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Gunther Bensch and Jörg Peters[1]

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Abstract

Today more than 2.7 billion people rely on biomass as their primary cooking fuel, with profound implications for the environment and people's well-being. Wood provision is often time-consuming and the emitted smoke has severe health effects – both burdens that afflict women in particular. The dissemination of Improved Cooking Stoves (ICS) is frequently considered an effective remedy for these problems. This paper evaluates the take-up of ICS and their impacts through a randomized controlled trial in rural Senegal. Although distributed for free, the ICS are used by almost 100 % of households. Furthermore, we find substantial effects on firewood consumption, eye infections, and respiratory disease symptoms. These findings substantiate the increasing efforts of the international community to improve access to improved cooking stoves and call for a more direct promotion of these stoves.

JEL Classification: C93, D12, O13, Q41, Q56

Keywords: Impact evaluation; randomized controlled trial; respiratory disease symptoms; energy access

March 2012

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1. Introduction

In September 2010, the *Global Alliance for Clean Cookstoves* was launched under the auspices of the *United Nations Foundation*, promoted by Hillary Clinton as one of its prominent ambassadors (ECONOMIST 2010). Funded by both public and private partners, among them many bi- and multilateral donors, the objective of the Alliance is to encourage 100 million households to adopt clean cookstoves by 2020.[1] Today, almost 600 million households or 2.7 billion people in developing countries rely on traditional biomass-based fuels, mostly firewood, for their daily cooking purposes. In rural Africa, the share of biomass users approaches 100 % (IEA 2010).

Biomass usage for cooking purposes is associated with various negative effects on living conditions. The emitted smoke is a major health threat: According to WHO (2009a), two million people die every year due to household air pollution – more deaths than are caused by malaria (MARTIN ET AL. 2011). To the extent that firewood has to be collected, woodfuel usage poses a heavy work burden that is mostly borne by women. If the firewood is purchased, significant monetary costs may be incurred. Not least, given that the woodfuel is not extracted sustainably, firewood or charcoal usage also contributes to deforestation – a serious problem particularly in arid countries.

While clean cookstoves as defined by the Global Alliance also comprise stoves using modern cooking fuels like electricity and Liquefied Petroleum Gas (LPG), so-called Improved Cooking Stoves (ICS) that still use biomass are considered a viable low-cost "bridging technology".[2] ICS are designed to reduce the fuel consumption per meal and to curb smoke emissions. The definition of ICS ranges from more sophisticated bricked stoves with chimneys leading the smoke out of the kitchen to very simple portable clay or metal stoves that just improve the heating process.[3] The present evaluation focuses on a portable clay-metal stove that has been disseminated widely in urban Africa, including

[1] See www.cleancookstoves.org for more information on the Global Alliance on Clean Cookstoves.
[2] See MARTIN ET AL. (2011) for a recent overview on the improved stoves and air pollution policy debate.
[3] See WORLD BANK (2011) for a more detailed discussion of different types of improved cookstoves.

Dakar, but also in rural areas in other African countries.[4] This ICS is expected to save around 40 % of firewood compared to traditional stoves according to laboratory tests and costs around 10 US$.

Desspite its seeming superiority – given the price of just a few dollars an ICS can be expected to amortize after some weeks – the ICS technology has not made inroads into African households. Various reasons could serve as explanations: Most of the benefits of ICS usage mentioned above are not monetary ones, which makes it more difficult for rural households to finance the investment given liquidity and credit constraints. Furthermore, the decision maker on investments such as buying an ICS within the household is often not responsible for cooking and, hence, does not bear the burden of firewood collection and usage. Not least, people might simply not be aware of the various benefits associated with ICS adoption (MILLER AND MOBARAK 2011).

This leads to a more general policy debate: Assuming that a certain product generates obvious and considerable benefits for users in addition to external effects beyond the user herself, should the government (or someone else) give it away for free or at a subsidized price if markets fail to generate a substantial penetration of the product? On the one hand, some argue that people do not appreciate and, consequently, do not use what they receive as a gift. In the particular case of ICS, most development practitioners share this opinion and reject the option of distributing ICS for free (MARTIN ET AL. 2011). This disapproval is in part rooted in the experience of many earlier programs that unsuccessfully tried to introduce ICS by strongly subsidizing them. On the other hand, the costs of establishing sustainable markets are high and recent experimental studies have shown that paying a positive price does not necessarily lead to higher usage rates. KREMER AND MIGUEL (2007), for example, persuasively argue in favor of providing access to health relevant goods for free to the extent they have a public good character, because "it may be difficult for external interventions to promote sustainable voluntary public good provision".

[4] The stove is called Jambar in Senegal and Jika in Kenya (see WORLD BANK 2011).

In this paper, we present results of a field experiment that we conducted in order to examine the take-up behavior of ICS that were assigned to people free of charge and to evaluate the impacts of ICS usage. We randomly distributed ICS among households in 12 villages in Senegal without previous access to ICS. In total, 253 households were interviewed, of which 98 were randomly selected to obtain an ICS for free after the baseline survey in November 2009. The follow-up survey was conducted in November 2010.

This randomized controlled trial (RCT) builds on BENSCH AND PETERS (2011), a quasi-experimental impact study of an ICS dissemination project implemented in urban Senegal by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). The GIZ cooking fuel project named *Foyers Améliorés au Sénégal* (FASEN) – one of the many projects participating in the Global Alliance for Clean Cookstoves – has hitherto supported the dissemination and local production of ICS mainly in urban areas, but envisages scaling-up its activities to rural areas.

The experimental set-up enables us to preclude selection biases that often afflict evaluation studies: The decision to obtain a treatment like ICS might be driven by characteristics that also affect outcome variables such as fuel consumption. The impact indicators for which we aim to test a causal relationship with ICS usage are firewood consumption, time savings and health effects, all observed at the household level. So far, these questions have hardly been examined in the field. While some evidence exists from Latin America and Asia, rigorous studies in Africa are virtually non-existent so far (see Section 2.1).

The remainder of the paper is organized as follows: Section 2 reviews the related literature as well as the country and intervention background, Section 3 presents the research design including the identification assumptions. Section 4 discusses the results, and Section 5 concludes.

