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Does participatory research stimulate sustained adoption of energy technologies? Lessons from stove dissemination in Gurué district, rural Mozambique

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A B S T R A C T

Research on energy transition to clean cooking suggests that the use of participatory approaches to design and evaluate the project impacts results in sustained adoption, user satisfaction, and continuous knowledge exchange between scientists and local stakeholders. However, the results of participatory approaches are mixed, and studies on long-term effects are rather scarce. This study uses an experimental design to test whether high stakeholder involvement in a participatory research approach is an effective tool for promoting the adoption of improved cookstoves. Data were collected from 138 participatory research participants and 448 conventional training participants. The results showed that participatory research is essential to stimulate early adoption, but is not sufficient to sustain adoption over time. Based on the results, we conclude that organizations implementing stove programs should not only consider strategies to encourage deep participation of potential beneficiaries in various stages (including planning, designing, testing, and modifying of improved cookstoves), but follow-up support should also occur. To sustain adoption, participation should be designed as a process that understands the mechanisms of unsustainable practices and the social demand for new technologies, going beyond adoption and promoting co-construction.

1. Introduction

The literature on participatory research approaches is rapidly expanding in various domains [1], resulting in diversity in definition, purpose, process design, and implementation [2]. According to Lilja and Bellon [3], participatory research can essentially be used to obtain two kinds of outcomes. First, by involving intended beneficiaries at different stages of the research process, participatory research can improve efficiency by accelerating and increasing adoption of research products. Second, participatory research can be used to empower intended beneficiaries by helping them establish groups capable of assessing their own needs and addressing them directly or through research organizations. The former is recommended when the intervention activities are limited to relatively few beneficiaries, while the latter should be sought by development organizations with longer-term interaction with beneficiaries [4].

In the context of energy transition to clean cooking, previous research suggests that the use of participatory approaches to design and evaluate the project impacts results in sustained adoption, user satisfaction, and continuous knowledge exchange between scientists and local stakeholders [5–8]. Clean cooking refers to the use of cooking technologies and fuels that reduce exposure to harmful emissions,

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improve indoor air quality, and promote environmental sustainability. Moreover, citizens should be strongly integrated into the decision-making processes of the energy transition by co-design and participatory research that incorporates local stakeholders' perspectives into the planning and implementation of more appropriate technology configurations [9].

Researchers advocate for participatory research approaches for a variety of reasons. Interventions based on scientific recommendations, regardless of the local knowledge and demand [8], have generally low success rates [10]. By allowing the involvement and active participation of stakeholders in the design, planning, implementation, monitoring and evaluation of transition processes [11], participatory approaches can improve technology adoption and facilitate social learning [12]. Participation fosters shared ownership and commitment to the process and outcomes, and enhances the likelihood of implementing the research findings [13].

Underlying participatory approaches is the assumption that innovations are designed to better fit context-specific needs [14]. Furthermore, participation ensures that innovations are better accepted and sustained by stakeholders and possibly even contribute to improved trust and collaboration between stakeholders, facilitating information exchange, support in case of crises (e.g., health, financial) and reducing conflict risk through improved communication between stakeholders [15,16].

However, participatory processes can also lead to negative results. This is intrinsically related to the fact that participation can vary in terms of stakeholders' involvement and control over the process [1]. In addition to the degree of stakeholder involvement, other factors could also explain the observed outcomes and changes [17]. Context-related framework conditions are also often stated as defining factors fostering adoption rates. Contact with more persuasive communicators such as peer farmers or a high-status market actors can impact technology adoption and result in a manipulative process [18–20]. Moreover, context-related behavioral factors and socio-demographic characteristics are also important determinants of farmers' decision to adopt new technologies [21–25]. In fact, the adoption of innovation does not necessarily ensure sustained usage [26,27], and it may vary or even decline over time [28,29]. Yet, studies on long term effects of participatory approaches in adoption process are rather scant. Most of the studies use a single data collection point to assess project impact. This lack of long-term perspective generally leads to an incomplete picture of the intervention outcome and limits the generalizations about adoption beyond the study samples. Thus, evidence is still needed to understand whether participatory approaches in which members of rural communities participate in designing the technology is enough to enhance long-term adoption [30]. In this context, this article aims to better understand whether participatory approach is increasing improved cookstoves sustained adoption in Central Mozambique.

