnel, respected community members) could act as both enablers and barriers to ICS acceptance and uptake. Specifically, the leaders' active involvement in ICS promotion facilitated ICS acceptance and increased trust in ICS programmes:

> Patricia: "At the beginning, I did not know the institution [implementing the ICS model] and I was afraid of them".
>
> Moderator: "And why did you let them into your house?"
> Dolores: "It was because the mayor [of the municipality] was with them".
> Patricia: "Yes, that is the reason why I let them in".
>
> – FGD in Cajamarca.

In general, the opinion of community leaders facilitated ICS acceptance and generated positive reinforcements for ICS uptake. This factor is closely connected to the Knowledge/Perception domain, as it describes different forms of social influence at the community level. For example, in a community in La Libertad, a mining company with a shady reputation was accepted when the local deputy mayor intervened and installed an ICS in his household:

> Martina: "The first stove was installed in the home of the deputy mayor, as an example".
> Julia: "Everyone came to see the stove".
> Moderator: "[…] and what did you think afterward"?
> Martina: "It was beautiful. I wanted it".
>
> – FGD in La Libertad.

Likewise, according to ICS programme managers in KIIs, the participation of community leaders in ICS programmes increased ICS acceptance and reduced distrust toward institutions. Political and institutional factors strongly influenced this participation. Community leaders reported a lack of administrative competencies and/or economic resources to promote ICS programmes, albeit being willing to support their implementation.

3.4. Institutional level

At the institutional level, the main enablers and barriers to ICS acceptance and uptake fell within the domains of Fuel/Technology, Market, and Programmatic/Policy (Table 5).

FGD participants highly valued ICS programmes that allowed them to select between different ICS models or involve communities in ICS model design (Fuel/Technology domain). However, ICS programme directors indicated that the majority of ICS programmes installed predesigned, standardised, and certified ICS models, as they needed to meet emission targets. Likewise, they declared that in the cases where the community was involved in ICS design, there were no model adaptations due to the need to meet certification requirements.

Regarding the Market domain, ICS programme managers in KIIs agreed that the absence of local entrepreneurs and ICS markets was a significant barrier to ICS acceptance and uptake. However, addressing this shortfall by introducing contact points and supply chains in rural

Table 4
Enablers and barriers to ICS acceptance and uptake in the community SEM level.

Domain	Enablers and benefits	Barriers
Market		- Spare parts not locally available
Financial		- Lack of ICS financing mechanisms - Inaccessibility to loans to purchase ICS
Programmatic/ Policy	- Active involvement of community leaders in ICS promotion positively influences ICS participation	- Lack of community groups to facilitate ICS demand - Insufficient competencies and resources of community leaders to promote ICS initiatives

Table 5
Enablers and barriers to ICS acceptance and uptake at the institutional SEM level.

Domain	Enablers	Barriers
Fuel/ Technology	- Community consultations to select ICS-models	- Mandatory standardised ICS-models - ICS models not adapted to local contexts
Market		- Lack of market strategies as part of ICS interventions
Programmatic/ Policy	- Interactions between ICS programme technicians and ICS users after ICS implementation - Development of ICS maintenance strategies - Involvement of local authorities in ICS interventions - Training for ICS repair/ maintenance	- ICS programmes focused on the installation of a specific number of stoves - Lack of interaction between implementers and users - Lack of attention to programme implementation. - No alliances or collaborations between institutions.

areas was not seen as their responsibility. ICS programme directors indicated that market development for cookstoves was not a priority within their programme strategies. This was because they were more focused on achieving stove distribution output and high coverage numbers.

While ICS programmes were output-oriented, FGD participants preferred long-term guidance and monitoring mechanisms for the post-implementation phase (Programmatic/Policy domain). Only a few ICS programmes stipulated goals related to long-term engagement with the communities. FGD participants reported that the lack of dialogue with institutions implementing ICS, the accelerated construction of the stoves in-house (often with little or no user involvement), and the resulting distrust toward the implementing institutions were key barriers to ICS acceptance:

> Mario: "They came back and made four stoves [of the same type] to see if we wanted them. We went to see the model and said we did not like it. However, they came again and gave stoves to 75 families; in the end, only 25 other families constructed the stove".
>
> – FGD in La Libertad.

In some exceptional cases, FGD participants reported that ICS programmes tore down the existing ICS in the house to install their own ICS models, which generated notable distrust toward institutions: "I liked my new stove… but they made me build another one". – Angela. FGD in La Libertad. Programmes that provided technical support and monitoring beyond the project implementation phase yielded higher ICS acceptance. However, across all sites it was noted that ICS institutions rarely returned to the communities to monitor ICS functioning:

> Moderator: "[…] then, the institution did not visit you. Did they just install the stoves?"
> Pepa: "[…] and nothing else. They never contacted us to check if the stove was fine".
> Laura: "nothing, nothing".
>
> – FGD in Cajamarca.