2. Literature and program background

2.1. Literature

The importance of cooking fuels and improved cookstoves for people's well-being has been frequently acknowledged both on the policy level and in the academic community. Most recently, MARTIN II ET AL. (2011) have highlighted the profound implications woodfuel usage for cooking purposes has for both the using people and the environment. At the same time, they call for more rigorous evaluations of ICS impacts. In fact, only few studies have been conducted worldwide, most of them in Latin America and Asia. For health impacts, SMITH-SIVERTSEN ET AL. (2009) find a substantial reduction in exposure to household air pollution and a reduction in risk for respiratory symptoms in a field experiment for which stationary chimney stoves were randomly assigned to replace traditional open fires in rural Guatemala (see as well SMITH-SIVERTSEN ET AL. 2004). MASERA ET AL. (2007) find similar results in rural Mexico and DIAZ ET AL. (2007) observe a significant reduction in headaches and eye infections in Guatemala, both also after introduction of chimney stoves. ADRIANZÉN (2010) examines ICS usage in Peru and finds a 30 % reduction in firewood consumption as well as a decreasing effect on respiratory disease and eye discomfort symptoms. YU (2011) examines the effects of behavioral interventions in combination with ICS interventions in rural China and find that this double treatment brings down respiratory diseases among children under five. This effect seems to be mainly triggered by behavioral changes, though. Also for China, MUELLER ET AL. (2012) find evidence for impacts of ICS ownership on self-reported health indicators. Another rigorous impact study is currently conducted in India by the Jameel Poverty Action Lab (J-Pal) (see DUFLO, GREENSTONE, AND HANNA 2008a, 2008b).

The only impact study on ICS usage in Africa so far is BENSCH AND PETERS (2011) who find that the ICS dissemination in urban Senegal has induced substantial reductions in charcoal consumption, whereas firewood is virtually nonexistent in these areas. Although LPG turned out to be the predominantly used cooking fuel, with charcoal being used only complementarily in most cases, the charcoal savings attributable to the dissemination project are found to be considerable. Health or time use effects, in contrast, could not be evidenced. The impacts of ICS usage in rural areas can be expected to differ considerably because of the prevalent usage of firewood with three-stone open fire stoves.

Beyond impacts of ICS usage, this paper examines take-up behavior for ICS. Practitioners working in ICS dissemination programs widely claim that people should pay a cost covering price of ICS. Based on experiences with former ICS programs the rational for this is that, first, a sustainable market for ICS is considered a pivotal long-term success factor and, second, it is expected that a "stove purchased by the consumer is inherently more valued than one that is received without charge" (MARTIN II ET AL. 2011). Likewise, BARNES ET AL. (1994) report programs to be unsuccessful if ICS are given away for free and state that "people just do not value things that are given to them". The question of whether usage of health relevant goods is influenced by whether people pay a positive price for the respective good has been studied in a set of RCTs recently. MILLER AND MOBARAK (2011) examine adoption behavior for two different ICS types – one with chimney and one without – while randomizing the price for which the ICS is offered to households. They find that only few households purchase the ICS when it is offered at full price. Adoption rate is substantially higher at 69 % if the ICS is offered for free. Usage intensity is not subject to their study.

TAROZZI ET AL. (2011) examine usage intensity of malaria bednets, also by means of an RCT in which one group receives the nets for free, while in another group people have to pay a positive price. They find that people who received the nets for free use it even more intensively than people who paid a price. Also for malaria bednets, COHEN AND DUPAS (2010) do not observe a difference in the take-up behavior between households who paid for the good and those who got it for free. These empirical results are somewhat inconsistent with the expectation of many practitioners in development cooperation suggesting that usage intensity increases if people pay a positive price. This expectation is due to what the academic literature refers to as the screening effect and the sunk cost effect. While the former denominates the fact that people willing to use a certain good can be expected to self-select into ownership. The sunk cost effect refers to the psychological effect that is also picked up for ICS by MARTIN II ET AL. (2011) and BARNES ET AL. (1994): If one has paid a positive price for a good one is more inclined to value this good. ASHRAF, BERRY, AND SHAPIRO (2010) examine the existence of these two effects in detail for usage behavior of a water purification product and only find some evidence for the screening effect, but they do not find that people respond to the sunk cost effect.

2.2. Cooking fuels and improved stoves in Senegal

Firewood is the prevailing cooking fuel in rural Senegal used by 89 % of households in rural areas, whereas 70 % of the urban Senegalese population predominantly use LPG for cooking purposes (ANSD 2006). Many urban households nevertheless use charcoal complementarily. Here, both cooking fuels are purchased, which makes the dissemination of ICS much easier in such urban areas compared to rural Senegal, where most households collect the firewood without monetary costs. Accordingly, ICS distribution and dissemination has so far been concentrated on urban areas. In 2006, the GIZ project FASEN was initiated to support the dissemination of ICS as part of the Dutch-German Energy Partnership *Energising Development*. In contrast to earlier ICS interventions, FASEN focuses on establishing a sustainable market for ICS. The most popular ICS is the Jambar, which was originally developed in Kenya in the 1980s. It is a portable stove with a fired clay combustion center enclosed by a metal casing. Both charcoal and firewood types exist. As firewood is the dominant fuel in rural areas, we used the firewood Jambar for our experiment (ICS in the following; see Appendix 1 for pictures of stove types used in the study region).

According to controlled cooking tests (CCT), the fuelwood saved when cooking with this ICS compared to traditional stoves amounts to around 40 % (see also Section 3.1). On rural markets the ICS is not available so far. It is the approach of the GIZ program to initiate this market by training retailers and women groups who could then sell the ICS produced in the district capital Kaolack. The market price will be around 4000 to 5000 FCFA (8-11 US$).

Traditional stove types used in rural areas are either three-stone stoves that are available at zero cost or metal stoves that can be bought for 500 to 2500 FCFA (1-5 US$).

Apart from the southern region Casamance, Senegal is an arid and Sahelian country. While it still counts a relatively high share of primary forests, these forests mainly consist of small trees and shrubbery. Apart from agricultural land clearance, wood usage for cooking purposes is the most important driving force of ongoing deforestation (see WEC/FAO 1999; FAO 2005a; 2005b, TAPPAN ET AL. 2004). In addition, a constant population growth of 2.6 % per year (AfDB 2010) increases pressure on fuelwood markets. As a consequence, households face an increasing scarcity of fuelwoods: firewood collection becomes more and more time-consuming, while fuelwood prices are rising. This constellation particularly applies to the Bassin Arachidier, the study area of this evaluation, situated some 200 kilometres South-East of Dakar.

Official data on the burden of firewood collection is not available for the Bassin Arachidier. BENSCH, PETERS, AND SIEVERT (2011) provide information on firewood collection for a sample of villages in this area: Virtually all households collect firewood instead of buying it. They spend on average 23 hours per week to obtain the wood.[5] This work is in most cases spread across two or three household members – practically always women. Even the few households who buy the wood still require one hour per week to do so. Considering that virtually all rural households prepare their meals in open fires and that 83 % of households in the target region of the RCT regularly cook inside, household air pollution represents another drawback of traditional cooking practises. WHO (2009b) reports some estimated 6,300 deaths per year due to household air pollution in Senegal.