Improved cookstoves (ICS) are cooking technologies that have been developed to improve cooking energy efficiency compared to traditional three-stone fire stoves (TSF). They reduce the amount of fuel required, fuel-gathering time and cooking time, resulting in reductions in fuelwood harvesting and particulate emissions, thus benefiting the local environment and global climate [31]. Furthermore, they can minimize the health dangers associated with indoor air pollution. In a study by Atanassov [32] in Mozambique, 23% of traditional biomass users reported conditions such as acute respiratory infections, chronic obstructive lung disease and lung cancer.

Based on a case study from Central Mozambique, this study follows a quantitative and experimental approach to test whether the use of a participatory approach as a potential entry point to implement ICS results in higher adoption rates compared to a controlled comparison approach, while controlling for the effect of other potential explanatory factors of ICS adoption in rural Mozambique. More specifically, we monitored the adoption rates over time to understand whether the participatory approach leads to sustained usage of ICS in Central Mozambique.

2. Methodology

2.1. Study design and participants

This study a follows comparative research design to evaluate the impacts of two implementation strategies on ICS adoption in Gurué district, located in the north of Zambézia province, Central Mozambique (Fig. 1). This is a rural, agriculture-based area with approximately 431,000 inhabitants, selected for being an example of an energy-scarce environment where energy interventions are necessary. Biomass is the main source of cooking energy, and it is also used for warming water, room heating and insect repellent purposes [33].

The methodological approach was based on three research phases: (a) first research phase: pre-implementation, (b) second research phase: participatory and non-participatory (i)/control ICS implementation (ii), and (c) adoption assessment.

a) First research phase: pre-implementation

The first research phase (a) was based on a survey of 296 households in the case study area, conducted in February and March 2020. The pre-implementation survey provided information that guided the development of the interventions. This information included household energy consumption, access to clean cooking fuels and interest in improved cooking technology. All interviewed households were using wood-burning stoves, particularly the TSF and nearly 90% were interested in trying a new cooking technology.

b) Second research phase: participatory and non-participatory/control ICS implementation

After the pre-implementation survey, we introduced a specific type of improved cookstoves (mud-ICS) in the study area. Improved cook stoves have been developed to improve cooking energy efficiency compared to TSF. They reduce the amount of fuel required, fuel-gathering time and cooking time, resulting in reductions in fuelwood harvesting and particulate emissions, thus benefiting the local environment [31]. Furthermore, they can minimize the health risks associated with indoor air pollution.

In phase (b), two different approaches were applied: (i) a participatory research approach, involving 150 randomly selected households and (ii) a conventional training of 510 households on how to construct, maintain, and use the ICS without any inclusion of participatory elements in innovation design and dissemination. To control for spillover effects, households in the control group (conventional training) were asked about their interactions with participatory research participants. In case where the answer was positive (yes), they were excluded from the research. Lastly, we evaluated the innovation's success by measuring the adoption rates in two rounds of semi-structured interviews. The description of both ICS implementation strategies is as follows.

i. Participatory research

With this group, activities commenced with an exploratory phase. Three facilitators from the research team conducted village meetings in Portuguese (including translation to the local language) in which participants reflected on the current condition of their cooking devices and ways of improving them. Subsequently, biomass ICS and their characteristics were presented to provide access to relevant information required for informed decision-making and a detailed discussion about the advantages and disadvantages of using an ICS took place. Images of different biomass-burning cookstoves introduced in Tanzania [5,8] and Kenya [34] and other regions of the world [35] were shown and the advantages and disadvantages of each model were openly discussed.

