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Experimental Evidence on Improved Cooking Stoves in Rural Senegal

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Gunther Bensch and Jörg Peters[1]

The Intensive Margin of Technology Adoption – Experimental Evidence on Improved Cooking Stoves in Rural Senegal

Abstract

Today 2.6 billion people in developing countries rely on biomass as primary cooking fuel, with profound negative implications for their well-being. Improved biomass cooking stoves are alleged to counteract these adverse effects. This paper evaluates take-up and impacts of low-cost improved stoves through a randomized controlled trial. The randomized stove is primarily designed to curb firewood consumption but not smoke emissions. Nonetheless, we find considerable effects not only on firewood consumption, but also on smoke exposure and smoke-related disease symptoms – induced by behavioural changes at the intensive margin affecting outside cooking and cooking time due to the new stove.

JEL Classification: C93, O12, O13, Q53, Q56

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

July 2014

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1. Introduction

Almost three billion people in developing countries rely on traditional biomass-based fuels for their daily cooking purposes. In rural sub-Saharan African, virtually all households cook with biomass, mostly firewood. The collection of and cooking with firewood is associated with various negative effects on the living conditions of the poor. According to the World Health Organization (WHO), the emitted smoke is the leading environmental cause of death and is responsible for 4.3 million premature deaths every year – more deaths than are caused by malaria or tuberculosis (WHO, 2014; Martin *et al.*, 2011). Furthermore, biomass usage for cooking is a major source of climate relevant emissions (Shindell *et al*. 2012). Improved biomass cooking stoves (ICSs) are often believed to be a game changer for cooking in developing countries. It is in this context that the United Nations set out the Sustainable Energy for All initiative with the ambitious goal of globally universal adoption of clean cooking stoves and electricity by 2030. There is, however, a wide range of ICSs with different levels of sophistication that have strong implications for smoke emissions and thus cleanliness. It is hence still a matter of ongoing debate under which conditions ICSs can be considered as clean, also compared to modern fuels like electricity and gas.[1]

This paper presents findings from a Randomized Controlled Trial (RCT) to analyse behavioural responses and impacts following the introduction of an ICS. The ICS, which was assigned free of charge, is a low-cost and maintenance-free portable clay-metal stove. It is produced in a fairly standardized way by local manufacturers (potters and whitesmiths) in their workshops and is marketed at a retail price of around 10 US$. The stove has already been widely used in large governmental dissemination programmes in urban and rural Africa. As such, this is the first study to assess a type of ICS whose design is geared towards fuel savings, ease of use, affordability and, hence, large-scale applicability, but one that lacks specific health-conducive technical features such as a cleaner burning process or a chimney. For that reason, the reduction in particulate matter that the randomized ICS can technically achieve is probably insufficient to induce positive health effects given the non-linear particulate exposure response found in medical research (see, for example, Ezzati and Kammen, 2001, Pope *et al.*, 2011, or Burnett *et al.*, 2014).

Our study sample comprised 253 households in twelve villages in Senegal, of which 98 were randomly assigned to obtain an ICS after a baseline study in November 2009. The follow-up surveys were conducted in November 2010 and March 2013, thereby covering the life span of the distributed ICSs, which are supposed to last for one to three years before they deteriorate and have to be replaced. The RCT was implemented in an unobtrusive way

[1] See World Bank (2011) for a more detailed discussion of different types of improved cooking stoves and Martin *et al.* (2011) for a recent overview on the improved stoves and air pollution policy debate.

in order to ensure that we observe real-world cooking behaviour. It was designed and conducted in cooperation with the ICS dissemination programme of the Government of Senegal, so that an upscaling of the intervention under real-world conditions would be possible. Taken together, these factors contribute to a high external validity of this field experiment for the African context.

The main impact indicators of this study are firewood consumption, time use, respiratory disease symptoms and eye infections. Effects on these indicators were assessed 12 months after randomization. The behavioural changes we look at – firewood usage patterns and smoke exposure – can be expected to materialize already in the first few months after ICS adoption. The changes in these indicators we observe after one year of ICS ownership therefore reflect impacts to be expected in the long run – as long as people continue to use the ICS and replace it by a new one once it is not functional anymore. The third wave of interviews in March 2013 is used to track the longer-term usage behaviour and the stove's durability at the end of what technically is the life span of the ICS.

We find that the ICSs are taken up by virtually all households and intensively used, even after three and a half years. For the most part, people only give up using the stove when it is not functional anymore and not because they lose interest in using it. We furthermore observe substantial effects on firewood consumption, which confirm savings rates determined in lab tests. In addition, we find a decrease in early indicators for respiratory diseases and eye infections. These effects on people's health status cannot be explained only by the take-up of the new ICS and the firewood savings, but rather by an additional reduction in smoke exposure due to more outside cooking and a reduced cooking time that is enabled by the new stove.

Our findings add to the existing body of evidence on ICS impacts, which so far is mainly represented by two RCTs: the RESPIRE study in Guatemala (see, for example, Smith-Sivertsen *et al*., 2004, 2009; Diaz *et al*., 2007; and Smith *et al*., 2011) and a study conducted by J-Pal in India (Hanna *et al*., 2012).[2] Both studies used stationary chimney ICSs that are installed in the user's kitchen, with the difference that the RESPIRE stoves are more expensive (100 to 150 US$), of higher quality, and require less maintenance than those used in the Hanna *et al.* (2012) study. While the RESPIRE study detects a substantial reduction in household air pollution and a reduction in the risk of respiratory disease symptoms and eye

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[2] In addition to these two studies, further evidence with mixed results exists for China (Mueller *et al.*, 2013, Yu, 2011), Mexico (Masera *et al.*, 2007) and urban Senegal (Bensch and Peters, 2013). Burwen and Levine (2012) conducted an RCT in Ghana using a very simple mud stove. As a major difference to the present study as well as the RESPIRE and the J-Pal study, tests in a controlled field lab setting already find that the stove does not perform better than the traditional ones. The poor performance is also reflected in low usage rates after a few months.

problems, Hanna *et al.* observe reductions in smoke inhalation only in the first year but not over a four year time horizon. This is mainly driven by maintenance being more and more neglected over time, which leads to a weak performance and low usage rates after some years.

Against this background, our paper is the first to add evidence on how people use an adapted and simple ICS in an unsupervised setup that is deemed to represent a more realistic study environment than the highly controlled medical trials conducted for RESPIRE. Our study contributes to the literature by providing compelling evidence that such a simpler and cheaper ICS can actually also trigger substantial impacts – if cooking behaviour also changes. Conceptually, these results confirm the findings of Hanna *et al*.: Looking at the technical features of an ICS is not enough, since the real-world behaviour of users strongly co-determines the results. Unlike Hanna *et al*., though, we find that the health effects of the simple ICS used in this RCT are enhanced by behavioural adaptations that are favourable for the health outcomes.

These differences in findings of the two studies show the potentials of disseminating ICS that are adapted to the target population and that facilitate cleaner cooking. The stove used in the Hanna *et al.* study requires regular maintenance, for which people in turn need to be trained (which not all of them were), while the stove randomized for our study is maintenance-free. Furthermore, our portable stove is well adapted to the local cooking habits, whereas the stove distributed in Hanna *et al.* interferes more with local cooking habits by requiring people to cook inside, which they are not accustomed to. In this sense, the stove in our study increases the number of choice variables for the users, while the one used in Hanna *et al.* decreases it. In this broader behavioural context, our study demonstrates that the analysis of technology adoption and related promotion programmes should encompass both a technical and an economic perspective, not only an assessment of the mechanical performance. This is in line with the concept of intensive and extensive margins of behaviour that has recently been brought into the debate on public health interventions (see Dupas, 2011): It is not only the mere technology adoption that counts (extensive margin). Rather, the full effect can only be determined if the way the new technology is used is accounted for as well, the intensive margin.

2. Programme Background and Methodological Approach

2.1. Improved Stove Dissemination and Cooking Fuels in Senegal

Despite its seeming superiority to traditional biomass cooking, the ICS technology has not made significant inroads into African households. There may be various reasons for this, which are comprehensively discussed in Rehfuess *et al.* (2014). One explanation relevant for the rural setting is that firewood can typically be collected for free so that most of the benefits of ICS usage are not monetary ones. This makes it more difficult for households to finance the investment given liquidity and credit constraints. On the supply side, the stove design may fail to meet user needs in preparing local dishes with available fuels and cooking utensils. Earlier programmes in various African countries relied on subsidies for ICS production or distributed them for free. Most of these programmes did not succeed, however, in triggering sustainable ICS usage. Based on such experience, it is frequently argued that people do not appreciate and, consequently, do not use what they receive as a gift. Therefore, most ICS practitioners reject the option of distributing ICSs for free (Barnes *et al*., 1994; Martin *et al*., 2011).