[5] WHO (2006) reports comparable numbers for other arid West African countries. Women in Burkina Faso and Niger are reported to spend 2.5 and 4 hours per day on firewood collection, respectively.

3. Methodological approach

3.1. Impact indicators

The first impact indicator of our study is the *household consumption of firewood*, which we observe for each dish cooked in a typical week. The rational for this indicator is that a reduction in firewood consumption has not only immediate implications for wood scarcity and deforestation pressures, but it is also a strong intermediate indicator for other ultimately relevant impacts such as health and time expenditures. In addition, impacts on health and time use are examined. For this purpose, we investigate the *time spent by household members on firewood collection and cooking*. To examine the prevalence of diseases that are potentially related to firewood usage we look at symptoms that are likely to be affected in the short-term after smoke emissions are reduced, this is *symptoms of respiratory diseases and eye problems*. For respiratory diseases, these are cough, asthma, or difficulties in breathing. These symptoms indicate acute respiratory infections and chronic obstructive pulmonary diseases, which are the leading causes of mortality and burden of disease induced by exposure to air pollution from solid fuels (EZZATI AND KAMMEN 2002). Exposure to particles could be detected as a causal agent of these and other serious respiratory diseases such as lung cancer or pneumonia (see DUFLO, GREENSTONE, AND HANNA 2008b, PATTANAYAK AND PFAFF 2009). Respiratory diseases and eye problems are elicited on a self-reporting basis: respondents are asked if any household member has suffered from these symptoms in the last six months. While such self-reported health indicators are sometimes viewed with concern because of potential measurement errors, the literature in fact supports their application by highlighting the correlation with effective illnesses (see BUTRICK ET AL. 2010, IDLER AND BENYAMINI 1997, MIILUNPALO 1997, PEABODY ET AL. 2006). In particular, if specific symptoms are precisely asked for (as was done in this study), respondents can be expected to report accurately. Hence, to the extent that these symptoms are early indicators for serious diseases, they should provide for a straightforward approximation of people’s respiratory health status, also in the long run.

While technically achievable firewood savings rates for ICS have already been determined in CCT, field testing the firewood consumption is essential to scrutinize if the CCT results can be confirmed under day-to-day cooking conditions. As ADRIANZÉN (2010) points out with regards to CCT, whether an ICS "reduces firewood consumption in a given context is an empirical question which must be addressed using household level data corresponding, as closely as possible, to real patterns of firewood consumption and stove usage patterns". In a CCT, a cooking woman prepares the same meal on both a traditional stove and an improved stove in order to compare the woodfuel consumption of both stove types. The effective savings in real-life households might deviate from such laboratory field tests for various reasons: First, the tests would need to mirror the cooking patterns across all three meals of a day, but they frequently only concentrate on the main meal. Second, cooks in CCT are likely to change their behavior as a result of being observed, which might bias the results. In addition, the CCT cannot sufficiently account for the heterogeneity of households in terms of cooking behavior and potential adjustment processes after acquisition of a more efficient stove: Households might prepare more hot meals because cooking becomes cheaper due to the higher efficiency of the ICS (or less exhaustive in terms of firewood collection) – a phenomenon referred to as *rebound effect* in the energy economics literature that is observed for different energy services after an increase in energy efficiency (see HERRING, SORREL, AND ELLIOTT 2009). Finally, it cannot be assured in a CCT that the cook is equally familiar with the different stoves that are tested. These deficiencies of CCT can be overcome by evaluating the woodfuel consumption based on a survey among a larger sample of households in which the diversity and dynamics of real-life cooking practises are captured. This is what is presented in this paper.

3.2. Identification strategy

In observational studies relying on non-experimental identification strategies the counterfactual situation has to be approximated, which is prone to biases resulting from self-selection processes. In the present case of ICS, for example, more modern women might be more open to adopt new technologies and at the same time be more able to economize fuels or health-conscious in general.[6] In the RCT we did for this evaluation, households are randomly assigned into the group of ICS owners (treatment group) or non-owners (control group). It is simply left to chance whether a household receives an ICS or not. As a consequence, the difference in outcome variables that can be measured after a certain period of time is the causal impact of ICS usage.

Although RCTs allow simply comparing the differences in mean values of the impact indicators at the time of the follow-up survey, controlling for other household characteristics and cooking patterns that have been collected in a baseline increases precision by reducing the variance of the estimator (see DUFLO, GLENNESTER, AND KREMER 2008). We therefore control for household characteristics like household size, but also for dish-specific cooking patterns and cooking behavior, using Ordinary Least Squares (OLS) estimation.

We determined the sample size based on a power calculation. Using the data collected for the quasi-experimental study presented in BENSCH AND PETERS (2011) from urban Senegal we approximated the relevant parameters ex-ante and, focussing on the indicator firewood savings, and obtained a required sample size of 250 households (see Appendix 2).

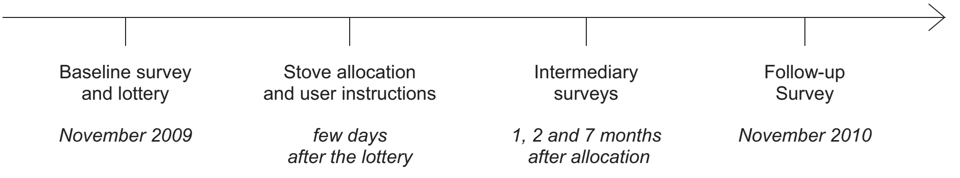
3.3. RCT implementation

The major survey tool is a structured questionnaire covering the socio-economic dimensions that characterize the relevant living conditions of the households. A particular

[6] MUELLER ET AL. (2012) examine adoption behavior of Chinese households and the implications this could have for non-randomized impact assessments.

focus of the questionnaire is on solid fuel use, cooking behavior, and patterns of fuel provision. This structured questionnaire delivers data for the quantitative analysis and is complemented by information from semi-structured qualitative interviews and focus group discussions with selected key informants such as women groups, stove and charcoal producers, teachers, regional administrators, and village chiefs.

