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Gunther Bensch and Jörg Peters[1]

Combating Deforestation? – Impacts of Improved Stove Dissemination on Charcoal Consumption in Urban Senegal

Abstract

With 2.7 billion people relying on woodfuels for cooking in developing countries, the dissemination of improved cooking stoves (ICS) is frequently considered an effective instrument to combat deforestation particularly in arid countries. This paper evaluates the impacts of an ICS dissemination project in urban Senegal on charcoal consumption using data collected among 624 households. The virtue of our data is that it allows for rigorously estimating charcoal savings by accounting for both household characteristics and meal-specific cooking patterns. We find average savings of 25 percent per dish. In total, the intervention reduces the Senegalese charcoal consumption by around 1 percent.

JEL Classification: O13, O22, Q41, Q56

Keywords: Impact evaluation; energy access; cooking fuels; deforestation; Africa

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1. Introduction

In most developing countries, biomass is the main source of energy, with 2.7 billion people globally using traditional biomass as their primary cooking fuel (IEA 2010). The reliance on biomass – essentially wood and charcoal – is particularly high in Sub-Saharan Africa. At 81 percent, the proportion of people relying on these fuels is higher than in any other region (UNDP/WHO 2009). Woodfuel usage for cooking purposes is associated with various negative effects on people's living conditions. The emitted smoke is a major health threat: According to WHO (2009a), 2 million people die every year as a consequence of so-called household air pollution – more deaths than are caused by malaria (MARTIN ET AL. 2011). In Senegal alone, some estimated 6,300 people die every year because of household air pollution (WHO 2009b). In rural areas, firewood often has to be collected posing a burden of workload – especially for women. In urban areas, woodfuels are mostly purchased, which incurs significant costs for households.

Furthermore, in arid countries with rather low biomass production such as Senegal, this reliance may cause wood to be extracted in an unsustainable manner. The resulting deforestation not only affects global climate due to a loss of carbon sinks, but also leads to more immediate regional and local environmental impacts, including land degradation and loss of biodiversity. The deforestation effect of charcoal, the primary woodfuel in urban Senegal, is even worse than that of firewood: First, the charcoal production process is intensive and puts more pressure on forest resources than does fuelwood collection, which is carried out by the rural population in a rather extensive way (KAMMEN AND LEW 2005). Second, charcoal production in its traditional form tends to be inefficient implying that cooking with charcoal requires roughly twice as much raw wood as does cooking with firewood. Not least, due to an increased urban usage of charcoal – a result of ongoing urbanization processes – the total consumption of woodfuel in Sub-Saharan Africa is steadily growing (FAO 2008, IEA 2006).

Besides policy interventions on the supply side, like improved forestry management systems or reforestation initiatives, two approaches can reduce deforestation pressure on the demand side: the usage of more efficient, so-called improved cooking stoves (ICS), or switching to non-wood fuels such as liquefied petroleum gas (LPG) or kerosene. In Senegal, both strategies have been pursued for several decades, leading to a situation in which LPG is dominantly used in urban areas. Although a national subsidy and promotion program to foster LPG usage was already launched already in the 1970's, charcoal is still used widely. Therefore, since the 1980's the international donor community and national governments have put much effort into disseminating ICS in Senegal and other developing countries. Recently, the harmful effects of biomass usage for cooking purposes and the dissemination of ICS have gained much public attention in the wake of the creation of the *Global Alliance for Clean Cookstoves*. As part of the *United Nations Foundation* and promoted by the US Secretary of State, Hillary Clinton, the Global Alliance intends to bring ICS or improved fuels like LPG to 100 million homes in developing countries by 2020.[1] In general, 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.[2]

While the assumptions about positive impacts of disseminating such cooking devices – reducing fuelwood consumption and thereby work load and health burdens as well as deforestation pressures – seem to be straightforward, rigorous impact evaluations of these development interventions are rare. For health impacts some evidence exists from Latin America and Asia. SMITH-SIVERTSEN ET AL. 2009, for example, find a substantial reduction in exposure to indoor air pollution and a reduction in risk for respiratory symptoms in the course of a field experiment for which chimney stoves were randomly assigned to replace traditional open fires in rural Guatemala (see as well SMITH-SIVERTSEN ET AL. 2004).

[1] See http://cleancookstoves.org for more information on the Global Alliance on Clean Cookstoves and MARTIN ET AL. (2011) for a recent overview on the improved stoves and air pollution policy debate.

[2] See WORLD BANK (2011) and BRYDEN ET AL. (2006) for further information on ICS and a more detailed presentation of existing stove types.