This is also the spirit underlying the ICS dissemination programme *Foyer Amélioré au Sénégal* (FASEN), which is implemented by the Senegalese Ministry of Energy in cooperation with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).[3] In contrast to earlier ICS interventions, FASEN focuses on establishing a sustainable and autonomous market for ICSs by testing performance, training producers and distributors, and supporting communication and promotional campaigns. Similar to other countries, FASEN so far concentrated its ICS dissemination on charcoal ICS in urban areas.

The ICS disseminated by FASEN, the *Jambaar*, is also used in the present RCT. Originally developed in Kenya in the 1980s, it is a portable single-pot stove with a fired clay combustion centre enclosed by a metal casing. Owing to basic design improvements of the Jambaar compared to traditional stoves, the woodfuel burns more efficiently and the heat is better conserved and focused towards the cooking pot. Both charcoal and firewood models exist. We chose the firewood Jambaar for our experiment as firewood is the dominant fuel in rural Senegal with 89% of rural households using it as their primary cooking fuel (ANSD, 2006). In rural areas ICSs have not been available so far. Stove types used here are either three-stone stoves available at zero cost or traditional metal stoves and open fire grills that can be bought for between 500 and 2,500 CFA Francs, which is equivalent to 1 to 5 US$ (see Appendix A for pictures of the ICS and other stove types used in the study region). The GIZ programme intends to expand its activities to rural areas and expects the price of the Jambaar for the rural market to be around 4,000 to 5,000 CFA Francs (8-11 US$), which is well below the prices of the more sophisticated ICS technologies widely disseminated in Latin America or Asia.

[3] GIZ provides technical assistance on behalf of the German Federal Ministry for Development and Economic Cooperation (BMZ) and is one of the largest bilateral development agencies in the world.

Cooking fuels are an issue of major importance in the daily life of Senegalese households. Households have the custom to cook inside, which leads to a higher exposure to smoke emissions than outside cooking. WHO (2009) holds household air pollution induced by solid fuel usage for cooking accountable for 6,300 premature deaths every year in Senegal alone. Apart from agricultural land clearance, wood usage for cooking purposes is moreover the most important driving force of ongoing deforestation in the mostly arid and Sahelian country (see WEC/FAO, 1999; Tappan *et al*., 2004; FAO 2005*a*, 2005*b*). A constant population growth of 2.6% per year puts further pressure on fuelwood resources. As a consequence, households face an increasing scarcity of fuelwoods: firewood collection is becoming increasingly time-consuming, while fuelwood prices are rising. This circumstance applies particularly to the Bassin Arachidier, the study area of this evaluation, situated some 200 kilometres southeast of Dakar.

2.2. Impact Indicators

The first impact indicator of our study is the *household consumption of firewood*. This indicator aggregates each dish cooked in a typical week, with a dish being one component of a meal that is prepared on a separate stove, for example rice and sauce. We thereby account for the fact that several stoves may be used simultaneously for the preparation of a single meal. The rationale for this indicator is that a reduction in firewood consumption not only has immediate implications for wood scarcity and deforestation pressures, but is also a strong intermediate indicator for other ultimately relevant impacts such as health and time use.

Impacts on health and time use are examined directly. We investigate the indicator *time spent by household members on firewood collection and cooking* and the prevalence of diseases that are potentially related to firewood usage. For this purpose, we look at symptoms that are likely to be affected in the short-term after smoke emissions are reduced; these are captured by the indicators *household member with symptoms of respiratory diseases* and *household member with eye problems*. We examine this indicator both on the household level and the household member level. For respiratory diseases, these symptoms are cough, asthma, or difficulty in breathing. They indicate acute respiratory infections and chronic obstructive pulmonary diseases, which are the leading causes of mortality and diseases 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 *et al.*, 2008*b*; Pattanayak and Pfaff, 2009).

Respiratory diseases and eye problems are elicited on a self-reporting basis: respondents are asked to give information on those household members who exhibited the symptoms of interest in the six months preceding the interviews. While such self-reported health indicators are sometimes viewed with concern because of potential measurement errors, the literature supports their application by highlighting the correlation with actual illnesses (see Idler and Benyamini, 1997; Miilunpalo *et al.*, 1997; Peabody *et al*., 2006; Butrick *et al*., 2010). In particular, if specific symptoms are asked about precisely as was done in this study, respondents can be expected to report accurately. A deterioration in recall accuracy of reported morbidity as found in Das, Hammer and Sánchez-Paramo (2012) is a concern in this study but would only reduce the precision of our health estimates and not induce any bias.

To record firewood consumption and cooking time, the person responsible for cooking is asked to specify the number of people cooked for and the types of stoves used for every meal throughout a typical day. For each stove application, we then record the cooking duration and the cooking fuel type. In case of firewood, the cooking person is additionally asked to pile up the amount of firewood used for the respective stove application, which is then weighed with scales. In combination with information on the frequency with which the respective stoves are used throughout a typical week, this data serves to determine the weekly *household consumption of firewood*. The indicator *time spent by household members on firewood collection* aggregates the time spells in which household members are occupied with gathering firewood in the course of a week.

Technically achievable savings rates for the Jambaar (referred to as ICS in the following) have already been determined in controlled cooking tests (CCTs), where a cooking person prepares the same meal on both a traditional stove and an improved stove in order to compare the woodfuel consumption of both stove types. However, the effective savings in real-life households might deviate from such laboratory field tests for various reasons summarized by Bensch and Peters (2013).[4] The 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 done in the present paper.

2.3. Identification Strategy

We employ two approaches to estimate the impact of ICS usage in this experimental setup. The intention-to-treat effect (ITT) is obtained by simply comparing mean values of impact indicators for the treatment and control group, without accounting for non-compliance from households that were assigned to the treatment group but for some reason do not use the ICS. In our case, the ITT serves to estimate the effect of providing the ICS for free to

[4] For example, the tests frequently concentrate on the main meal only and they cannot account for the fact that households might prepare more hot meals because cooking becomes cheaper due to the higher efficiency of the ICS (or less exhausting in terms of firewood collection) – a phenomenon, which is referred to as the *rebound effect* in the energy economics literature (see Frondel *et al.*, 2008, Herring *et al.*, 2009).

households who do not yet own one. The average treatment effect on the treated (ATT), by contrast, accounts for non-usage in the treatment group and potential take-up in the control group and thereby serves to estimate the impact of effective ICS usage. For this purpose, instrumental variable (IV) estimations are applied with the random assignment into the treatment group as an instrument for the effective usage of the ICS. In our case, ITT and ATT are very similar given the high compliance rate in the treatment group and given that only one household in the control group acquired an ICS from another source. Although RCTs allow for a simple comparison of the impact indicators at the time of the follow-up, the precision of the estimates can be increased by controlling for other household characteristics that have been collected in a baseline survey. We therefore implement both the ITT and ATT approach with and without controlling for baseline household characteristics such as education and income using Ordinary Least Squares (OLS) regression.

In order to shed more light on how reductions in firewood consumption are induced by ICS usage, we also do an OLS regression on the individual dish level, additionally controlling for a set of potential dish- and meal-specific confounders such as the number of people cooked for. This dish-level regression has to be interpreted with some care, since – in spite of the random ICS assignment – the households that received a new stove can still choose whether to use the ICS or a traditional stove for the respective meal. This choice might then be driven by unobservable factors, which would distort the savings estimates if the unobservables are also correlated with firewood consumption.

Finally, we employ probit regressions on the health status of households and of individual household members. In principle, these estimations might as well suffer from some endogeneity induced by intra-household bargaining processes: healthier and more powerful women might bargain themselves out of cooking with the dirtier stove and into cooking with the cleaner ICS (see Pitt *et al*. 2006). This potentially leads to a spurious correlation between ICS ownership and improvements in the health status. In our context, though, this is very unlikely, since the assignment to the cooking duty does not seem to be a result of short-term negotiations, but it is rather determined by cultural norms with one or two women per household being continuously responsible for cooking. Even if post-randomization selection processes occurred, they would be uncovered by the health indicators we use, because we observe both the people responsible for cooking and those who are not.

2.4. RCT Design and Implementation

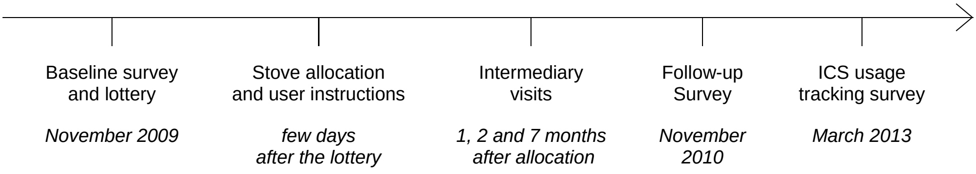
The study design followed the guidelines on the implementation of RCTs provided in Duflo *et al*. (2008*a*). The first decision that had to be taken was the level on which to randomize the treatment – the village or the individual household. In the present case, it is sensible to randomize on the household level, since the decision about whether to adopt an ICS is taken in the household and not on a regional level. Furthermore, our impact indicators are measured on household level (or below). One reason to randomize on the village level instead of the household level would be to account for spillover effects. These are expected to be negligible, since the ICSs are only used by the households themselves and the penetration rate per village envisaged in this RCT is too low to affect, for example, local firewood supply.