Figure 1: Steps in RCT implementation



The study implementation followed the guideline on the implementation of RCT provided in Duflo, Glennerster, and Kremer (2008). The first decision that has to be taken is on which level to randomize the treatment – the village or the individual household. Our purpose is to evaluate the impact of ICS usage, so the choice is quite straightforward: Due to potential self-selection processes at the household level, we randomize among households, not among villages.[7] The randomization was realized in 12 villages in the Bassin Arachidier region around Kaolack, where ICS are principally not available, because the villages are far from trading hubs and FASEN-supported ICS producers. By this choice, we minimized the risk of *treatment contamination,* which occurs if households that are randomly assigned to the control group buy an ICS between the baseline and the follow-up survey and thereby become treated. Since we implemented the RCT in the target region of a planned GIZ rural electrification intervention, the field researchers introduced the study to the households as related preparatory field work.

[7] In principle, one has to account for potential spillover effects. For example, a decrease in firewood scarcity might occur, which could lead to an increase in firewood consumption in all households including the control households. However, this effect can be expected to be negligible with only on average 15 percent of households in a village that received an ICS.

The random assignment was put into practice through a lottery. We presented the "awards" of this lottery, an ICS or a 5kg bag of rice[8], as a compensation for the participation in the electrification baseline study.[9] This avoids that the households feel as being part of an experiment, which could lead to a biasing Hawthorne or John Henry effect in case members of the treatment or control group alter their behavior. In order to increase the feeling of fairness, we conducted the randomization on the ground by doing the lottery on the same day as the interview and informed the households immediately which prize they would get.[10] We applied simple stratified randomization with the villages as stratification criterion. As suggested in BRUHN AND MCKENZIE (2009), we included village dummies in the statistical analysis to account for this stratification. Even though we expected to achieve a balanced sample in the given setup, as a precaution we decided to interview slighty more control households. By assigning a probability of 60 % to the 5kg-rice-outcome and a 40 % probability to the ICS-outcome, we would be able to select control households in case of balancing problems. Section 4.1, though, shows that our expectation was justified and the two groups are balanced.

Eventually, a total of 253 households were randomly sampled and interviewed in the baseline phase, among which 98 received an improved stove and 155 a bag of rice. The rice and ICS awards were distributed within three days after the baseline interview. The distribution was accompanied by a short 15 minutes instruction on the proper usage of the ICS. Households were, for example, informed that the clay inlay of the ICS could easily break if the fire would be put out with cold water and that – different from open fires for which people typically use large branches or even trunks – the firewood has to be chopped first in order to fit the relatively small fuel feed entrance of the ICS. The survey villages were then visited three times by community workers, also as part of the preparation of the planned electrification project. These visits were also used to check if ICS households in

[8] Taking into account that the average per capita consumption in Senegal is 84 kg per year, this amount can be expected to serve an average surveyed household for around two days (GAIN 2011). The provision with 5kg of rice can therefore not be considered a treatment by itself, since it is implausible that it affected any of our impact indicators.

[9] See also DE MEL, MCKENZIE, AND WOODRUFF (2008).

[10] This procedure implied that we could not re-randomize to improve the balancing.

fact use the ICS and whether technical problems had occurred. It turned out that only one household did not use the new stove and another ICS was completely broken. Apart from them, all ICS winners used the new stove for daily cooking.

For the follow-up phase at the end of 2010, virtually all households could be retrieved. Only four households could either not be relocated or had moved out of the village. In addition, we encountered 15 households – 5 in the treatment group and 10 in the control group – that already had owned an improved stove before the study (not necessarily the Jambar stove used in the RCT). However, as expected, the ICS did not enter the villages systematically. In most cases, relatives brought them as a gift from urban areas. We excluded them from data analysis, because these households cannot be expected to buy another ICS in a non-RCT world and, hence, can neither belong to the treatment, nor to the control group. Altogether, 227 households were included in the impact analysis.[11]

4. Results

4.1. Socio-economic conditions and cooking behavior

The socio-economic characteristics and the cooking behavior of the population presented in this section are based on the baseline survey, which was conducted before the ICS were distributed. The purpose of this section is, first, to scrutinize the balancing of the two randomized groups, which is important, since we did not re-randomize in order to achieve balancing before assigning the ICS. The second purpose is to illustrate the socio-economic environment in which the RCT has been implemented. Table 1 documents the baseline characteristics of the 227 households. As can be seen from the *p*-values for two-sided tests of equality of the values for the two compared groups in the right column, there are no statistically significant differences between the two groups. In other words, the groups are balanced in the relevant observable socio-economic characteristics. In addition, Figure 2 and Figure 3 show the distribution in non-agricultural and agricultural

[11] We furthermore excluded four households with affiliated Quran schools from the analysis, since they were simply too large to be compared to family households.

income distribution: the treatment and the control group overlap to a strikingly high degree.

Table 1: Baseline characteristics of randomly assigned ICS owners and non-owners

	All	ICS Owners (Treatment group)	ICS Non-owners (Control Group)	
	mean	mean (sd)	mean (sd)	***p*-value**
Number of observations	227	88	139	
Demography				
Household size	12.96	13.02 (5.49)	12.93 (5.85)	0.90
Ethnicity				0.85
Wolof	51.1%	51.1%	51.1%	
Sérère	20.3%	21.6%	19.4%	
Peulh	11.9%	13.6%	10.8%	
Education				
Father's education level				0.90
None	11.4%	12.8%	10.5%	
Alphabetisation	77.7%	77.9%	77.6%	
Primary	6.8%	5.8%	7.5%	
At least secondary	4.1%	3.5%	4.5%	
Mother's education level				0.75
None	40.7%	42.5%	39.6%	
Alphabetisation	53.1%	50.6%	54.7%	
Primary	5.8%	6.9%	5.0%	
At least secondary	0.4%	0%	0.7%	
Gender				
Mother is member of an association	73.0%	71.3%	74.1%	0.64
Father is responsible for household budget	96.0%	95.5%	96.4%	0.72
Household member responsible for decision to buy fuels				0.73
Father	25.8%	27.9%	24.6%	
Mother	67.0%	67.1%	66.9%	
Both	6.7%	7.7%	5.1%	
Other	0.5%	0.8%	0%	
Other Socio-economic Characteristics				
Father's primary activity				0.80
Subsistence farming	81.7%	80.0%	82.8%	
Services and manufacturing	15.5%	16.5%	14.9%	
Retirement	2.7%	3.5%	2.2%	
Any household member emigrated	69.2%	64.8%	71.9%	0.25
Ownership of bank account	6.6%	6.8%	6.5%	0.92
Ownership of sheep	62.6%	61.4%	63.3%	0.77
Ownership of electricity source	40.1%	46.6%	36.0%	0.11
Number of mobile phones	1.97	1.84 (1.30)	2.06 (2.16)	0.40

Notes: sd – standard deviation; sample size varies slightly due to non-applicables and missings.