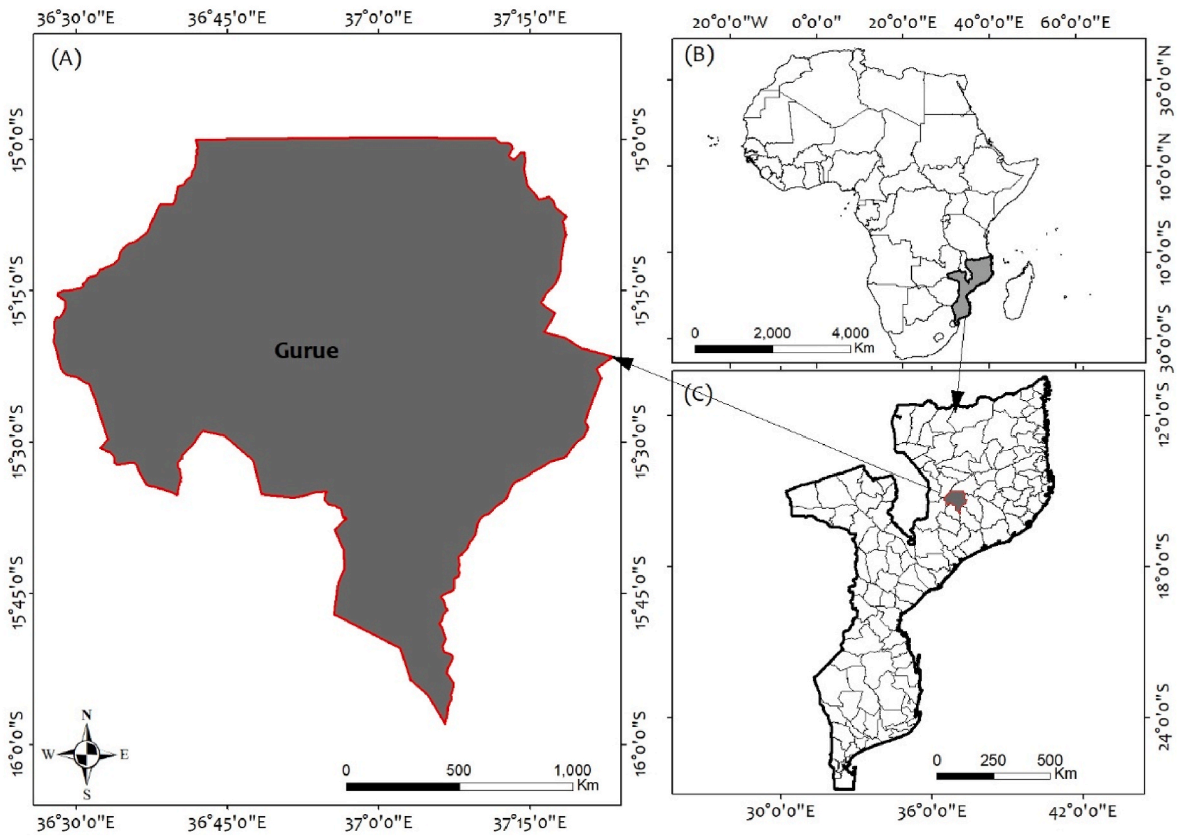

Fig. 1. Study area: Gurue district (Zambézia province, Mozambique).

These discussions were used to promote interactive discussions about the design and adoption of ICS. These group discussions allowed participants to openly discuss the pros and cons of various ICS models, fostering a collaborative decision-making process. To address potential power differentials in the discussions, participants were informed that they were free to support, contradict, and challenge each other regardless of background or social status [36]. Facilitators monitored the discussions closely and used strategies such as smaller group discussions to ensure that all participants had the opportunity to voice their opinions. While no overt tensions or domination of the discussions by more powerful participants were observed, we recognize that subtle dynamics of power may still have influenced the process. These challenges are inherent in participatory research and warrant continuous attention and reflection. As such, all participants were actively engaged in the discussions, and were allowed to validate or oppose opinions from all other participants regardless of their status in the community. The discussion culminated in an agreement on five points: 1) The ICS should have a chimney to prevent smoke accumulation in kitchens; 2) it has to be a two-pots design; 3) the building materials needed to be locally available (e.g. mud and banana stem); 4) it should have one fuel supply opening; and 5) firewood should be the main fuel. Based on the agreements reached during the discussions, two proposals of ICS were generated, a few adjustments were made by the group and the design presented in Fig. 2 was generated and approved.