The next decision regards the sample size, both in terms of households and villages. We determined the sample size based on a power calculation focusing on the indicator firewood savings. We approximated the relevant parameters ex-ante using the data collected for the quasi-experimental study presented in Bensch and Peters (2013). Taking into account these parameters and the probability of being assigned to the treatment group, we obtained a required sample size of 250 households spread across 12 villages (see Appendix B). We selected villages that are far away from GIZ-supported ICS producers in order to avoid treatment contamination that might occur if households randomly assigned to the control group obtain an ICS independently.[5] Furthermore, we selected the 12 villages from the target region of a planned GIZ rural electrification intervention so that we could introduce the study as preparatory field work related to the electrification project and, thereby, reduce attention paid to the randomization.

In November 2009, we conducted the baseline survey among 253 randomly sampled households (see Figure 1 for the timeline of the RCT). Information was gathered using a structured questionnaire covering the socio-economic dimensions that characterize the relevant living conditions of the households. While a particular focus of the questionnaire was on solid fuel use and cooking behaviour, the questionnaire also covered a set of socio-economic and energy-related dimensions like electricity. Consequently, the cooking-related parts of the interviews did not draw particular attention. This is important to avoid auspices biases and Hawthorne effects (see Appendix E). We complementarily gathered qualitative information in focus group discussions and semi-structured interviews with key informants such as women's groups, stove and charcoal producers, teachers, regional administrators, and village chiefs.

[5] Two further channels exist through which the treatment may be contaminated. First, treatment households may share their stoves with control households. This did not occur. Second, the two household groups may exchange about determinants of respiratory health, for example. Yet, the treatment did not involve any awareness raising and cooking is also a rather private issue, as stated in open interviews, that is hardly a talking point in women's conversations. As a consequence, only minor contamination effects are conceivable that, furthermore, would rather lead to an underestimation of effects.

Figure 1: Steps in RCT Implementation



The random assignment was put into practice through a lottery directly following the baseline interviews. We presented the "awards" of this lottery, an ICS or a 5kg bag of rice[6], as recompense for participation in the baseline study. Participants were therefore not aware of being part of an experiment. In order to increase trust in the fairness of the lottery, we conducted it in each of the villages directly after completing the interviews and informed the households immediately about which prize they would get. Hence, we applied simple stratified randomization with the villages as the stratification criterion. Of the 253 households interviewed for the baseline, 98 received an ICS and 155 a bag of rice. The rice and ICS awards were distributed within three days of the baseline interview. The ICS winning households received a brief 15-minute introduction on how to use the stove. The ICS and rice bag distribution as well as the instruction were done by field workers who were involved in the preparation of the electrification project and who were visiting the village anyhow. No specific village gathering was organized. The ICS was presented as a fuel-saving device, which requires a few precautions. Households were, for example, informed that, in contrast to 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. In line with what real-world users are told about this type of ICS, households were also briefly informed about the convenience co-benefits of fuel savings, which are a quicker cooking process, less smoke and a cleaner kitchen. No information about potential repercussions on the health status was provided. The complete instructions on the functioning and proper usage of the ICS and related information provided are presented in Appendix C.

Between the baseline and the follow-up phase, local community workers conducted three preparatory visits in the survey villages for the planned electrification project. Once in the field, the community workers additionally checked if ICS households were using the ICS and whether they had encountered technical problems (which were in any case very rare). Again, no further treatment in terms of awareness raising or usage encouragement was

[6] Taking into account that the average rice consumption per capita in Senegal is 84 kg per year (GAIN, 2011), this amount serves an average surveyed household for around two days. The provision with 5kg will therefore not affect any of our impact indicators.

undertaken. While a few of households were not yet making frequent use of their new stove one month after ICS allocation, by the time of the second visit virtually all ICS-winning households cooked regularly on the ICS.[7] For the follow-up phase at the end of 2010, the same structured questionnaire was used as in the baseline phase. Attrition was very low: only four households either could not be located or had moved out of the village, three in the control and one in the treatment group. None of the households refused to participate in the follow-up survey.

We excluded two groups of households from the analysis: four households with affiliated Quran schools, where usually between 50 and 150 students live and eat and which are therefore not comparable to family households, as well as households that prior to the study had already received improved stoves other than the ICS used in the RCT from urban relatives. These six treatment and ten control households cannot be expected to have bought another ICS in a non-RCT world and therefore do not represent the population of interest. They were originally included in the randomization only because we conducted the randomization on-site and directly after the survey. Altogether, the sample used for the subsequent impact analysis in Section 3.2 to 3.4 comprised 229 households. As a robustness check shows, not discarding these two groups of households and, hence, performing the analysis with all 249 households for which baseline and follow-up data is available does not change any of our findings, neither when applying ITT nor ATT.

In March 2013, approximately three and a half years after the randomization, an ICS usage tracking survey among the ICS-winning households was conducted by enumerators familiar with the ICS. All but one of the 90 ICS-winning households included in the impact analysis could be retrieved for this interview wave. In addition to asking the households simple usage questions, the enumerators recorded their own assessment on the condition of the ICS. The results of this usage tracking survey are presented in Section 3.5.

3. Results

3.1. Socio-economic Conditions and Cooking Behaviour

The primary purpose of this section is to scrutinize the balancing of the two randomized groups, since we abstained from explicitly balancing them through re-randomization before

[7] It is not likely that the delayed take-up was triggered by the visits or in any way related to them. Instead, the visits revealed that, first, a few housewives traveled outside the village and therefore had not used the ICS so far. Second, some women needed to adapt to the quicker cooking with the ICS, which at the beginning created a feeling of insecurity. Third, some households were reluctant at the beginning as they wanted to preserve their ICS and used it only sparsely. Fourth, a few polygamous households needed some time to decide on who would use the ICS and when.

assigning the ICSs. The second purpose is to illustrate the socio-economic environment in which the RCT was implemented. Table 1 documents the baseline socio-economic and cooking-related characteristics of the 229 households before stove distribution, which are also used as control variables in the subsequent impact assessment. In addition to *income*, *telecommunication expenditures* serve as an economic measure of living standards. *Bank account ownership* is used as a proxy for the household's access to credits and ability to pay. Housing conditions as a wealth indicator are captured by whether the *flooring material* in the household is soil. As can be seen from the *p*-values in the right-hand column, two-sided tests of equality of the values for the two compared groups do not reveal statistically significant differences. The groups are balanced in the relevant observable characteristics. In addition, Figure 2 and Figure 3 show the distribution in non-agricultural and agricultural income: the treatment and the control group overlap to a strikingly high degree.[8]

Regarding the baseline stove usage patterns reflected in the table, two stove types dominate rural kitchens in Senegal: open fires (*three-stone stoves* or *Os* in which the open fire burns between metal feet) and traditional metal stoves, the *Malagasy* and *Cire*. LPG stoves are rarely used in rural Senegal; in our sample only three households mainly use LPG for cooking. 90% of dishes are prepared with firewood. Around 15% of all meals are prepared with more than one stove, primarily to prepare rice on one stove and a sauce on a second one. On average, each household prepares 21 hot dishes per week using one of its stoves. As sometimes more than one stove is used for one meal, the range of weekly stove applications is between 14 and 49.

Figure 2: Distribution of Non-farm Income at Baseline

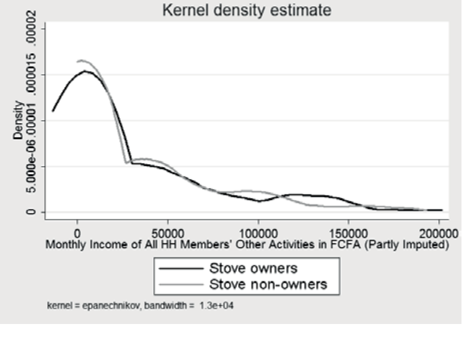
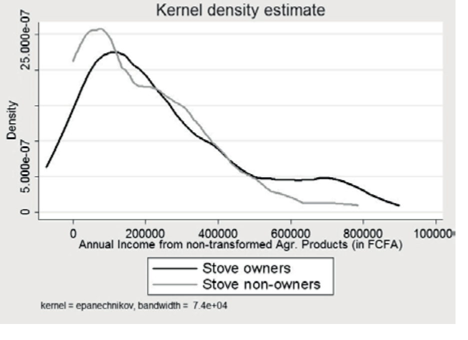


Figure 3: Distribution of Farm Income at Baseline



[8] We additionally performed a probit regression to check the correlation between ICS allocation and the joint set of cooking-related as well as socio-economic characteristics and village dummies. The regression validates the findings from the univariate comparisons of no correlation. All tests have as well been carried out with the original sample of 253 baseline households, for which statistically significant differences cannot be observed either.