Most ICS programme managers reported being aware that poor programme implementation generated dissatisfaction among users. In Cusco, an ICS programme selected a type of brick (*pandereta*) about which ICS users had voiced concerns regarding the durability and availability in the area; indeed, the stoves' bricks did not last long and broke down quickly according to some FGD participants. ICS programme managers interviewed said they had no control over the selection of construction materials, as these were decisions made by individuals at a higher level.

FGD participants indicated that time delays of large-dissemination programmes (e.g., taking several months to construct the stoves) and the use of unsuitable materials were barriers to ICS acceptance:

> Irene: "[…] stoves were weak. Bricks did not sustain daily use and the combustion chamber broke easily".
> Moderator: "And which type of brick would be better?"
> Irene: "Here in Cajamarca you can find good bricks, but they told us the materials came from elsewhere. These bricks do not break but they get very hot".
> Moderator: "And the bricks remain hot after cooking?"
> Irene: "Yes, and we did not like that. Bricks have to cool down after cooking. Otherwise, we cannot touch the stove".
>
> – FGD in Cajamarca.

According to KIIs, ICS programme managers argued that logistic constraints (e.g., delivery of materials, lack of local staff) generally led to poor quality or incomplete ICS construction. In La Libertad, a programme manager indicated that about a third of the stoves were obsolete or broken at the first monitoring visit. Another ICS programme manager from Cusco indicated that up to 80 % of ICS were faulty within six months of installation.

Alternatively, ICS programmes that included construction demonstrations resulted in non-ICS recipients building their own ICS. Additionally, construction demonstrations provided community members with insights into potential self-repair and encouraged ICS uptake:

> Moderator: "What happened to the people who did not receive the stove?"
> Angustias: "They copied the model. They knew how to make it".
> Lorena: "Yes, the majority copied the model and received help from us".
>
> – FGD in Cajamarca.

3.5. Policy level

At the policy level, the main enablers and barriers to ICS acceptance and uptake fell within the domains of Financial, Market, Regulation/Legislation, Programmatic/Policy, and Knowledge/Perception (Table 6).

Under the Financial and Market domains, ICS programme directors voiced that no specific efforts were made for supporting the creation of ICS markets. This included not providing subsidies for ICS acquisition or not developing repair and spare part community supply chains. Policies were generally focused on distributing the largest possible numbers of ICS.

Related to the Regulation/Legislation, domain, ICS programme directors highlighted the implementation of national energy policies to incentivise ICS dissemination. However, they reported a progressive decrease in political and economic support for ICS programmes after 2011. They also acknowledged the importance of implementing ICS certification requirements to comply with international standards. However, some of them acknowledged that the strict regulation for ICS certification (mandatory to subcontract with the government) might have reduced the capacities of small ICS constructors to expand their business and generate ICS market structures.

That said, under the Programmatic/Policy domain, ICS programme directors indicated that the changes in certification requirements were not accompanied by the development of strategies to monitor and control the quality of the ICS after implementation on site. Regional authorities also declared that numerous state bodies were involved in ICS dissemination but that there were no efforts to coordinate the numerous ICS programmes in the country. When ICS programme managers were asked specifically whether they received any government support and whom to address as responsible for programme

Table 6
Enablers and barriers to ICS acceptance and uptake in the policy SEM level.

Domain	Enablers	Barriers
Financial		- Lack of financial subsidies for ICS acquisition
Market		- Lack of policies to support ICS market development
Regulation/ Legislation	- Implementation of ICS certification requirements - Implementation of national energy policies that incentive ICS diffusion	- ICS promotion with a short-term focus and without political continuity - Expensive requirements to certify ICS
Programmatic/ Policy	- Involvement of a large number of state bodies	- Lack of monitoring and quality control - Lack of state-led harmonisation - Strong centralisation of ICS programmes
Knowledge/ Perception		- Discrepancies between ICS stakeholders - Lack of attention to user perceptions concerning ICS quality

implementation and harmonisation, they declared having no guidance from their superiors or policies. While ICS interventions were implemented locally, ICS programme directors indicated that the majority of projects were centralised, meaning that local branches were not directly involved in programme design. The issue of centralisation was also noted in a disconnect and miscommunication between ICS implementers and government bodies; an ICS programme manager (subcontracted by a state ICS programme) refused to install stoves in communities that had already benefited from another ICS programme within the past six months – which would have resulted in over 30 % of duplication. In other instances, there was evidence of duplication: some homes had two ICS installed (anecdotal reports from ICS programme managers). Consequently, the government withdrew the programme contract and cut-off relations with the subcontractor. According to other ICS programme managers, these situations were not uncommon, as they had the obligation to reach concrete installation outputs. This top-down approach emerged multiple times as a key barrier to ICS intervention success.