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. YU (2011) examines the effects of behavioral interventions in combination with ICS measures in rural China and finds that this double treatment brings down respiratory diseases among children under five. This effect seems to be mainly triggered by the behavioral part, though. Further rigorous studies are currently being conducted by J-Pal in India and Bangladesh (see DUFLO, GREENSTONE, AND HANNA 2008a, 2008b).[3]

For Africa, BENSCH AND PETERS (2011) evaluate the impacts of ICS usage in rural Senegal by means of a field experiment for which ICS were randomly assigned to households. They find a substantial reduction of firewood consumption and self-reported respiratory disease and eye infection symptoms. Cooking time is also considerably reduced, whereas we do not find a significant impact on firewood collection time. Beyond this study, evidence for Africa, in particular for urban areas, is completely lacking. The impacts of ICS usage in cities can be expected to differ considerably from ICS impacts it rural areas because different fuels and stoves are used here. The present paper aims to address this lacuna with a rigorous evaluation of the impacts of ICS usage on charcoal consumption related to a dissemination project by *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ) in urban Senegal. The GIZ intervention called *Foyers Améliorés au Sénégal* (FASEN) is one of the many projects that participate in the Global Alliance for Clean Cookstoves. The ICS disseminated by FASEN are simple portable metal stoves with a clay inlay to store the heat, which have also been disseminated in other Africa countries.[4]

The research project was assigned by the *Independent Evaluation Unit* of GIZ. Based on a survey among 624 urban households conducted between August and September 2009 in the target areas of the GIZ intervention in the cities of Dakar and Kaolack, we examine the

[3] No document is published on the Bangladesh evaluation yet. *See* www.povertyactionlab.org for details.
[4] The stove is called Jambar in Senegal and Jika in Kenya (see WORLD BANK 2011).

potential reduction in charcoal consumption induced by the usage of ICS. Beyond the direct environmental impact, the reduction in charcoal consumption is decisive for all potential subsequent impacts like reduced smoke emissions and energy expenditures. Hence, by rigorously assessing charcoal consumption, we also examine the plausibility of impacts on the level of these subsequent indicators. To the extent that charcoal is economized, for example, one can assume that people's exposure to harmful particles is also reduced.

The virtue of our data is that it contains detailed information on cooking behavior and fuel usage for each meal of a typical day for the respective household and for each stove that is used for this meal. In our context, a typical meal is composed of two dishes, mostly rice and sauces, which are prepared on two stoves. Having this data at hand, we are able to estimate *charcoal savings per dish* using Ordinary Least Squares (OLS) regression in combination with propensity score matching, the so-called propensity score weighted regression approach. This method controls for household-specific characteristics, as well as dish- and meal-specific cooking patterns such as the number of persons cooked for and the type of dish that is cooked. In addition to controlling for observable heterogeneity between ICS users and non users, we scrutinize the existence of possible unobservable differences by extensive qualitative investigations that complemented the survey field work. Additionally accounting for changes in cooking frequency and fuel choices allows us to estimate the *total charcoal savings* induced by the GIZ project. Since this indicator is assessed on the household level, we apply conventional propensity score matching here.

The identification assumption at the heart of this methodology is discussed in Section 4 after a review of the country and project background and a presentation of the research design in Section 2 and 3, respectively. In Section 5, we present the results. Section 6 concludes.

2. Country and project background

Urban cooking in Senegal is dominated by LPG. Already in the 1970's, the butanisation program, a subsidy and promotion program to foster LPG usage, was launched. LPG continues to be subsidized,[5] and Senegal is among the countries with the highest LPG consumption per capita in the region (WORLD BANK/WLPGA 2001). In 2002, around 71 percent of urban households in Senegal and 88 percent of households in Dakar used LPG as the primary cooking fuel (ANSD 2006). Nevertheless, charcoal is used by most households as a complementary fuel. Moreover, charcoal demand is rising in part due to a steady population growth of 3.1 percent per year in urban areas, where the charcoal is mostly used (CIA 2010). At the time of the survey, the price per kilogram of charcoal in Dakar was at 200 FCFA (0.42 US$).