Table 1: Baseline Characteristics of Randomly Assigned ICS Owners and Non-owners

	Treatment mean (sd)	Control mean (sd)	*p*-value for test on difference in means (2)-(1)
	(1)	(2)	(3)
Socio-economic characteristics			
Household size	12.88 (5.55)	12.94 (5.82)	0.94
Father's education level (%)			0.88
None	12.5	9.8	
Alphabetisation	77.3	77.4	
Primary	5.7	7.5	
At least secondary	4.5	5.3	
Mother's education level (%)			0.84
None	41.6	39.6	
Alphabetisation	51.7	53.9	
Primary	6.7	5.8	
At least secondary	0.0	0.7	
Telecommunication expenditures (CFA F)	4250 (440)	5090 (830)	0.43
Ownership of bank account (1 = yes)	0.08	0.06	0.55
Flooring material is soil (1 = yes)	0.36	0.27	0.16
Mother is member of an association (1 = yes)	0.72	0.73	0.81
Father's primary activity (%)			0.57
Subsistence farming	79.3	83.4	
Services and manufacturing	16.1	14.3	
Retirement	4.6	2.3	
Cooking-related characteristics			
Most utilized stove type (%)			0.33
Open fire (three-stones or Os†)	72.2	72.7	
Traditional metal wood stove	24.4	26.6	
LPG stove	3.3	0.7	
Stove usage in times per week	21.01 (4.10)	21.43 (4.98)	0.50
Firewood consumption per dish (kg)			
Three-stones	4.85	5.14	0.37
Os†	4.84	4.84	1.00
Firewood provision (%)			0.99
Only collected	75.6	76.3	
Only bought	2.3	2.2	
Both collected and bought	22.1	21.6	
Number of observations	90	139	

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 shows no changes in the control group: the most often used stove types are three-stone stoves (53%), traditional metal stoves (25%) or Os (20%). Accordingly, the savings potentials of ICS usage are relatively high with 73% of households mainly using open fire stoves in the absence of an ICS. For the treatment group, the follow-up data shows that the ICSs have achieved broad acceptance among users. There are only two non-compliers: one ICS was completely broken in an accident and one household did not use the new stove. Otherwise, as many as 95% of the distributed ICSs are used at least seven times per week; for 85% of ICS-winning households the ICS became the predominantly used stove. The proportion of individual dishes prepared with the different stove types also mirrors this usage pattern (see Table 2). As such, our set-up mimics the most likely scenario where ICS-winning households have one ICS at their disposal and continue to use less efficient traditional stoves, because one stove is not sufficient to prepare the required amount of food or because the ICS is too small for the pot sizes used in a few large households.

Table 2: Utilisation rates of Different Stove Types at Follow-up

	Treatment	**Control**
Open fire	19.5%	70.5%
Traditional metal wood stove	7.7%	24.1%
ICS	69.1%	0.7%[†]
LPG stove	3.7%	4.7%

Note: 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; [†] ICS usage among the control group is due to the fact that one household which was not randomly assigned to receive an ICS acquired one individually after the randomization.

3.2. Firewood Consumption

ITT and ATT estimates for the *household consumption of firewood* indicator are calculated both with and without baseline household-level control variables. These controls comprise variables for the socio-economic characteristics listed in the upper part of Table 1 as well as income shown in Figure 2 and Figure 3.[9] As suggested in Bruhn and McKenzie (2009), we additionally include village dummies in order to account for the stratified randomization. According to our findings presented in columns (1) and (2) of Table 3, firewood savings are substantial, with around 27 kg being saved per week in every household after introduction of the ICS. These are ITT results. As expected, ATT estimates differ only marginally being slightly higher. As these observations hold in the same way for the other impact indicators, we will only present the more conservative ITT estimates in the following (ATT estimates can be taken from Table D1 in Appendix D). Inserting in the regression the values 1 and 0 for the binary treatment variable and average values for the covariates gives us the absolute ICS consumption values shown at the bottom of the table. This implies that 30% of the households' total firewood consumption is saved.

[9] The results do not change if other wealth and income indicators are included.

Table 3: Effect of ICS Usage on Firewood Consumption per Week and per Dish

	Coefficient (Standard Error in parentheses)			
Estimator:	Ordinary Least Squares, ITT			
Dependent variable:	Firewood Consumption per Week in kg		Firewood Weight per Dish in kg	
Variable	(1)	(2)	(3)	(4)
Dish variables†				
Dish is cooked on open fire			Ref.	Ref.
Dish is cooked on ICS			-1.94*** (0.19)	-1.88*** (0.19)
Dish is cooked on traditional metal stove			-0.34 (0.39)	Ref.
Main dish			0.90*** (0.25)	
Short cooking (< 30 min)			-0.96*** (0.17)	
Meal variables†				
Number of people the meal is cooked for (in terms of the logarithm of adult equivalents)			1.82*** (0.52)	
Lunch			Ref.	
Breakfast			-1.60*** (0.17)	
Dinner			-0.16* (0.10)	
Multiple stoves			-0.06 (0.28)	
Household variables				
Household with ICS	-26.28*** (5.98)	-26.96*** (6.10)	-	
Average number of people cooked for (in terms of the logarithm of adult equivalents)	42.65** (14.04)		-	
Father has formal education	3.70 (8.22)		0.09 (0.28)	
Mother has formal education	5.30 (5.11)		0.21 (0.19)	
Household income (in logarithmic terms)	1.29 (2.52)		0.04 (0.06)	
Telecommunication expenditures (in logarithmic terms)	0.59 (0.98)		0.04 (0.03)	
Bank account ownership	2.91 (15.74)		0.38 (1.02)	
Flooring material is soil	-17.29** (6.67)		-0.69*** (0.21)	
Association membership of the mother	-7.32 (8.07)		-0.69** (0.28)	
Village dummies	*included*	*included*	*included*	*included*
Constant	-17.69 (44.13)	82.56*** (8.83)	-0.78 (1.55)	3.84 (0.33)

Table continues next page

Table continued

Mean of treatment group	61.10	60.69	4.17	4.16
Mean of control group	87.38	87.65	2.23	2.28
Savings rate (%)	30.1	30.8	46.5	45.2
Number of observations	228	228	748	757
Adjusted R-squared	0.25	0.13	0.43	0.17
F-Test	4.83***	3.40***	21.42***	12.62***

Notes: † For an explanation of the dish- and meal-level control variables, see Bensch and Peters (2013); computations on household level (columns 1 and 2) are performed with heteroskedasticity corrected standard errors accounting for heterogeneity in treatment responses; standard errors for the dish-level estimations (columns 3 and 49 are clustered by household; *, ** and *** indicate significance levels of 10%, 5% and 1%, respectively.

This is clearly less than the 40 to 50% found in CCTs. Rebound effects (see also footnote 4) do not seem to play a role, since the number of hot meals cooked does not increase in the treatment group and households reported that the quantity and type of food prepared has not changed since receiving the ICS. Another likely reason for this difference is the fact that households still cook on traditional stoves. In order to assess this issue, we additionally compare the firewood consumption for dishes prepared on an ICS to dishes prepared on traditional stove types. Even though the analysis of firewood savings on the dish level may be endogenous, the dish-specific savings provide an upper bound estimate of savings potentials where households had access to several ICSs to potentially abandon traditional stoves completely. These estimations furthermore provide insights into how the savings materialize on the individual dish level, since they make it possible to examine the influence of dish- and meal-specific variables. Table 3 shows in columns (3) and (4) the results for the OLS regression that controls for household characteristics and characteristics specific to the stove application. It reveals the differential effects of various dish- and meal-specific variables and a statistically highly significant ICS coefficient that would imply an average ICS savings rate of 47%, i.e. in the range of the CCT results.

An unbiased alternative to come up with a firewood savings estimate for the case of adopting ICS for the entire range of stove applications is to perform a slightly adapted version of the IV estimation in the calculation of the ATT for total firewood consumption. We now instrument a new treatment variable, *ICS usage intensity*, by the random assignment. Usage intensity is coded as a continuous variable obtained by dividing the number of dishes prepared on an ICS by the total number of dishes prepared in the respective household. It thus ranges from 0 to 100%. The resulting Wald estimator yields an average rate of 44.3 to 45.0% (with and without controls). This unbiased IV estimate substantiates the potentially endogenous estimate on the dish level. We conclude that if all meals in a household were cooked on an ICS, the savings rate obtained in columns (1) and (2) of Table 3 could well exceed 40%.

3.3. *Time Use*

As many as 96% of all households collect at least part of the firewood they use for cooking. A reduction in firewood consumption is likely to lead to households spending less time on firewood collection. In fact, the reduction in the aggregate *time spent by household members on firewood collection* is approximately two and a half hours per week, which corresponds to 15 to 17% (Table 4). The reduction, though, is not statistically significant (*p*-values of between 0.15 and 0.20 for ITT with and without controls), a finding that does not seem to be fully consistent with the reduction in total firewood consumption of around 30% found in the previous section. Still, it is not surprising that time savings are less pronounced than savings in firewood. 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 statistical insignificance of the difference might be due to inaccuracies in the time usage variable, which increases the standard error and, thus, reduces power. The inaccuracies are induced, for example, by the fact that 31% of households collect the wood on their own land while farming, which makes it difficult to disentangle time spent on the task of collection from time spent on ordinary field work. Also, some households do not collect the firewood every week but instead hold a stock that is typically replenished before the rainy season.