After the selection of the stove design, field testing of the ICS using a controlled cooking test (CCT) [37] was jointly conducted to analyze how efficient the ICS is compared to TSF. Prior to the tests, the quantity of ingredients, types of fuels and pots used during the CCT were jointly agreed upon with the study participants to reflect the normal cooking preferences and practices of the community. Whenever possible, both male and female representatives of each selected household were involved in the process. Nevertheless, this was not always possible and, thus, only a female or male representative was trained from the

Fig. 2. Selected stove design.

household. Overall, 75% of the participants were female and 25% were male. This gender imbalance reflects the traditional gender roles in rural Mozambique, where women are typically responsible for cooking and managing household energy needs. As a result, women were more inclined to participate in the training sessions, as improved cookstoves directly impacted their daily activities. Conversely, men, who are often less involved in these household tasks, showed lower participation rates. Understanding these gendered social norms is important for designing and implementing effective interventions, as addressing potential barriers to male participation or stigmas around women's involvement in such initiatives can enhance the inclusivity and success of these programs. After the CCT, the participants analyzed the sensory characteristics of the food cooked in the ICS, comparing it with the food cooked in the TSF. This process resulted in the final ICS design according to local needs.

After the tests, the participants were trained on how to construct, maintain, and use the ICS. This process took 32 days and two separate sessions of 10 participants each were held per day. In total, each group of 10 people attended four sessions in four consecutive days. Thus, in the first 28 days, 20 households were covered every four days (totaling 140 households). The remaining ten households were trained from day 29–32. The number of participants per training session was restricted to ten due to the presidential decree issued in the context of the Covid-19 pandemic. Although there were no restrictions on who could participate in the sessions, the group of participants mainly consisted of small-scale farmers.

ii. Non-participatory training approach/control

The stove design generated during the participatory process was also introduced to a second group of study participants using a non-participatory approach. Since the project to which this research is linked also aimed to disseminate the ICS to the largest possible number of residents, in this process the number of participants was even higher. As such, 510 household representatives were randomly selected to attend the workshops in groups of ten or individually during which they were trained on how to construct, maintain and use the ICS. The training participants were from communities that were not part of the participatory research activities. The training included theoretical aspects of the ICS, its advantages and disadvantages as well as demonstrations and explanations on how to construct, use and maintain the ICS. At the end of the training sessions, pamphlets were provided to participants for future reference. As in the participatory research activities, both male and female representatives of each selected household were targeted; however, it was not always possible. Overall, 84% of participants were female and 16% were male. Since the trainings involved both theoretical and practical modules, two different groups of instructors were involved. The theoretical aspects were provided by the research team, and the practical aspects were conducted by previously trained local residents.

c) Third research phase: adoption assessment

To assess adoption rates and drivers fostering and hindering adoption (research phase c), the experiment was accompanied by semi-structured questionnaires, administered to respondents in January 2021 (one month after the participatory research and training activities) and between January and February 2022 (one year after the first questionnaire). This assessment of adoption rates in two data collection periods was done to capture variations in adoption rates over time. Similar to the ICS introduction activities, for each sampled household, both male and female respondents were interviewed together whenever possible. The questionnaire included questions to collect socioeconomic and demographic information (age of household head, education level, household size, etc.) and whether the household had adopted the ICS. Following Troncoso [38], we considered adopters, households using the ICS at least two times per week.