Figure 2: Distribution of non-farm income at baseline

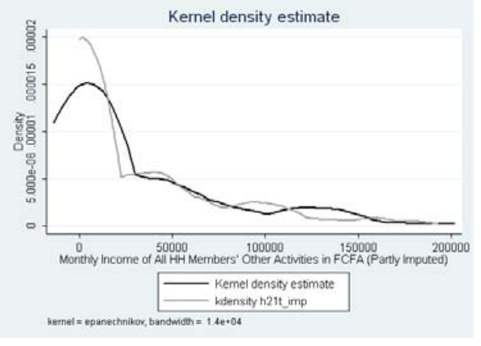


Figure 3: Distribution of farm income at baseline

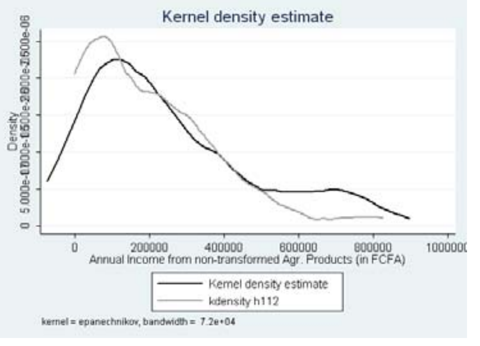


Table 2 shows stove usage patterns for ICS owners and non-owners before the randomization. Again, *p*-values related to test statistics for the equality of both groups are provided in the right column and, again, no significant differences can be observed. With the joint set of cooking-related and socio-economic characteristics presented above, we additionally performed a probit regression to check their correlation with ICS allocation. The regression validates the findings from the univariate comparisons of mean values: All variables exhibit statistically insignificant coefficients and also a test on the joint influence of the included characteristics does not support any systematical difference between ICS owners and non-owners.

Regarding the cooking behavior reflected in Table 2, stoves that dominate rural kitchens in Senegal are open fires (*three stone stoves* or *Os* in which the open fire burns between metal feet) and traditional metal stoves, the *Cire* and *Malagasy*. Two types exist: one that is employed with agricultural residues and a version used with firewood. Merely three households in the sample use a gas stove as principal stove. Around 15 % of all meals (i.e. breakfast, lunch, or dinner) are prepared with more than one stove, primarily to prepare rice on one stove and a sauce on a second one. On average, 21 times per week any stove is used to prepare a hot meal or one part of it. Because of multiple stove usage, the range of weekly stove applications is between 14 and 49.

Table 2: Cooking-related Baseline Characteristics

		ICS Owners (Treatment)	ICS Non-owners (Control)	
	mean	mean (sd)	mean (sd)	***p*-value**
Most utilized stove type(s)				0.58
3 stones or Os	74.2%	75.0%	73.7%	
traditional metal wood stove	24.4%	22.7%	25.6%	
Gas stove	1.4%	2.3%	0.8%	
Stove usage in times per week	21.24	21.01 (4.12)	21.38 (5.02)	0.56
Firewood consumption per dish				
3 stones	5.14 kg	4.85 kg	5.12 kg	0.37
Os	4.89 kg	4.82 kg	4.89 kg	0.87
Firewood provision				0.98
only collected	75.9%	76.5%	75.5%	
only bought	2.2%	2.4%	2.2%	
both collected and bought	21.9%	21.2%	22.3%	

Notes: The Os is a stove in which an open fire burns between three metal feet. sd – standard deviation.

The follow-up data on stove usage underpins that the ICS have achieved broad acceptance among the users. As many as 96 % of ICS are used at least seven times per week; for 87 % of ICS-winning households the ICS now also is the predominantly used stove. Only 9 % predominantly cook on an open fire any longer. In the control group, households mainly cook with three stone stoves (54 %), traditional metal wood stoves (24 %) or Os (19 %). No treatment contamination occurred: Neither did any of the control households obtain an ICS between the baseline and the follow-up study nor did they use the improved stove of ICS owning neighbours. Thus, any bias arising from non-compliance or treatment contamination can be ruled out.

In assessing the effectiveness of ICS usage, the question of which stove type is replaced by an ICS is an important one: The savings potentials are, of course, higher if open fire stoves are replaced than if traditional metal stoves are replaced. In the control group around 71 % of the dishes are prepared with three stone stoves, followed by traditional metal stoves with a share of almost 24 % (see Table 3). In contrast, both stove types are crowded out by the ICS in the treatment group: Now, the ICS is used for 71 % of the dishes with the usage of the three stone stoves going down to less than 19 %. Still, this figure reveals that inefficient traditional stoves continue to be used, also because for some large households the ICS is too small if large pots are used that do not fit the ICS. Furthermore, sometimes people simply use more than one stove for one meal.

Table 3: Usage shares of different stove types at follow-up

	ICS Owners (Treatment)	ICS Non-owners (Control)
3 stones or Os	18.6 %	70.8 %
Traditional wood stove	7.1 %	23.6 %
ICS	70.9 %	-
LPG stove	3.4 %	5.6 %

Notes: The shares represent the ratio between the number of times the respective stove type is used and the total number of stove applications – per household and week.

4.2. Impacts on firewood consumption

Typically, a meal in the survey area consists of two dishes, mostly rice and a sauce. Some households prepare the meal using several stoves simultaneously. Hence, to identify the savings, we analyse the data on the level of stoves with each preparation of a hot dishe as one observation.

In each household, we elicited for every meal throughout a typical day the number of stoves used for this meal, which stoves were used, as well as the type and amount of cooking fuel that was used. The person responsible for cooking indicated for each stove and meal individually how much firewood was used. She was asked to physically show the respective amount, which was then weighed with a scale. Based on this information, we calculate the reduction in firewood consumption that can be attributed to ICS usage. We first examine the mean values of firewood consumption for the three different stove types, open fire, traditional metal stoves, and ICS. We include only those 90 % of dishes that are prepared with firewood and thereby exclude meals prepared with LPG, agricultural residues, or charcoal.

Table 4 shows the firewood consumption for the different stove types, dish types, and meals. It can be seen that for all meals and dish types the ICS consumes substantially less firewood than the traditional metal stove and in particular than the open fire stoves. Compared with the open fire, the savings range between 39 % and 46 %. The reduction is less pronounced for breakfast preparation (-14 % relative to traditional metal stoves).