Table 4: Effect of ICS Usage on Time Expenditures

	Treatment	**Control**	**Difference in means (2)-(1)**		**Regression-adjusted difference in means**	
	mean	mean	mean (sd)	*p*-value (H_0: Diff = 0)	mean (sd)	*p*-value (H_0: Diff = 0)
	(1)	(2)	(3)	(4)	(5)	(6)
Duration of firewood collection per week (min)	719’	867’	148’ (102.5’)	0.15	125’ (97.6’)	0.20
Number of observations	86	134				
Cooking duration per day (min)	251’	333’	81’ (22.1’)	0.00***	77’ (20.7’)	0.00***
Number of observations	90	139				

Notes: † For the firewood collection indicator, the nine missing observations (5 control and 4 treatment) are due to households that were not able to specify the firewood collection time spells; all values derived from ITT estimations with heteroskedasticity corrected standard errors (in parentheses); *** indicate a significance level of 1%.

ICS households might moreover save time because cooking is facilitated and quicker. In qualitative interviews women repeatedly pointed out that the ICS allows them to regulate the temperature more easily, which, in turn, makes it easier to do other things while cooking. The cooking duration of all three meals throughout a typical day decreases significantly by more than 75 minutes (Table 4), where preparation of an individual meal on an ICS takes around one and a half hours. These savings far exceed the time that households additionally invest in cutting the firewood into smaller pieces, which takes not more than 15 minutes per day. Due to a lack of local job and business opportunities, a shift of time towards income-generating activities cannot be observed. The cooking women do not seem to sleep more either, since their time awake differs by mere 5 minutes between the two compared groups. Qualitative discussions rather suggest that the facilitation of the cooking task helps them to execute household duties in a less hurried way and to take more rest during the day.

3.4. Health

The negative effect of firewood usage on people's health may be alleviated by ICS usage via two channels. First, reductions in firewood consumption can be expected to reduce harmful smoke *emissions*, although it is unclear whether simple ICSs like those used in this RCT reduce smoke emission sufficiently to induce positive health effects.[10] Second, *exposure* to the emitted smoke might be reduced, either via reductions in the cooking duration (as found in Section 3.3) or if cooking behaviour changes because of the new stove. In general, smoke exposure is very high in rural Senegal, with around two-thirds of the household members responsible for cooking staying next to the stove most of the time they are cooking. Furthermore, the vast majority of households cook inside, predominantly in a separate kitchen. While in the control group the proportion of outside cookers stays stable, in the treatment group it doubles from 11% to 23% between baseline and follow-up. The main reason for this can be traced to the fact that the ICS better shields the fuel from wind than three-stone stoves; also, from the households' perspective, wind and dust are indeed the main drawback. In addition, the ICS requires less supervision, allowing the cook to dedicate more of her attention to other tasks away from the smoke source.

Virtually all persons responsible for cooking are women, on average two per household with no difference between treatment and control. We examine whether chronic symptoms of respiratory diseases and eye infections prevail among the women responsible for cooking and, as placebo outcomes, among the women not responsible for cooking and male household members. We first look at two dummy variables: *at least one household member with symptoms of respiratory diseases* and *at least one household member with eye problems* take the value one if at least one household member of the respective group reports having suffered from these symptoms at some point in the last six months before the interview. The results are displayed in Table 5 and indicate the share of households for which these variables take

[10] See, for example, Ezzati and Kammen (2001), Pope *et al.* (2011), or Burnett *et al*. (2014) for evidence on the non-linear particulate exposure response found in medical research.

the value one. The gender-differentiated data provides for striking indications of health effects: for women responsible for cooking, 9.0% of treated households report at least one of them suffering from respiratory disease symptoms. The corresponding value for the control group of 17.7% is almost twice as large – with this difference being statistically significant.

Table 5: Effect of ICS Usage on Health Status

	Treatment	**Control**	**Difference in means (2)-(1)**		**Regression-adjusted difference in means**	
	mean	mean	mean	*p*-value (H_0: Diff = 0)	mean (sd)	*p*-value (H_0: Diff = 0)
	(1)	(2)	(3)	(4)	(5)	(6)
Household level analysis						
Respiratory system disease (%)						†
any woman responsible for cooking	9.0	17.7	8.7	0.07*		
any male	7.9	6.5	-1.4	0.69		
any woman not responsible for cooking	3.5	6.2	2.7	0.38		
Eye problems (%)						†
any woman responsible for cooking	4.5	14.0	9.5	0.02**		
any male	4.5	7.3	2.8	0.40		
any woman not responsible for cooking	8.1	7.1	-1.0	0.78		
Number of observations‡	86 - 90	127 - 139				
Individual level analysis§						
Cook in household shows symptoms of… (%)						
a respiratory system disease	4.7	11.8	7.1	0.01**	7.0	0.01***
eye problems	2.9	9.8	6.9	0.01**	5.7	0.01***
Number of observations	778	1199				

Note: † ITT with inclusion of controls is not shown in this table, since for some control variables (bank account ownership, flooring material, village dummies) failure is perfectly predicted in the estimated probit regressions; ‡ Differences in the number of observations are due to a few missing values and some households without any woman not responsible for cooking; § the values in this analysis are marginal means and marginal effects derived from estimations that can be found in regression form in Appendix D, Table D2. They are conventionally calculated at the mean of the other independent variables taking into account the particularities of calculating margins for interaction terms in non-linear models and conditioning on household members who are cooks; standard errors for the household level estimations are heteroskedasticity corrected, those for individual household member level estimations are clustered by household; *,** and *** indicate significance levels of 10%, 5% and 1%, respectively.

If we look at the same proportion for male household members, who usually do not spend time around the cooking spot, treatment and control group households do not differ significantly from each other, nor do we find a difference for women not responsible for cooking. The same pattern is observable for eye infections: 14.0% of households report that at least one woman responsible for cooking suffers from eye problems in the control group compared with 4.5% in the treatment group. The difference is significantly different from zero. No such statistically significant difference is observed for men and women not responsible for cooking. With respect to the potential selection processes outlined in Section 2.3, the fact that the prevalence does not change in the group of women who are not responsible for cooking also indicates that there is no bargaining into or out of cooking in our sample.

The bottom of Table 5 refers to results derived from ITT probit regressions for the same disease symptoms on the level of individual household members.[11] We now look at the dummy variables *household member with symptoms of respiratory diseases* and *household member with eye problems*, which take the value one if the respective household member reports having suffered from these symptoms at some point in the last six months before the interview. The results confirm the findings of the household level estimations. In the group of household members responsible for cooking the prevalence rates for both respiratory disease symptoms and eye infections go down by almost seven percentage points. Significance levels are even more pronounced with *p*-values of 0.01 for both estimations with and without control variables respectively reflecting the more accurate definition of the indicator and the larger sample size. The estimations as well corroborate that the treatment has no effect at all on the group of household members not responsible for cooking (not shown in the table).

Altogether, while the reduction in smoke due to fuel savings might be too modest to trigger perceivable health effects by itself, it is likely that the combination with the change in cooking behaviour enabled by the ICS explains the observed improvements in health indicators: the ICS facilitates outdoor cooking, the cooking duration is reduced, and the cooking and combustion process requires less supervision.

3.5. Impact sustainability and upscaling the intervention

Hitherto we have found quite strong and robust evidence for high take-up and impacts of ICS usage after one year that are, given the experimental set-up, internally valid. Internal validity, though, is only a necessary condition for high policy relevance. The decisive questions in a next step are, first, whether these usage rates and impacts persist over time, second, whether the intervention yields benefits that outweigh the costs and if so, third, whether it can be upscaled.

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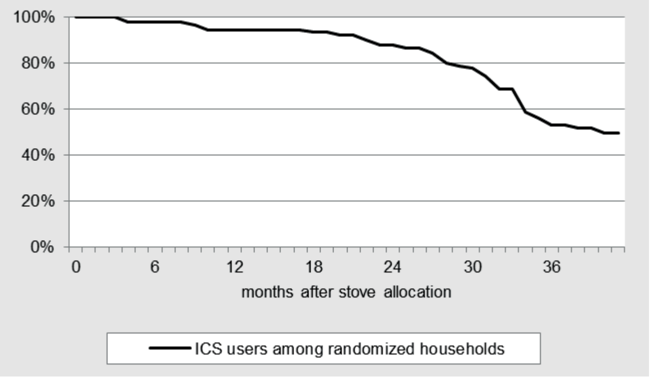
[11] We abstain from showing ATT estimations here, since the specification requires interacting the treatment status with the dummy variable that indicates the cooking responsibility. We would thus need to instrument the ICS uptake and the interaction term, respectively. Using the random assignment as instrument for both ICS uptake and also in the interaction term (which is a controversial procedure) does not deliver any result in our case, since the estimations do not converge.