According to data gathered by the *National Union of Forest Workers* (UNCEFS) in 2010, the capital city of Dakar alone consumed 94,000 tons of charcoal per year, which corresponds to one fifth of the national consumption (SIE 2007). This demand can only be met using wood cut several hundred kilometers from the capital. The charcoal is often produced in the neighboring country, Gambia, or in the Casamance region in Southern Senegal. These more humid areas produce much more biomass than the arid regions in the rest of Senegal. While Senegal still has a relatively high share of primary forests, these forests mainly consist of small trees and shrubbery. Deforestation leads to annual forest losses of around 0.5 percent, which is slightly above the average for Western and Central African countries (FAO 2010). FAO figures on Africa and Senegal indicate that agricultural land clearance has been the predominant cause of deforestation (WEC/FAO 1999 and FAO 2005). TAPPAN ET AL. (2004) support this view, but also emphasize the role of charcoal production in the decline of woody cover in the remaining forests in Senegal. According to

[5] While direct fuel subsidies were removed in June 2009 under the ongoing pressure of the International Monetary Fund (IMF), the government still uses different indirect subsidies to avoid that international price increases pass through. For example, LPG is exempted from customs duties and VAT (LAAN, BEATON, AND PRESTA 2010, MEB 2009, APS 2010).

their surveys, charcoal production has led to a degradation of 28 percent of Senegal's wooded savannas and woodlands (TAPPAN 2000). In fact, it is particularly charcoal that harms forest stands, since – due to an inefficient production process - cooking with charcoal requires roughly twice the amount of raw wood that is needed when cooking with firewood (see Section 1).

Against this background of deforestation and woodfuel scarcities, GIZ is active in the Senegalese energy sector with a wide range of interventions put together under the umbrella of the energy program PERACOD (*Programme pour la promotion des énergies renouvelables, de l'électrification rurale et de l'approvisionnement durable en combustibles domestiques*). One of PERACOD's components addresses the supply of charcoal via promoting sustainable forest management and more efficient charcoal production approaches. On the demand side, PERACOD promotes the dissemination of ICS via its sub-component *Foyers Améliorés au Sénégal* (FASEN). The FASEN ICS intervention is the focus of the present paper.

The ICS promoted by FASEN is called *Jambar*. The Jambar is a simple stove, composed of a metal casing and an insert of fired clay. Thanks to simple design improvements, the fuel burns more efficiently, the heat is better conserved and much more focused towards the cooking pot than with traditional stoves. Different ICS models exist that are fuelled with firewood or charcoal. The charcoal model is the relevant one for urban Senegal, where charcoal is virtually the only woodfuel used. The traditional counterpart is the so-called *Malagasy*, a simple pyramid-shaped single-pot metal charcoal stove. In controlled cooking tests (CCT), field laboratory tests in which local women cook typical meals under day-to-day conditions with both stove types, the Jambar stove saved 40 percent of charcoal compared to the Malagasy. The Jambar is sold on local markets or directly by whitesmiths at a price ranging between 4,500 FCFA and 9,000 FCFA (9.50 to 18.9 US$), depending on the size. The Malagasy stove is sold at 1,500 FCFA (3.15 US$).

FASEN at first focused on urban areas. It started its activities in Dakar in June 2006 and extended them to Kaolack in 2007. While the metropolitan area of the capital Dakar counts some 2.5 million inhabitants, Kaolack has roughly 200,000 inhabitants, making it the fourth largest city in Senegal. Kaolack is an important peanut trading and processing center and is situated 190 kilometres south-east of Dakar in the heart of the Bassin Arachidier, Senegal's main agricultural region.

The FASEN dissemination strategy has drawn lessons from the inability of predecessor projects to create a sustainable market for ICS in Senegal. In spite of large ICS programs since the 1980s, the market for ICS was virtually non-existent when FASEN started its activities. In demarcation to these earlier programs, the project does not directly subsidize the production or purchase of ICS. Instead, on the supply side potters and whitesmiths are trained in producing ICS that fulfill pre-defined quality requirements. They are also supported through specific financing mechanisms and in the marketing of their products. On the demand side, women's groups and retailers are supported in marketing ICS to households. For example, cooking demonstrations are organized as social events, in which cooking with the traditional Malagasy stove is compared to preparing a dish with an ICS.

FASEN is part of the outcome-oriented Dutch-German Energy Partnership *Energising Development* (EnDev), which is financed by the German Federal Ministry for Economic Cooperation and Development (BMZ) and the Netherlands' Directorate General for International Cooperation (DGIS) and implemented by GIZ. As part of EnDev, FASEN has to report how many people in the project's intervention areas have acquired an ICS and, hence, have benefited from the FASEN development measure. For this purpose, the number of disseminated ICS is meticulously monitored at the level of the whitesmiths. Around 40 of them work with FASEN on a regular basis and are visited by a FASEN staff member two times a month. This FASEN staff member collects the production figures from the whitesmiths. They are then cross-checked with production figures from potters and the number of ICS sold at women's groups and retailers. In total, around 78,500 ICS were disseminated by the end of 2009, 71,600 in Dakar and 6,900 in Kaolack.