Finally, in the Knowledge/Perception domain, we noted blame for programme failures being directed at different people and reasons. For example, some ICS programme managers tended to complain about their superiors for the programme failures:

> Aurelio: "I think we did not conduct any monitoring of the stoves. There was a discrepancy in that aspect. I told the people in charge that it was not a matter of saying in the report that everything was fine. It was a matter of understanding the truth. If the project is not working or it is poorly implemented, we need to be honest. There were many setbacks because the [our] implementation was poorly coordinated from the start. However, it is always easier to blame others than to acknowledge that things were not done correctly".
>
> – KII with an ICS programme manager in La Libertad

4. Discussion

In this paper, we investigate factors influencing improved biomass cookstove (ICS) acceptance and uptake in three Peruvian regions (Andean Cajamarca and Cusco and coastal La Libertad) drawing on both, the disease-ecology adaptation of the socio-ecological model (SEM) framework [13] and the ICS adoption domains framework [7]. To our knowledge, we present one of the few studies that addresses determinants of ICS acceptance and uptake by applying a systems-level approach in South America.

The SEM and ICS adoption domains frameworks shared complementary characteristics and were useful to identify which actions should be prioritised to increase the acceptance and uptake of ICS interventions at various system levels in our Peruvian setting.

Our results show how factors identified at each level are closely related and interconnected with one another. This means that even minor decisions at any level can influence user perceptions regarding ICS acceptance and uptake. For example, we found that enabling factors identified at the intrapersonal, interpersonal, and community levels were strongly influenced by decisions made at the institutional and policy levels. Overall, the institutional and policy levels had a strong negative impact on all the other levels. From a systems-level perspective, these results describe how the acceptance and uptake of cooking fuels and technologies are not only based on personal choices, availability dimensions, or cultural perceptions (e.g., distance to forest or better food taste) [21,24], but also on specific experiences linked to social influence, programme implementation and political decisions. Therefore, cooking interventions should ensure that all levels of the system are addressed.

The ultimate goal of any cooking programme is to achieve technology uptake and continuous use. Yet, most cooking programmes today focus on installing as many stoves as possible without considering long-term factors (e.g., availability of supplies for future repairs or maintenance capacities in the community). This has resulted in limited "success" of ICS interventions in past decades [25,26]. In our setting, we identified several factors that limited stove acceptance and uptake: i) ICS implementers did not develop mechanisms for stove repair and maintenance, ii) ICS users were not able to choose which stove model to install, iii) community leaders were not involved in ICS diffusion, iv) there was no communication between ICS implementers and users, v) men were not considered targets of ICS interventions, and vi) political barriers discouraged ICS diffusion. These findings concur with other (local) studies that highlight top-down dynamics in global cooking interventions [26,27].We found that knowing how to build an ICS or having access to spare parts fostered ICS acceptance and uptake, as well as stove maintenance, repair, and replication. However, these attitudes were negatively influenced by the lack of strategies and policies at higher levels. This was because ICS implementers did not support the development of local markets or provide training in construction, repair, and maintenance. Another cross-sectional study conducted in our three Peruvian settings found that knowing someone who can build or repair an ICS was significantly associated with daily stove use, as was having ICS parts available in the community with TCS displacement [28]. Also in Peru, other studies confirmed that access to ICS spare parts is complicated [29], ICS post-acquisition services are uncommon [30], or that families keep using stoves in damaged condition, with only a few reporting attempts to repair or replace them [29–32]. Shortfalls in arranging mechanisms for stove maintenance and repair and ensuring spare part availability in the community have also been described in other South American and African countries such as Mexico, Uganda, Tanzania, and Kenya [33,34].

We also found that ICS users preferred to choose between different stove models with specific features. Overall, the application of community consultations to select ICS models and the active interaction between programme technicians and stove users in our setting facilitated stove acceptance and uptake. Likewise, the active participation of formal or informal community leaders in cooking interventions effectively reduced negative perceptions toward ICS implementers. However, these strategies were not commonly applied, as ICS managers had no power to implement these changes. In addition, ICS implementers did not consider specific alliances with community authorities, and local leaders declared to have insufficient competencies and resources to promote and support ICS programmes. Similar findings have been reported in other LMICs. A recent review of 191 papers showed that households in LMICs largely preferred stoves that were versatile in size and functions. However, these demands were rarely met by ICS implementers [35]. Likewise, the importance of social networks and leader opinions in stove acceptance and uptake has been described in other settings such as Honduras and Bangladesh [36,37].