Table 4: Average per capita firewood consumption per dish (savings rates in parentheses)

	ICS	traditional metal stove	open fire
Breakfast	0.13 kg	0.15 kg (-14%)	0.23 kg (-45%)
Main dish lunch and dinner	0.23 kg	0.33 kg (-31%)	0.42 kg (-46%)
Side dish lunch and dinner	0.22 kg	0.27 kg (-19%)	0.36 kg (-39%)
All dishes	0.20 kg	0.27 kg (-27%)	0.36 kg (-45%)

Note: Savings rates in parentheses refer to the comparison ICS vs. traditional metal stove and ICS vs. open fire, respectively.

In a next step, we analyse the impact of ICS usage applying Ordinary Least Squares regressions (OLS) with a dummy variable indicating whether the *dish is cooked on ICS* as the variable of interest. We control for various variables that can be expected to affect the firewood consumption per meal and, as a result, also the savings potentials. More specifically, we first add a *traditional metal stove* dummy additional to the ICS dummy such that cooking with an open fire stove represents the reference case. We account for the *number of persons the meal is cooked for* by including an adult equivalents variable. Due to a household size of up to 50 in the observed rural households, we take the logarithm of this value in order to account for a non-linear and presumably decreasing relationship between household size and firewood consumption per dish. Furthermore, we include a *main dish* dummy that takes the value one if the stove is used to cook the main dish (mainly rice) and zero if it is used to prepare a side dish like sauce. We also differentiate between *breakfast*, *dinner*, and lunch meals. We add another dummy indicating whether the respective meal is prepared on *multiple stoves* or on one single stove only. The *short* *cooking* dummy accounts for the fact that the households sometimes just warm up a dish instead of preparing a proper meal.

Table 5: Impact of ICS usage on firewood consumption per dish

Estimator:	Ordinary Least Squares
Dependent variable:	Wood Fuel Weight for Dish (in kg)
Variable	Coefficient (Standard Error in parentheses)
Stove variables	
Dish is cooked on ICS	-2.01***
	(0.19)
Dish is cooked on traditional metal stove	-0.32
	(0.43)
Number of people the meal is cooked for (in terms of the logarithm of adult equivalents)	1.83***
	(0.53)
Main dish	0.96***
	(0.26)
Breakfast	-1.55***
	(0.17)
Dinner	-0.15
	(0.10)
Multiple stoves	-0.07
	(0.29)
Short cooking (< 30 min)	-1.11***
	(0.19)
Household variables	
Father has formal education	0.05
	(0.31)
Mother has formal education	0.30
	(0.20)
Household income (in logarithmic terms)	-0.04
	(0.05)
Telecommunication expenditures (in logarithmic terms)	0.06
	(0.04)
Bank account ownership	-0.35
	(0.45)
Flooring material is soil	-0.39**
	(0.19)
Mother is member of an association	-0.45
	(0.34)
Village dummies	*Included*
Constant	0.00
	(1.36)
Number of observations	739
Adjusted R-squared	0.42
F-Test	21.22***

Notes: Standard errors are clustered by household. *, ** and *** indicate significance levels of 10 %, 5 % and 1 %, respectively.

In addition, we incorporate household level control variables, which of course do not change from one meal to another. These comprise variables for both the father and the mother that indicate whether he or she has attended *formal education*. Apart from *income* as an economic measure of living standards, we take *telecommunication expenditures* (in logarithmic terms) as a proxy. We do so, since empirical studies have shown that consumption is less volatile and also more accurate than income and, therefore, a better measure of living standards in the absence of multiple seasonal visits (DEATON AND ZAIDI 2002). Furthermore, we include a dummy for *bank account ownership* as a proxy for the household's access to credits and ability to pay. Housing conditions as a wealth indictor are captured by whether the *flooring material* in the household is soil. *Association membership of the mother* is included to capture the woman's status and access to information and networks. Finally, in order to account for the stratified randomization we include village dummies for each of the 12 survey locations (coefficients are not presented).

The results depicted in Table 5 show a highly significant effect of using an ICS on the firewood consumed for the respective meal. Transferred to absolute terms an open fire consumes around 4.2 kg of firewood and an ICS only 2.2 kg per stove utilization. This yields an average savings rate per stove application of 48 %. Most of the other meal-specific variables exhibit a strongly significant influence on fuel consumption as expected. Household and village level variables do not have a significant influence with the exception of the wealth indicator *flooring material*.

Beyond savings on the dish level, we determine the total weekly firewood savings of a household. The two saving rates are expected to differ from each other due to the continued use of traditional stoves in ICS-winning households or the rebound effect (see Section 3.1). The calculation is based on stove-specific woodfuel consumption data for each meal throughout a typical day and the information on how many times each stove in the household is used per week for cooking. According to our findings presented in Table 6, firewood savings are substantial, with almost 27 kg being saved in every household after introduction of the ICS. This makes up more than 30 % of the household's total firewood consumption.

Table 6: Firewood consumption per week and savings rates

	Number of observa-tions	ICS owners (Treatment) mean	ICS non-owners (Control) mean	Difference mean	*t*-test on difference in means
All Meals	226	60.83 kg	87.68 kg	26.85 kg -30.6%	|t| = 3.92***
All Meals, OLS	224	59.37 kg	88.45 kg	29.08 kg -32.9%	|t| = 4.81***

Note: *, ** and *** indicate significance levels of 10 %, 5 % and 1 %, respectively.

4.3. Time use

A reduction in firewood consumption is likely to also reduce the time households spend on firewood collection. In addition, also the cooking time can be reduced by using an ICS. As many as 97 % of all households collect at least part of the firewood they use for cooking, among them 21 % sometimes collect, sometimes buy (depending on demand, availability and budget). The persons who collect firewood are primarily women. Children are involved only in 10 % of households (see Table 7).

Table 7: Time for collecting firewood and characteristics of collecting person

	Household collecting firewood	Average number of household members collecting firewood	Share of female among person collecting firewood	Share of households in which children collect firewood	Average weekly duration
ICS owners	98%	2.20	75%	10%	14.0h
ICS non-owners	96%	2.26	75%	11%	15.0h
				Difference:	**- 7%** **p = 0.65**

While the usage of an ICS induced a reduction in total firewood consumption between 25 and 30 %, the reduction in the total time used for firewood collection is 7 %, which corresponds to approximately one hour. The reduction, though, is not statistically significant. This finding does not seem to be consistent with the perception of ICS users who declared in open qualitative interviews and focus group discussions that they spend substantially less time on firewood collection and ranked the induced time savings as the most important impact of ICS. Still, it is not surprising that the reduction in time savings is lower than the saved firewood and statistically insignificant. One reason for the lower savings is that ICS-using households might just collect less wood during one excursion, instead of reducing the number of excursions. The insignificance of the difference might be due to inaccuracies in the time usage variable, which induces a high standard error. First, rural people in general are not very familiar with time durations. Second, 31 % of households collect the wood on their own land while farming, which makes it difficult to disentangle time spent on the collection task from ordinary field work. Third, some households do not collect the firewood every week but rather hold a stock that is typically refilled before the rainy season. In a nutshell, the sample size and thus the power of our survey might not be sufficient to properly grasp differences in such a noisy variable.