In order to assess the sustainability of the observed impacts we conducted an ICS usage tracking survey three and a half years after the random assignment. This enables us to examine the durability of the randomized ICS under day-to-day rural cooking conditions and the usage behaviour over the full life-span of the ICS. We found that 49% of ICS-winning households still used the randomized ICS. Considering a life span of two to three years in urban areas for the charcoal Jambaar ICS, which is quite similar to the firewood ICS used in this RCT, this proportion can be considered surprisingly high. In the enumerators' appraisal, half of these ICS were still in good condition. The proportion of dishes prepared with an ICS among ICS users declined only slightly from 70% in 2010 to 62%. As can be seen in Figure 4, those ICS winners who do not use the ICS anymore (51%) only slowly ceased to use their ICS. All of them have done so because the stove has deteriorated and 90% of them still used their ICS two years after randomization.[12]

Figure 4: Decline in the Percentage of ICS Users among Randomized Households



Against this background of persisting usage behaviour we conduct a simple cost-benefit analysis. The costs of the ICS are represented by the market price of around 10 US $. For a conservative estimate of the benefits, to begin with, we only account for reductions in firewood consumption. We take the average price of 0.02 US$ per kg of firewood paid by firewood-purchasing households at the time of the follow-up survey as the shadow price for collected firewood. Valuing the firewood that ICS users save compared to traditional stove users shows that the savings amount to 2.03 US$ per month. Already at this stage it is obvious that the benefits of ICSs outweigh the costs by far over its life span. If health benefits, the reduction in cooking duration and the potential alleviation of deforestation

[12] Within the complete investigation period of three and a half years, the ICS was destroyed in two cases, once because of heavy rainfall and once because the kitchen wall collapsed. In four cases, the ICS was stolen.

pressures were taken into account, the benefits would be even greater. As a consequence, upscaling the intervention seems to be economically sensible.

However, some threats to the external validity of the RCT might make it difficult to transfer the results to an upscaled intervention or to other regions. In Appendix E, we discuss the aspects raised by Duflo *et al.* (2008*a*): general equilibrium effects, Hawthorne and John Henry effects as well as possible limitations to generalizations beyond our specific intervention and beyond our sample. Overall, the external validity of this RCT is quite high. In particular, the fact that our field experiment was implemented in an unobtrusive way enables us to transfer the findings to a non-experimental set-up. In terms of transferability of the high take-up rates, the severe firewood scarcity in our study area may have increased the incentives for households to effectively use the ICS. Take-up in more biomass-abundant regions could hence be lower. Another driver of high usage rates, though, is the fact that we are working with a type of ICS that is adapted to the rural conditions not only in our study area but also beyond. Furthermore, we conducted the study together with the Government of Senegal and GIZ and thereby mimicked a typical ICS dissemination intervention.

In sum, if permanent access to ICS is ensured and provided that the ICS is slightly modified in response to potentially different cooking habits elsewhere (e.g. pot sizes or cooking fuel), our findings are transferable to different populations in (Western) Africa.

4. Discussion and Conclusion

In this paper we evaluated take-up behaviour and impacts of improved cooking stoves (ICSs) in rural Senegal by means of a randomized controlled trial (RCT). ICSs are widely seen as an option for developing countries to combat the devastating effects of woodfuel usage for cooking purposes on people's health, work load as well as the environment. The first finding is that ICS take-up was close to 100% among the randomly assigned households and that people only cease to use the ICS if it deteriorates. This sustainably high take-up rate comes as a surprise, since it is often argued among development practitioners that people would not use ICSs for which they have not paid. It also constitutes a major difference to the findings in Hanna *et al.* (2012). Major reasons for this are probably differences in how convenient and advantageous the ICS technology is from the household perspective and to which degree the ICS has a better performance than the existing stove portfolio. First, the ICS used in our study is maybe closer to the regular cooking habits of the target population. It is easier to use, does not require any maintenance and due to its portability households can decide themselves where to cook. Second, wood scarcity is probably higher in our study area thereby increasing the relevance of an ICS. Third, more than a fourth of the households in the study in India already also used cleaner fuels like electricity and gas before the randomization so that the randomized ICS did not necessarily represent an improvement for them.

The firewood savings were found to be statistically significant and substantial. They amount to around 30% per week in the most likely scenario where households have one ICS and continue to use traditional stoves complementarily. If these complementarily used traditional stoves were also replaced by ICSs, the savings could increase further up to and above 40%. Such a reduction in firewood consumption is an important impact in an arid country like Senegal, where forests are permanently under pressure and firewood provision is a daily hardship for rural women. Moreover, the CO2 that is sequestered in both dead wood and green wood is set free with obvious implications for climate change processes. Deforestation and forest degradation are in fact a relevant source of global CO2 emissions. IPCC (2013) estimates that net land-use change, mainly deforestation, is responsible for about 10% of the total anthropogenic CO2 emissions. To the extent woodfuel usage contributes to these processes, dissemination of ICS as used in this study can help to reduce such losses of carbon sinks.

We also observe a reduction in firewood collection time, but this is only borderline significant. Furthermore, we find that cooking duration is decreased significantly by over 20%. In addition, the cooking process is facilitated so that the time the cook needs to be in direct proximity to the cooking spot is reduced. Together with an increase in outdoor cooking, this leads to an evident reduction in exposure to harmful smoke. Consequently, we also find a clear indication of a decrease in respiratory disease symptoms and eye problems, with a drop of around 9 percentage points each for the women responsible for cooking.

Our self-reported health outcomes might of course feed criticism that objective indicators such as individual particulate matter exposure as measured in the RESPIRE study deliver more accurate information. Apart from the high costs of executing such a survey, there is also a trade-off between the increased accuracy and a Hawthorne effect. Study participants can be expected to behave differently if they are asked to wear exposure monitoring tools for 24 hours, for example. Hence, self-reported and objective measurements can rather be seen as complements. In addition, one might suspect an auspices or courtesy bias in our data where respondents express their gratitude for having received the ICS or expect additional benefits from a satisfied implementing agency. In their stove study in Ghana, Burwen and Levine (2012) suspect that this effect biases their results, since the positive effects on self-reported health they observe are not plausible given that smoke exposure is not reduced. However, this bias is not likely in the present case, since participating households were not aware of the study's focus on ICSs. 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 observe any health effect among household members not responsible for cooking strongly underpins this view. Hence, different from the Burwen and Levine (2012) study, placebo outcome indicators corroborated our findings. Finally, the magnitude of observed savings is in the range of what is expected based on laboratory tests and, thus, does not feed the suspicion of biased responses.

Altogether, the substantial and statistically significant impacts on different levels of indicators including positive external effects such as reduced deforestation and household air pollution substantiate the efforts that the international community dedicates to the dissemination of ICSs. The findings on the health level fit into the concept of intensive and extensive margins of behaviour that has recently been brought into the debate on public health-relevant behaviour (see Dupas, 2011). The present analysis suggests that not only the extensive margins of cooking should be addressed by disseminating cleaner stoves, but also the intensive margins by, for instance, raising awareness of the need to reduce smoke exposure. This behavioural dimension should also be taken into account by the Global Alliance for Clean Cookstoves and the United Nations in outlining future policies to increase access to improved or clean cooking stoves. Even ICSs that still emit considerable amounts of smoke might trigger positive health effects if they also induce exposure-relevant behavioural changes.

The almost universal take-up among randomly assigned ICS owners suggests that if they have an easy opportunity to obtain an ICS that is adapted to local cooking habits people also use it. The high usage rates, however, do not necessarily mean that households are also ready or able to pay for the ICS, despite the fact that a simple back-of-the-envelope cost-benefit calculation made it clear that investing in an ICS would be a profitable investment from the point of view of the individual households. The interplay of cash and credit constraints, the lack of information, and the fact that in many cases the women responsible for cooking do not manage the household budget, all this raises doubts about whether households would be able and willing to pay the market price for ICSs, even if the stoves were readily available on the market. The majority of rural households would therefore probably stick to the cheaper traditional three-stone or metal stoves.[13] The experience from long-standing pilot dissemination activities in neighbouring rural areas in Senegal seems to support this presumption. As the strategy of promoting the creation of sustainable ICS markets has already proven to be difficult in urban areas, where fuels are purchased and ICS benefits are clearly monetary ones, it can be expected to require even more efforts and resources in rural areas.

[13] See Miller and Mobarak (2013) for evidence on low purchase rates of ICS in Bangladesh.