2.2. Data collection

In all research phases, data were collected through semi-structured interviews, conducted by local enumerators who had attained at least the 12th grade and had a good comprehension of Portuguese and the local language. These interviews included a mix of open-ended and closed-ended questions to allow respondents to provide detailed qualitative insights while maintaining a structured format for comparison. The interviews typically lasted between 30 and 60 minutes, and were conducted privately in respondents' homes or other confidential settings. Both male and female household representatives were interviewed together whenever possible, or individually when necessary. This approach enabled the collection of both consistent and in-depth data across households. The enumerators were recruited and trained for at least two days on the administration of the study questionnaire. A pre-test of the questionnaire was also conducted before the actual field-work to ensure that the questions were understood by the respondents and elicited meaningful or desired responses. Before the interview, all survey participants provided informed oral consent. Data collection was performed in accordance with the guidelines laid down in the 'Declaration of Helsinki' and ethically reviewed by the Mozambican National Committee of Bioethics in Health (IRB00002657, Ref 370/CNBS/19). The local authorities were consulted and provided research permission. Participation in the survey was completely voluntary and participants had the option to skip questions or end the interview at any moment.

2.3. Data analysis

For the adoption assessment, initially, the data were cleaned and incomplete entries from individuals whose responses on ICS adoption were missing in at least one of the data collection rounds were removed. This reduced the number of households included in our analysis to 138 participants from participatory research (group i) (88 % of the full sample) and 448 participants of conventional training (group ii) (88 %).

Descriptive statistics were used to provide summaries of the data. Welch's *t*-test was used to compare the means for continuous variables due to differences in sample size, and the chi-square test of independence was used to detect statistically significant differences in the categorical variables. To examine the effect of the participatory approach on the adoption of ICS, a random effects probit model was applied, controlling for household-level control variables. This model is designed for the case in which the individuals are repeatedly classified on a binary outcome variable [39], and the independent variable is randomly assigned by the experimenter [40]. It assumes that there is an unobserved latent variable [41], represented as:

$$Y^*_{i,t} = \alpha + \beta X_{i,t} + \varepsilon_{i,t} + u_i \quad (1)$$

Where $Y^*_{i,t}$ is the latent variable, $X_{i,t}$ is the vector of independent variables (see Table 1 and Fig. 2), β is the vector of coefficients, $\varepsilon_{i,t}$ and u_i are the idiosyncratic and individual-specific error terms, respectively. The

Table 1
Overview of household characteristics.

Variable	Conventional Training (n = 448)	Participatory Research (n = 138)	Statistical Test	p-value
Quantitative Variables				
Age (years)	43.23 (13.86) [19–70]	41.67 (10.96) [19–67]	t = 1.36	0.17
Education (years)	5.08 (2.91) [0–16]	6.00 (2.40) [2–12]	t = −3.74	<0.001
Income (MZN)	5244.44 (4837.03) [1000–43224]	4746.49 (2130.87) [1000–7800]	t = 1.71	0.09
Household Size	6.07 (2.41) [1–13]	5.74 (2.52) [1–13]	t = 1.35	0.18
Qualitative Variables				
Network Adopting (%)	38 %	52 %	$\chi^2 = 8.25$	0.004
Female Household Heads (%)	16 %	10 %	$\chi^2 = 2.96$	0.085
Previous Experience with ICS (%)	3 %	1 %	$\chi^2 = 1.12$	0.291

observed binary dependent variable occurs when $Y_{i,t}^{*}$ exceeds a given threshold [42]:

$$Y_{i,t} = \begin{cases} 1 \text{ if } Y_{i,t}^{*} \geq 0 \\ 0 \text{ if } Y_{i,t}^{*} < 0 \end{cases} \quad (2)$$

We estimated the probability that a randomly chosen individual from the population adopts an ICS conditional on participation in the process, while controlling for the effects of socioeconomic and demographic characteristics. The dependent variable is a dummy variable that equals 1 if the household adopted the ICS and 0 otherwise. Participation in the process is one of the independent variables, measured as a dummy variable that equals 1 if the study participant participated in the participatory process and 0 otherwise. The marginal effects of the participatory approach on the probability of adopting ICS were estimated using the following equation:

$$Pr\left[Y_{i,t}=1|X_{i,t}\right] = \Phi\left(\frac{\alpha+\beta X_{i,t}}{\sqrt{1+\sigma_u^2}}\right) \quad (3)$$

Where Φ is the standard normal cumulative density function [40]. $Y_{i,t}$ is the dependent variable that equals 1 if the household adopted the ICS and 0 otherwise.