Table 8: Cooking duration

	Number of observa-tions	Meal cooked with ICS	Meal cooked without ICS	Difference	*p*-value
		mean	mean	mean	
per Meal					
All meals	642	88 min	112 min	24 min -21 %	0.00
All meals, OLS	636	90 min	111 min	21 min -19 %	0.00
	Number of Observa-tions	**ICS owners (Treatment)**	**ICS non-owners (Control)**	**Difference**	**p-value**
		mean	mean	mean	
per Day					
All meals	227	253 min	331 min	78 min -24 %	0.00
All meals, OLS	224	259 min	328 min	69 min -21 %	0.00

Notes: In the analysis on meal level, only meals have been considered that have been only prepared by firewood. ***,** and * indicate significance levels of 1%, 5% and 10%, respectively.

In addition to firewood collection, households might save time because cooking is facilitated. Some 84 % of interviewed households state that cooking is quicker with an ICS. The remaining 16 % do not see a difference. In fact, the perceptive statements can be corroborated by the effective cooking behavior: cooking durations for the individual meals decreases significantly by more than 20 minutes per meal and around 70 minutes per day. Table 8 shows simple difference in means results as well as the results from an OLS regression that includes the same control variables as in the regression analysis presented in Table 5.

4.4. Health

Since the consumption of firewood is significantly decreased when ICS are used, we can also expect a substantial reduction in smoke emissions that are harmful to the exposed people. In order to assess potential health improvements, we first look at the *exposure* to the emitted smoke, expressed in the cooking behavior of households: The vast majority of households cooks inside, only 17 % usually cook outside at the baseline stage, but also only during the dry season. In the rainy season, they typically use a living room for cooking. Our first finding is that the availability of a portable ICS makes more people cook outdoors if it is not raining. While the share of people cooking outdoors stayed constant at 20 % in the control group, the share in the treatment group doubled between baseline and follow-up from around 12 % to 23 %.

Some 60 % of the members responsible for cooking stay next to the stove most of the cooking time. Around 30 % usually even carry a baby while cooking. So, generally, exposure to smoke is high and, as a consequence, smoke reduction due to ICS usage as well as reduced exposure due to increased outside cooking might have consequences on people's health status. We examine whether chronic symptoms of respiratory diseases and eye infections prevail in the household, first among the women responsible for cooking and, second, for male household members. In Table 9, differences in the share of people exhibiting the respective symptoms between the two groups are displayed. The genderdifferentiated data provides for striking indications of health effects: For women responsible for cooking, 9.1 % of households report at least one of them suffering from respiratory disease symptoms. The corresponding value for the control group of 17.3 % is almost twice as large – with this difference being statistically significant. A probit regression that additionally controls for exposure to smoke (remaining close to stove while cooking) and education level of cook corroborates the significance levels found. If we look at male household members, who are virtually never responsible for cooking and never spend time around the cooking spot, treatment and control group households do not differ from each other. The same is observable for eye infections, which for the women responsible for cooking go down from 14.4 % in the control group to 4.5 % in the treatment group. The difference is significantly different from zero. Again, no such statistically significant difference can be observed for men.

Table 9: Respiratory diseases and eye infections

	Number of Observa-tions	ICS Owners (Treatment) mean	ICS Non-owners (Control) mean	*p*-value
Respiratory system disease				
at least one male household member showing symptoms	227	8.0 %	6.5 %	0.67
at least one woman responsible for cooking showing symptoms	227	9.1 %	17.3 %	0.09
Eye problems				
at least one male household member showing symptoms	225	4.5 %	7.3 %	0.40
at least one woman responsible for cooking showing symptoms	225	4.5 %	14.4 %	0.02
Indoor air quality is considered bad	179	66.2%	89.2 %	0.00

Altogether, in spite of the subjectivity of the health related indicators, we find clear differences that suggest an effect of ICS usage on both eye problems and respiratory disease symptoms. This impact can be attributed to both the reduction of smoke emissions and facilitated outside cooking.

5. Conclusion

In this paper we evaluated take-up behavior and impacts of improved cooking stoves (ICS) in rural Senegal by means of a randomized controlled trial (RCT). ICS are widely considered as an option in developing countries to combat the devastating effects of woodfuel usage for cooking purposes on people's health and work load as well as on the environment. The first finding is that the take-up of the ICS was close to 100 % among the randomly assigned households. This comes as a surprise, since it is widely argued, in particular among practitioners working in ICS dissemination projects, that people would not use ICS for which they have not paid.

The savings rate of firewood consumption per stove application was found to be statistically significant and substantial. It amounts to 48 % across different model specifications and averaging over all meals and households. The reduction in total firewood consumption over one week is somewhat lower but still high at 31 %. Such a reduction in firewood consumption is an important impact in an arid country like Senegal, where forests are permanently under pressure. It has become evident that controlling for meal-specific characteristics such as the cooking duration, the number of persons cooked for, and the type of meal is critical to determine a reliable savings rate. Having these meal-specific details at hand is a key virtue of our data.

Furthermore, we find a clear indication for a decrease in respiratory disease symptoms and eye problems as well as for substantial time savings because of a shorter cooking duration. Respiratory disease symptoms for cooking women drop by 8 % and eye problems by 10 %. Cooking duration is shortened by 20 %. A statistically significant decrease in firewood collection time, in contrast, could not be found. The caveat for this indicator is that it is more prone to inaccuracies increasing the variance of the estimator and call for a higher sample size. Hence, the fact that we do not find a significant effect here does not mean that there is no effect.

One might suspect an auspices bias in these variables, since respondents could be expected to express their gratitude for having received the ICS. However, this is not very likely for two reasons: First, households perceived the whole exercise as a preparation study for a rural electrification programme and were not aware of being part of an ICS experiment (which could have altered also the take-up rates). Second, even if some households noticed the role the ICS played in this study, they were unlikely to relate its usage to health outcomes. The fact that we did not see any difference in health outcomes for male household members underpins this view. An auspices bias is also unlikely for firewood savings, as we did not ask for savings directly, but for absolute firewood consumption. Moreover, the observed savings are totally in line with what is technically possible.