In combination, the high take-up and the positive external effects of ICS usage observed in this study would suggest that more direct options of ICS promotion should be reconsidered. This could mean, for example, directly subsidizing the production of ICSs in rural areas so that end-user prices can compete with traditional stoves. If the findings can be confirmed in other rural areas, it might even be an option to distribute ICSs directly to the households, either for free or at a very low, symbolic price. While this would be in contrast to the strategies pursued by most ICS dissemination programmes, and many practitioners are opposed to a free distribution policy, the empirical literature provides evidence from other field experiments that supports the idea. Paying a positive price does not necessarily lead to higher usage rates of health-relevant goods (Cohen and Dupas, 2010; Tarozzi *et al.*, 2012) and charging cost-sharing prices substantially reduce take-up (Kremer and Miguel, 2007). Any ICS promotion policy has to be designed in close cooperation with local stakeholders, putting particular effort into the choice of technically and culturally appropriate ICS models. Institutions have to be created to sustain the distribution of direct subsidies for the ICSs, thereby avoiding the flash-in-the-pan effect that has been observed in unsuccessful earlier ICS subsidization programmes.

As these recommendations can only be an interim conclusion, further research on the take-up behaviour and on the impacts of ICS usage has to follow up in other regions. The indication of positive health effects of the simpler ICS used in this RCT calls for taking into account cooking behaviour in these studies. As evidenced by the lower take-up of ICSs in the Hanna *et al.* (2012) study in India, the results may vary in different environments and if other ICS types are used. In addition, further experimental studies should examine the mechanisms behind take-up behaviour, such as the households' willingness-to-pay for ICSs, but also the role of credit constraints, information, and woodfuel scarcity. Such research efforts can substantiate – or contradict – the findings in this study and will thereby help to decide under which circumstances and to which degree subsidies might in fact be required to encourage rural people to obtain ICSs.

Appendix A: Stove types used in the survey area

Open fire stoves

Three-stone stoves	Os
	

Traditional metal stoves

Cire khatach (fuelled with crop residues)	Cire wood	Malagasy stove
		

Improved Cooking Stove (ICS) Jambaar

Appendix B: Power calculation

Since information on our decisive impact variable, firewood consumption, was not 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 (2013) 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 (retrospective 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 B1 provides 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. We defined the probability of being assigned to the control group to be 60% and that for the ICS treatment group to be 40%.

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 B1. In order to account for the sensitivity 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 sample size required to measure significant effects tends to be substantially higher. The reason is that the effect on respiratory diseases, for example, 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 B1: 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	0.069	household data
m	Mean number of interviewed households per cluster (village)	20	229/12 = 19.1	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	90/139 = 0.65	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)
$ES = \lvert X_2 - X_1 \rvert / X_1$	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	229 = 90 + 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.

Appendix C: Data Policy Requirements

Design of the field experiment

The original design of the experiment was drafted in an inception report for the Independent Evaluation Unit of Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and finalized on August 20, 2009. It was concretized during an in-country preparation mission between October 12 and 22, 2009 and is outlined in Section 3.3 of this paper ('RCT design and implementation').

Selection and eligibility of participants

We selected twelve villages from the target region of a planned GIZ rural electrification intervention in Foundiougne District that are far away from GIZ-supported producers of improved cooking stoves (see Figure C1 and Table C1). Within the villages, all households were eligible. They were randomly sampled and none of the sampled households refused to participate in the RCT (see also Figure C2).

Instructions given to participants

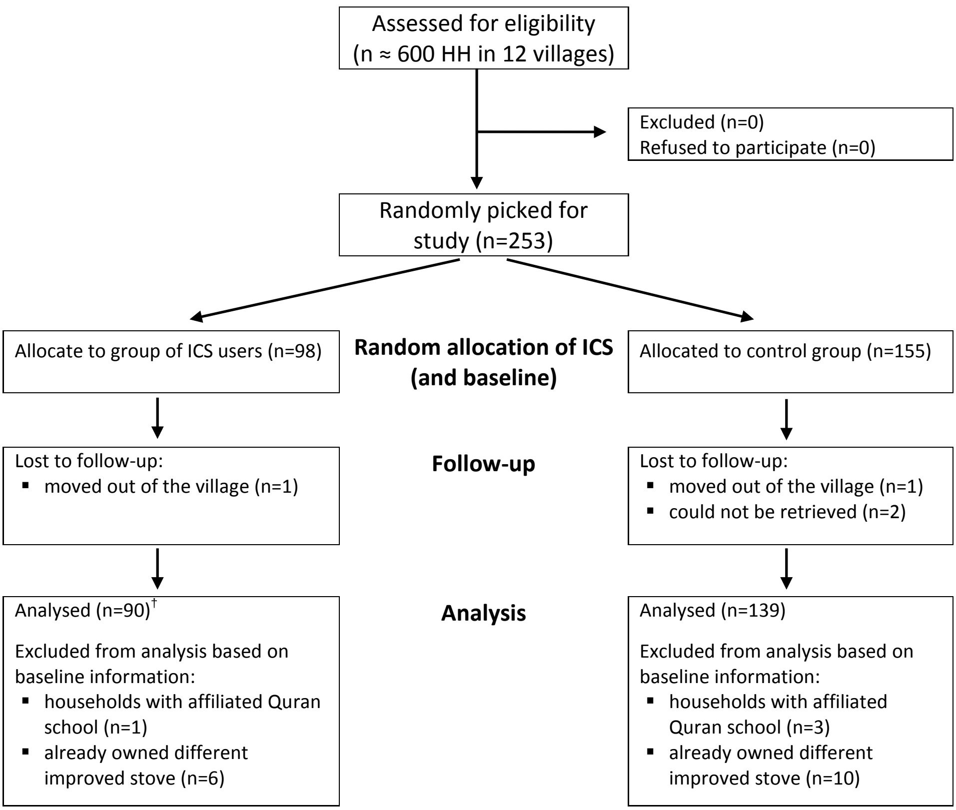
On the day of the ICS distribution, households were reminded via phone in order to make sure the person responsible for cooking in the household was present. A local staff member with several years of experience in ICS usage training had a meeting with those women who had received an ICS. In the local language Wolof, he presented the ICS as a fuel-saving device and briefly informed about convenience co-benefits: a quicker cooking process, less smoke, and a cleaner kitchen. He verbally informed the women about the functioning of the stove and the proper utilization. He explained to them that the clay inlay of the ICS serves the purpose of storing the heat and that it could easily break if the embers were doused with water; instead they were told to put the fire out with sand on the ground. Moreover, unlike with open fires for which people typically use entire branches or even trunks, the firewood has to be chopped in order to fit the fuel feed entrance of the ICS. He advised them not to use pot sizes that are too big for the stove and not to move the pot when it is placed on the stove. Households were also given a leaflet summarizing these instructions (Figure C3). This is all regular information that is also provided by ICS traders in a non-RCT-set-up. In addition, in order to avoid ICS misuse the women were also asked not to share the ICS with other households or lend it to other women. From a methodological point of view, this was also intended to avoid treatment contamination.