Furthermore, we computed a log-linear model, as defined by Buis [43], to test whether the patterns of adoption – i.e., the differences in the number of ICS adopters between the two training approaches (participatory and non-participatory) and across the two years (2021 and 2022) – varied significantly. To assess these patterns, we included interaction effects between the number of adopters and non-adopters and training method, as well as between the year and the adoption rate (number of adopters and non-adopters). This allowed us to capture how the adoption rates varied across different years and between training methods. A Poisson regression model was used for this analysis, as the data consist of counts (the number of adopters and non-adopters), obtained by cross-tabulating the number of (non-)adopters by each year and the training method.

3. Results

3.1. Descriptive statistics

The household-level characteristics of the study participants are shown in Table 1. Quantitative variables are summarized using their mean values (the average), standard deviation (a measure of variability), and min–max (the range of observed values). For categorical (qualitative) variables, the table shows the percentage of participants in each category. The table also includes the results of Welch's *t*-test for comparing the means of the quantitative variables and Pearson's chi-square test for assessing the association between the qualitative variables. The p-values indicate whether the differences between the two groups (participatory research and conventional training) are statistically significant.

Overall, there were no statistically significant differences between participants in group i (participatory research) and group ii (conventional training) in terms of age, monthly income, household size, previous experience with ICS, and the proportion of female-headed households. However, differences were observed in education levels and interaction with other ICS adopters. The mean education level of the household head was higher among participatory research participants. A majority of participants in group i (52%) had interacted with other ICS adopters, but only 38% of conventional training participants had a network of other ICS adopters (referred to as "Network adopting"). In this context, having a network means having someone in the participant's social network (such as family, friends, or community members) who has already adopted ICS.

3.2. Participatory research effects

Table 2 presents the random effects probit model results following equation (3), which includes a dummy variable indicating participation in the participatory research. Participation in participatory process activities is a significant predictor of ICS adoption. The average marginal effect of the participation dummy on the probability of ICS adoption is 0.605, indicating that the probability of adopting ICS increases by more than 60% when the farmer participates in the participatory approach. Moreover, the results also indicate that interaction with other ICS adopters increases the probability of ICS adoption. The other potential predictors had no influence on adoption. The model's rho (ρ) value of 0.08 suggests that 8% of the variation in ICS adoption is due to unobserved household-specific factors, indicating that household-level differences play a smaller role compared to individual-level factors and observed predictors.

3.3. Adoption rates over time

The results of adoption rates at the two data collection points are shown in Fig. 3. Initial adoption of ICS is higher among participatory research participants. However, over time, the proportion of adopters decreased to the same level as the training participants. This implies that participatory research is effective in stimulating early adoption but follow-up activities seem to be necessary to ensure the use of ICS in the long run and thus sustain adoption. In 2021, the adoption rate was 41 % among participatory research participants and 18 % among conventional training participants. One year after the first data collection, the values dropped to 13 % for both implementation approaches.

Not surprisingly, the difference between the adoption rates in the two years is statistically significant (Table 3). The incidence rate ratios (IRR) from the Poisson regression model show that the odds of adopting ICS when trained via the participatory approach are 2.62 times higher than the odds of adopting after a non-participatory approach. Moreover, the odds of adopting the ICS in 2022 are 62% [(0.38–1)*100%] less than the odds of adopting an ICS in 2021.

The interaction effects show how the impact of training method and year on adoption differs when considered together. Specifically, the interaction term between Year (2022) X Adoption shows that the difference in adoption between 2021 and 2022 varies based on the adoption process. Similarly, the interaction term between Adoption X Participatory Research reflects that the influence of participatory research on adoption may differ depending on the year of adoption.

4. Discussion

This study investigated the impact of participation in participatory research on the adoption of improved cookstoves (ICS) in Gurue district,

Table 2
Random effects Probit model estimates.