Altogether, the substantial and statistically significant impacts on different levels of indicators substantiate the efforts that the international community dedicates to the dissemination of ICS. On the project level, the results support the intention of the FASEN project to roll out the ICS activities to rural areas in order to improve the gender and health relevant effects of ICS dissemination projects.

While studies in other settings need to corroborate this finding, the almost universal take-up among randomly assigned ICS owners suggests the conclusion that people – if they have an easy opportunity to obtain an ICS – also use it. This, as a matter of course, does not yet mean that they are also ready or able to pay for it. The interplay of credit constraints, information deficits, and the fact that in many cases the women responsible for cooking do not manage the household's budget raises doubts if households would be able and willing to pay the market price for ICS – even if the stoves were readily available. The majority of rural households is short on cash and it is quite likely that they would stick to their traditional three stones stoves (which are virtually for free) or to their traditional metal stoves (which are a few dollars cheaper than ICS). Of course, clear promotion strategies and measures to assure the availability of ICS in rural areas might help to overcome this situation. Yet, this strategy has proven to be already difficult in urban areas and can be expected to require even more efforts and resources in rural areas.

The high take-up observed in this study and the positive external effects of ICS usage such as reduced deforestation and household air pollution suggest reconsidering more direct options of ICS promotion. This could, for example, mean directly subsidizing the production of ICS in rural areas so that end-user prices can compete with traditional stoves. If the take-up behavior but also the strong impacts can be confirmed in other rural areas, it might be an option to distribute ICS directly to the households – for free or at a very low, rather symbolic price. Direct subsidies, of course, are frequently condemned and distributing ICS for free is on the "Don't-do-list" of most development cooperation practitioners (MARTIN ET AL. 2011, WORLD BANK 2011). However, exceptions to the rule might be legitimate if evidence shows that the benefits are convincing and the alleged classical problems – i.e. not paying for a good leads to non-usage of the good – do not occur.

Any ICS promotion policy, of course, has to be designed in close cooperation with local stakeholders. Institutions have to be built to sustain the distribution of direct subsidies or the ICS, thereby avoiding the flash-in-the-pan effect that has been observed in unsuccesful earlier ICS subsidization programs. Likewise, the short instruction on how to use the ICS that we gave to our ICS winners has to be provided by some local stakeholders, for example by women groups.

As these recommendations can only be an interim conclusion, further research on the take-up behavior and on the impacts of ICS usage in other regions has to follow-up. Different cooking patterns, different ICS, as well as different firewood availability might alter the results on both take-up behavior and impacts in ICS-using households. In addition, further experimental studies should examine the households' willingness-to-pay for ICS. Such research efforts can substantiate – or contradict – the findings in this study and will thereby help to decide if and under which circumstances subsidies are in fact required to make rural people obtain ICS and if so, how high these subsidies have to be.

Appendix 1: Stove types used in the survey area

Open fire stoves

Three stones

Os

Traditional metal stoves

Cire khatach
(fuelled with crop residues)

Cire wood

Malagasy stove

Improved Cooking Stove (ICS) Jambar

Appendix 2: Power calculation

Since information on our decisive impact variable, firewood consumption, had not been available in existing data sets for the target region of our study, we took data collected in the quasi-experimental study presented in BENSCH AND PETERS (2011) from urban Senegal to approximate the relevant parameters (prospective power analysis). After the follow-up survey, we verified these parameters by rerunning the analysis with the actual baseline data for those households included in the analysis (retrospecetive power analysis).

The sample size n is given by the following formula:

$$n = D[(Z_{\alpha} + Z_{\beta})^2 \frac{\frac{1}{r}(sd_1^2 + sd_2^2)}{(X_2 - X_1)^2}]$$

.

Table 10 provides for the description, the values and the sources of the different parameters. The decisive parameter to be defined by the researcher is the minimum detectable effect size (ES), which reflects the smallest relative reduction in woodfuel consumption that we are able to detect at the given significance level (see BLOOM 1995). While the CCT suggest an effect size of 40%, we chose a minimum detectable effect size of 30 % in order to account for the possibility of an overestimated effect size in the CCT.

Taking these parameters into account, we obtain a required sample size of around 200 households, as is indicated in the last row of the column for the prospective analysis in Table 10. In order to account for the sensitiveness of the different parameters in the power calculation and potential attrition or non-compliance, we built in a cushion and increased the number of households to be interviewed to 250.

With respect to health and time savings impacts, the required sample size to measure significant effects tends to be substantially higher. The reason is that the effect on, for example, respiratory diseases can be expected to be less pronounced. The implication of this is that the power of our study is not necessarily sufficient to detect all relevant health and time savings effects.

Table 10: Parameters for power calculation

	Description	Value		Source
		prospective	retrospective	
$D = 1 + \rho(m+1)$ with	Design effect, accounting for the loss of variation in the data if clustered instead of simple random sampling is used	1.59	2.25	household data
ρ	Intra-cluster correlation, i.e. the proportion of the overall variance with respect to firewood consumption explained by within-village (cluster) variance in the data	0.031	0.062	household data
m	Mean number of interviewed households per cluster (village)	20	227/12 = 18.9	defined
Z_α	Critical value (Z-score) for a given level of confidence α reflecting the probability that the null hypothesis is rejected given that it is in fact true	1.96 (α = 5%)	1.96 (α = 5%)	defined (conventional)
Z_β	Z-score for a given level of confidence β reflecting the probability that the null hypothesis is rejected given that it is in fact false	0.84 (β = 80%)	0.84 (β = 80%)	defined (conventional)
r	Ratio of ICS winners to non-winners	0.66	88/139 = 0.63	lottery outcome defined in sampling design
sd_1	Standard deviation of firewood consumption of ICS non-owners	0.266	0.259	household data
sd_2	Standard deviation of firewood consumption of ICS owners	0.186	0.181	implicitly defined through minimum detectable effect size (see below)
X_1	Per capita firewood consumption of ICS non-owners (in kg)	0.384	0.411	household data
X_2	Expected per capita firewood consumption of ICS owners (in kg)	0.269	0.288	implicitly defined through minimum detectable effect size (see below)
$ES = \|X_2 - X_1\| / X_1$	Minimum detectable effect size	30 %	30 %	defined based on experiences with laboratory tests
n = n (ICS winners) + n (non-winners)	Result of power calculation: required minimum sample sizes for treatment and control group	192 = 76 + 116	227 = 88 + 139	

Notes: Household data refers to the data from the urban quasi-experimental study (“prospective”) and to the baseline data from the present study (“retrospective”) to corroborate the calculations of the prospective analysis.

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