Figure C1: Location of Survey Sites

Table C1: List of Survey Sites

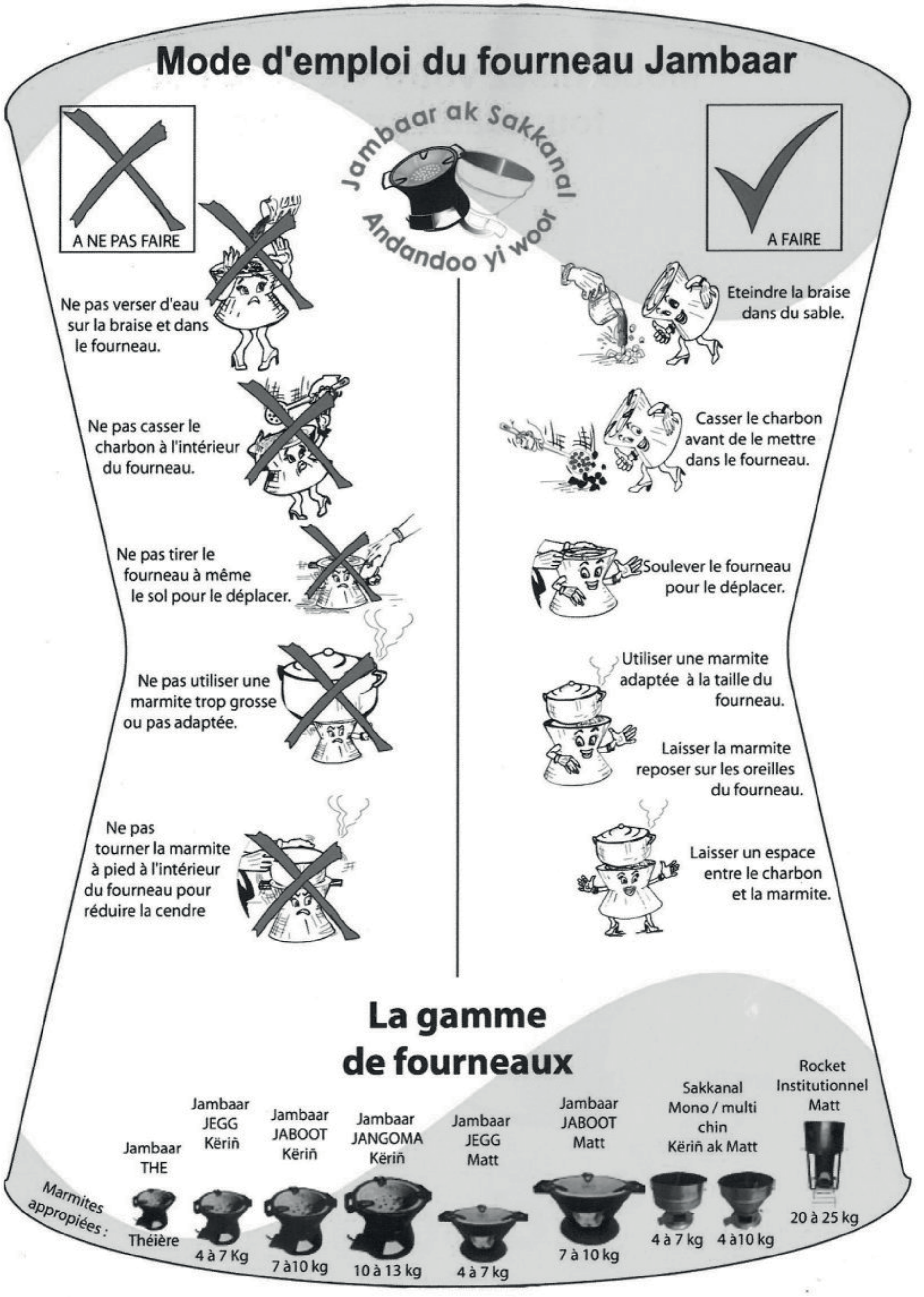
Village	Rural Community
Pethie	Djilor
Keur Mandao	Djilor
Ndoffane Ndarry	Djilor
Keur Omar	Djilor
Goudeme Sidy	Djilor
Darou Keur Mor Khoredi	Diossong
Thiamene Ndiagnene	Diossong
Simong Bambara	Nioro A. Tall
Ndiayene Kad	Nioro A. Tall
Keur Bacar Santhie	Keur S. Diané
Keur Maniane	Keur S. Diané
Nema Bah	Toubacouta

Figure C2: Participant Flow



Note: † The sample used for our intention to treat (ITT) analysis also includes the two households that stopped using the ICS – the ICS of one household was completely broken in an accident and another household did not use the ICS.

Figure C3: Leaflet Provided to ICS-winning Households



Note: The leaflet was originally designed for urban areas on which the ICS dissemination project had focused. Here, as households mostly use charcoal, the leaflet also contains information on charcoal usage and charcoal ICSs. The two firewood ICSs are “Jambaar Jegg Matt” and “Jambaar Jaboot Matt”, of which the latter was used in the present study.

Appendix D: Additional Estimation Results

Table D1: ATT Results for Household Level Indicators on Firewood Consumption, Time Expenditures, and Health

	Difference in means		**Regression-adjusted difference in means**	
	(sd)	*p*-value (H_0: Diff = 0)	mean (sd)	*p*-value (H_0: Diff = 0)
	(1)	(2)	(3)	(4)
Firewood Consumption per Week (kg)	27.74*** (6.53)	0.00***	27.13*** (5.95)	0.00***
Duration of firewood collection per week (min)	153' (102.9')	0.14	130' (96.2')	0.18
Cooking duration per day (min)	84' (22.1')	0.00***	80' (20.5')	0.00***
Respiratory system disease (%)				
any woman responsible for cooking	9.1	0.05*	9.2	0.04**
any male	-1.0	0.77	-0.9	0.79
any woman not responsible for cooking	2.7	0.39	3.0	0.34
Eye problems (%)				
any woman responsible for cooking	9.9	0.02**	10.2	0.01**
any male	2.5	0.75	2.5	0.76
any woman not responsible for cooking	-1.5	0.70	-1.0	0.78

Note: All computations on household level are performed with heteroskedasticity corrected standard errors accounting for heterogeneity in treatment responses and include village dummies; *,** and *** indicate significance levels of 10%, 5% and 1%, respectively.

Table D2: Probit Regression on Health Status of Household Members

	Coefficient (Standard Error in parentheses)			
Estimator:	Probit, ITT			
Dependent variable:	Household member with respiratory system disease		Household member with eye problem	
Variable	(1)	(2)	(3)	(4)
ICS dummy	-0.12 (0.16)	-0.08 (0.16)	-0.06 (0.16)	-0.02 (0.15)
Household member is responsible for cooking	0.84*** (0.18)	0.87*** (0.16)	0.68*** (0.16)	0.77*** (0.15)
Household member is responsible for cooking x ICS dummy	-0.41 (0.28)	-0.43 (0.28)	-0.60** (0.29)	-0.59** (0.28)
Further household member variables				
Household member's sex	0.03 (0.17)		0.20* (0.15)	
Household member's age	0.01** (0.00)		0.02*** (0.00)	
Household variables				
Average number of people cooked for (in terms of the logarithm of adult equivalents)	-0.35** (0.16)		-0.20 (0.17)	
Father has formal education	-0.15 (0.17)		-0.28 (0.26)	
Mother has formal education	0.19 (0.12)		0.21 (0.13)	
Household income (in logarithmic terms)	0.01 (0.04)		-0.01 (0.06)	
Telecommunication expenditures (in logarithmic terms)	0.04* (0.02)		-0.01 (0.02)	
Bank account ownership	-0.52 (0.45)		-0.58 (0.39)	
Association membership of the mother	0.08 (0.12)		-0.11 (0.14)	
Village dummies	*included*	*included*	*included*	*included*
Constant	-1.91*** (0.56)	-2.07*** (0.20)	-2.10*** (0.75)	-2.14*** (0.22)
Number of observations	1977	1977	1977	1977
p-value of interaction term	0.146	0.119	0.034	0.037
Pseudo R-squared	0.130	0.103	0.168	0.090

Notes: The household control variables *flooring material* is not included, since it predicts failure perfectly in the estimated probit regressions; standard errors are clustered by household; *, ** and *** indicate significance levels of 10%, 5% and 1%, respectively.

Appendix E: External Validity

General equilibrium effects may occur in the present case if widespread ICS usage leads to a sizable reduction in firewood demand and, in turn, to a reduction in the costs of firewood provision, either because prices decrease or because firewood is less scarce and easier to collect. This might induce households to consume more of the now cheaper fuel. Although this would bring welfare benefits such as more hot meals, from a public health and resource saving perspective this might be considered an adverse second-round effect. Since most households in rural Senegal collect firewood and do not buy it, this effect can be expected to be less pronounced than for market-based energy sources.

One major risk to the external validity of RCT results is if participants change their behaviour because they know that they are participating in an experiment or are somehow under observation. While so-called *Hawthorne effects* (if treatment group members change their behaviour) or *John Henry effects (*if control group members change their behaviour) can never be ruled out completely, we reduced the risk considerably by first embedding the interviews in a baseline survey for an electrification intervention under preparation in the studied areas. The applied questionnaire covered a comprehensive set of socio-economic and energy-related dimensions such as electricity so that attention was not focused primarily on cooking-related parts of the interviews. Second, the lottery was framed as a reward for all households to recompense them for participation in the electrification baseline survey, a similar procedure as applied by De Mel, McKenzie and Woodruff (2008) in an RCT on business grants among micro-enterprises in Sri Lanka. Third, all survey activities were conducted in an unobtrusive way by local interviewers and community workers.[*]

According to Duflo *et al.* (2008*a*), three problems may hamper a valid *generalization beyond the specific programme and sample*. First, it may be that the particular care with which the randomized treatment was implemented makes it difficult to upscale the intervention. As outlined in Section 2.4 and the instructions given to participants (see Appendix C) we keep to what real-world users are told about the randomized ICS. Second, the question arises as to whether we can transfer the results to a slightly modified intervention. Here, the fact that we distributed the ICS for free deserves some attention as usage behaviour might change if households need to pay for the ICS. If a change can be suspected when households with sufficient willingness-to-pay self-select into the treatment, then most practitioners would expect an intensification of usage and, thus, also impacts. Yet, usage intensity is already high so that no substantial increase can be expected. The third point is the particularity of the study population. The most important characteristics here are the fuels used for cooking and their availability. Firewood availability in our study area is typical of large parts of interior

[*] See Zwane *et al.* (2011) for an examination of how being surveyed might affect response behaviour. The authors generally call for an unobtrusive method of data collection.

Western Africa and dry savannah regions in general. All the households in our target area use firewood, which is the case in virtually all rural areas in Africa. Take-up rates and consequently impacts might change, though, in regions in which firewood is more abundantly available (e.g. the southern region of Senegal) or in which cleaner fuels are already available such as in urban Africa or in parts of rural Asia (see Hanna *et al.*, 2012 for an example).

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