Variables	Coefficients	Standard errors	Marginal effects	p_{value}
Participatory research participant	0.61	0.13	0.605	<0.001
Network adopting	0.25	0.12	0.251	0.04
Gender	0.00	0.16	0.002	0.99
Age	0.00	0.01	<0.001	0.96
Education	0.02	0.02	0.016	0.43
Previous experience with ICS	0.13	0.34	0.131	0.70
Income	0.00	0.00	<0.001	0.14
HH Size	0.03	0.02	0.027	0.23
Constant (α)	−1.00	0.48		0.04
$\ln(\sigma_u^2)$	−2.44	1.07		
σ_u	0.30	0.16		
rho (ρ)	0.08	0.08		

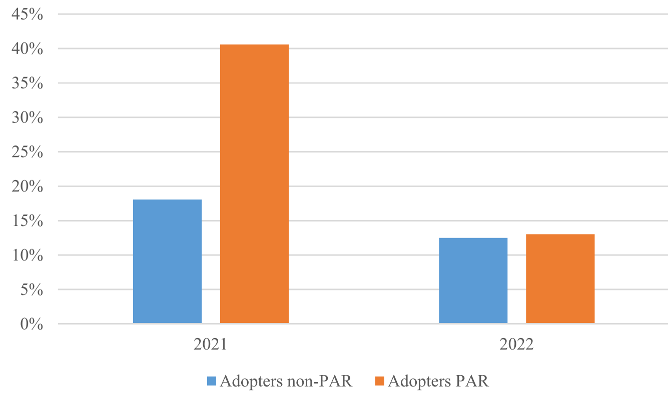

Fig. 3. Adoption rates over time.

Table 3
Poisson regression model.

	IRR	Std. Err.	z	p_{value}
Adoption	0.69	0.09	−2.89	0.004
Participatory research	0.21	0.03	−11.52	<0.001
Year	1.40	0.15	3.24	0.001
Adoption X Participatory research	2.62	0.52	4.85	<0.001
Year (2022) X Adoption	0.38	0.07	−5.36	<0.001
Constant	129.38	10.79	58.29	<0.001

Central Mozambique. Overall, our results suggest that participation in the participatory research activities is associated with early adoption of ICS. Participatory research participants were 60% more likely to adopt ICS than the control group, according to the random effects probit model estimates. These results align with studies that advocate for more participatory approaches to disseminate ICS [5–8,44]. However, participatory research alone was not sufficient to sustain the adoption over time. One year after the initial data collection, the levels of adoption decreased from 41% to nearly 13%, the same levels as the non-participatory approach.

The decline in adoption underscores the need for continued community engagement and the adoption of broader frameworks that ensure the long-term sustainability of low-carbon technologies. As highlighted by Boateng [45], political ecology frameworks for sustainable energy transitions stress the importance of inclusivity and attention to power dynamics, particularly in the Global South. Ensuring that these transitions are just and equitable is essential, as simple technologies like cookstoves play a critical role in energy access and sustainability. These findings imply that while participatory approaches are effective in driving initial adoption, they must be supplemented with ongoing support and engagement to avoid the diminishing benefits over time. This reinforces the need for local participation and context-specific strategies to avoid the risks of exclusion and ensure sustained use, as advocated in broader energy transition frameworks.

The results of the log-linear model confirmed that the odds of adopting ICS were significantly higher for participants in the participatory approach compared to those in the non-participatory approach. However, the model also revealed that in 2022, the odds of adoption were 62% lower than in 2021. These findings suggest that while participatory approaches are effective in promoting early adoption, they may not be sufficient to ensure sustained use over time without continued support. In fact, the decline in adoption rates over time highlights the potential for initial gains to diminish, which could undermine the long-term benefits and sustainability of ICS adoption and usage [28,29].