Rumours and negative perceptions toward ICS implementers also affected ICS acceptance and uptake in our setting. The lack of interaction between ICS implementers and users and the lack of attention paid to programme implementation may partially explain why these perceptions were common in the three sites of our study. These effects have been analysed [38], but only a few have mentioned this barrier for cooking interventions. In rural Mexico, ICS users reported that distrust of local builders and NGO technicians influenced the acceptance of stoves [39]. In Guatemala and Peru, distrust among local LPG retailers reduced LPG uptake [19,20]. For these reasons, relationships between local communities and ICS implementers should be considered critical to ICS acceptance and uptake.

In our study, gender and family dynamics influenced stove acceptance, repair, and maintenance. The majority of cooking interventions in LMICs focus exclusively on women and children based on the premise that cooking is associated with normative gender roles [40]. However, our findings indicate that this approach may miss the importance of context-bound gender inequalities and relationships [41,42], as those men who were sensitised to and involved in ICS programmes were often more supportive of the interventions. Facilitating a positive attitude

toward male involvement in cooking interventions has been successful not only in terms of uptake, but also in terms of increasing diffusion and acceptance of these technologies. Experiences from Guatemala, Bangladesh, and Kenya show that men (who generally control household economic resources) tend to favour improved cooking technologies in the long term when they feel part of the interventions [36,43]. In Kenya, the availability of improved stoves enticed men to perform more household chores [44] and, in Uganda, the distribution of ICS led to reductions in self-reported domestic violence [45]. However, the inclusion of men as targets in ICS interventions is still limited. A recent review of stove programmes in LMIC implementing strategies to engage household members to promote stove uptake showed that only 18 studies implemented this approach and, in those who did, men were rarely purposefully engaged ($N = 4$) [46].

Finally, we found that expensive ICS certification prices and the lack of political continuity of ICS policies prevented the establishment of local entrepreneurs and reduced ICS diffusion. At the time of the study, the costs for certifying an ICS model in Peru were around US$ 600. This limited the capacity of small businesses to certify their own ICS models. This limitation prevented the diffusion of ICS models that were a needed commodity and had the potential of improving general wellbeing. In addition, the progressive decrease in political and economic support for ICS programmes after 2011 (partly caused by changes in the Peruvian priorities concerning clean cooking energies) negatively affected ICS diffusion [14]. The political support for the promotion of cleaner cooking energies, such as electricity or LPG over biomass, has also occurred in other countries where the use of biomass in rural areas was widespread, such as Ecuador, Brazil, Mexico, or India [47–50].

Our study has limitations. We invited men and women to FGDs, but nonetheless 95 % of FGD participants were women. In all the three regions, men were heavily engaged in agricultural work and had limited time to join FGDs. However, we believe the low presence of men helped women to speak freely about the role of men in the acceptance of ICS interventions, and it reflected the reality that mostly women interact with the ICS. In addition, the cross-sectional nature of the research did not allow for exploration of the dynamics and interactions between societal domains over time. Our results indicate the need to complement studies on system-level dynamics with methodologies borrowing from ethnography, being more focused in the analysis of social norms, group ideologies and daily social interactions over time [51]. Nevertheless, the systems level approach we applied helps to understand the systemic nature of processes involved in stove acceptance and uptake and prioritises the analysis of contextual relationships (e.g., interactions between users and implementing institutions), which we found to be relevant for stove acceptance – yet, they are rarely addressed in energy research [52]. Overall, our study shows that the combined application of the SEM and ICS adoption domains frameworks is useful to assess the success and failure of ICS interventions. As this approach focuses on both local, institutional, and policy knowledge, it facilitates the acquisition of an overall vision of the dynamics involved in stove programmes and the identification of concrete actions for improvement. Moreover, the structure of the frameworks can be easily adapted to other contexts and types of cooking fuels and technologies, such as LPG. The application of systems level approaches provides a valuable framework to understand multi-level dynamics in cookstove interventions. The analysis of the societal dimensions proposed by the SEM prior to ICS programme implementation may improve intervention design, facilitate programme success and effectiveness, prevent unforeseen programme adaptations, and improve cost-effectiveness of interventions. By lowering financial and time investments, based on the premise that the understanding multi-sectorial interactions and local contexts, could lead to better budget management and accountability.

5. Conclusion

This qualitative research in three Peruvian regions using systems level approaches demonstrates that factors linked to the acceptance and uptake of improved biomass cookstoves (ICS) are strongly influenced by complex dynamics at different societal levels. Action points to improve the success of large-scale ICS interventions in terms of acceptance and uptake include the need to incorporate people-oriented approaches (listen to ICS users); to develop multi-sectorial coordination, communication, and monitoring strategies; and to promote long-term political incentives. The application of systems level approaches prior to cookstove interventions provide valuable resources to prevent potential setbacks in programme implementation and improve cost-effectiveness.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2023.102958.

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