Our analysis further showed that interaction with ICS adopters significantly increases the likelihood of adoption. Specifically, households that interacted with ICS adopters were 25.1% more likely to adopt ICS compared to those without such interactions. Thus, a central conclusion derived from the results of this study is that participatory implementation processes of ICS might have to be supplemented with other behavior changing or persuasive techniques such as peer-to-peer communication to sustain adoption. Seguin [46] conducted a study in Rwanda in which they found that households who adopted ICS were mainly those who received positive feedback on reduced expenses and cooking time and increased cleanliness, while negative feedback on the damage to cooking pots and overcooked food prevented adoption. As such, interaction with other users is key for households' decision to adopt ICS. It is noteworthy, however, that peer influence can be positive or negative. Therefore, participatory approaches are still important as they ensure that the design of the ICS corresponds to the expectations and needs of the users [6,7]. Moreover, early adoption is also essential especially among the so called "independent adopters", who have the ability to influence their peers' decision to adopt [47].

Contrary to our expectations, factors such as age and education of the household head, gender, household size and income had no effect on adoption. More specifically, gender is an important aspect, since women are most often responsible for duties associated with cooking. However, in the context of our study, both male and female representatives were, whenever possible, involved in the dissemination processes. Thus, in general, both women and men were included in the decision-making process, and we postulate that we have removed the adoption barrier related to poor communication between men and women on cooking and fuel choice issues [48]. Other studies have also found household-level characteristics such as household expenditure, age, sex, education or household size as non-significant predictors of ICS adoption [49,50]. However, we recommend caution regarding generalization of these findings, since cooking needs and preferences are highly context-specific and can influence the take-up of new ICS [50]. Our findings should be framed in the context of our study location.

Although household size and income did not have a statistically significant effect on ICS adoption in our study, we recognize the broader issue of energy poverty and the potential for stigmatisation around admitting financial difficulties. In this particular context, the minimal cost of building the ICS, due to the availability of free local materials, likely reduced the impact of income on adoption. Additionally, the participatory approach ensured that the stove design was accessible and aligned with the community's resources. However, we acknowledge that in different settings, energy poverty and social stigma could play a more significant role in limiting access to improved cooking technologies. Future research should explore these factors more explicitly to understand how financial constraints might influence adoption in contexts with different resource availability. Moreover, we recommend that promotion and dissemination programs should first consider local context to design an optimal and user-friendly ICS. Involving community members and stakeholders in co-designing is also essential to improve community cohesion and help neighbors work together to make a positive change in their collective behavior and living environment [51].

Regarding research limitations, we indicate that, first, the adoption rate was calculated based on self-reported usage of ICS, which makes it possible that social desirability bias might have contributed to the study results. Second, we were unable to include potential predictors of adoption, namely, fuel availability [52] and household assets [50] due to issues related to strategic under-reporting [53]. Finally, it was not always possible to include both men and women in research activities. This might have influenced the adoption rate since involving women in the decision-making process can influence adoption [48]. However, despite these limitations, our experimental approach allowed us to control for most study conditions generating consistent conclusions.

5. Conclusion

In this study, we explore the influence of participatory research on the adoption of improved cookstoves. This study finds that participatory research increases the likelihood of improved cookstoves adoption. Nevertheless, participatory research only stimulates adoption at early stages. These findings suggest that participatory design of technology is a key but not the sole condition necessary for a successful sustained adoption. The priority of the participatory process might be focusing on a deep understanding of the local problems, the mechanisms of unsustainable practices and social demand for the new technologies, going beyond adoption and promoting co-construction. Therefore, organizations implementing stove programs should not only consider strategies to encourage deep participation of potential beneficiaries in various stages, including planning, designing, testing, and modifying of ICS, but also provide follow-up support

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Declarations of interest

none.

CRediT authorship contribution statement

Custodio Efraim Matavel: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **Harry Hoffmann:** Funding acquisition, Project administration, Writing – review & editing. **Harald Kaechele:** Conceptualization, Methodology, Writing – review & editing. **Katharina Löhr:** Writing – review & editing. **Michelle Bonatti:** Conceptualization, Writing – review & editing. **Harison K. Kipkulei:** Writing – review & editing. **Hamza Moluh Njoya:** Writing – review & editing. **Jonas Massuque:** Investigation, Writing – review & editing. **Stefan Sieber:** Funding acquisition, Supervision, Writing – review & editing. **Constance Rybak:** Funding acquisition, Writing – review & editing.

Data availability

Data will be made available on request.

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