3. Data and research design

3.1. Identification Strategy

The primary objective of this evaluation is to identify how much woodfuel is saved in households using ICS. For this purpose, we use two impact indicators: (a) *woodfuel savings per stove application* and (b) *total woodfuel savings on the household level* in the course of one week. We also use this second indicator to eventually determine the overall woodfuel savings accruing to the FASEN intervention. In general, controlled cooking tests (CCT) provide for an estimate on the woodfuel saved when cooking with an ICS compared to traditional stoves. The test was conducted on behalf of FASEN by a Dakar based research institute and yielded a reduction in charcoal consumption of 40 percent in Dakar.[6] The effective savings, however, most probably deviate from these results due to different types of efficiency gains or losses.

First, the actual day-to-day cooking habits are more complex because they often involve the simultaneous use of different cookstoves (e.g. LPG and charcoal stoves) and different savings rates for different dishes. The CCT typically simulate the lunch meal. Savings potentials for breakfast or dinner meals are different because different dishes are prepared. Second, the CCT may be biased from what is known as the Hawthorne effect: If women's activities are observed or measured, their cooking behavior can be expected to deviate from day-to-day cooking at home. Third, the CCT cannot account for the heterogeneity of households in terms of socio-economic characteristics that might affect user skill and thereby fuel consumption – such as income or education. Fourth, the cook in

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[6] The WORLD BANK (2011) reports the same savings rate from tests in Kenya using the Jika stove, which is identical in fabrication.

a CCT cannot be expected to be equally habituated in cooking with the different stove types.

For total woodfuel savings, an additional fifth factor is not represented in the savings rate determined through a CCT: Households might prepare more hot meals or cook for more people because cooking becomes cheaper due to the higher efficiency of the ICS – a phenomenon referred to as *rebound effect* that is observed for different energy services after an increase in energy efficiency (see HERRING, SORREL, AND ELLIOTT 2009). Likewise because cooking becomes cheaper using the ICS, households might switch from LPG to charcoal for certain dishes or meals. All these deficiencies of CCT can be overcome by evaluating real-life woodfuel consumption based on a survey among a large sample of households that captures the diversity and dynamics of day-to-day cooking practices.

In designing our identification strategy we account for the methodological issues that are typical to evaluations and that are comprehensively addressed in FRONDEL AND SCHMIDT (2005) and RAVALLION (2008). An ideal evaluation framework would be to observe the same ICS using households i in the factual situation with an ICS (T_i = 1) and in the counterfactual situation without an ICS (T_i = 0). We would then just compare woodfuel consumption (or other impact indicators), denoted Y_i, in both situations and calculate the mean treatment effect on the treated, M_i. Formally, M_i can be written as the difference of the conditional expectations E for the impact variable:

$$M_i = E(Y_i^{T_i=1} \mid T_i = 1) - E(Y_i^{T_i=0} \mid T_i = 1) \qquad (1).$$

Obviously, we can never observe both situations for the same household, since it either has purchased an ICS or not. In order to overcome this fundamental evaluation problem, we have to replace the unobservable and, hence, non-computable counterfactual outcome. For this purpose, we apply a cross-sectional comparison of factual ICS users and factual ICS non-users.

While the identification assumptions that are required to justify the appropriateness of a cross-sectional approach are more demanding than for a difference-in-difference approach or experimental methods, the cross-sectional comparison is simply the only viable approach in our setting. A field experiment was not feasible due to the unrestricted access to ICS in the urban areas; households in the randomized control group could readily obtain ICS on the market, thereby compromising the validity of the experiment. The methodologically second-best option, a difference-in-difference approach based on before-after data is also not practical, since attrition is typically strong in urban Africa, in particular if one intends to look at a sufficiently long ICS usage period, which is two to three years in our case.

In order to derive an unbiased estimate for the woodfuel savings using this cross-sectional approach, the identification assumption has to hold that the ICS non-owning control households behave like the ICS owning households would if they had not bought an ICS. A crucial point to be taken into account here is that the FASEN project follows a market-based approach. Households decide on their own whether to get an ICS or not and, hence, self-select into the treatment so that the group of ICS owners might be different from the non-owners. For example, one might expect that better educated households are more likely to buy an ICS, because they better understand its advantages or financial benefits. In order to avoid that the level of education of household members confounds the impact assessment, we control for it, in the same manner as we do for other relevant characteristics which all enter the covariate vector X_i.

A second key aspect in our analysis is that our two impact indicators have to be determined on two different levels: woodfuel savings on the level of each stove application (or dish) and total woodfuel savings on the level of each household. For the dish level, a myriad of different stove and fuel choice patterns exists. For example, households prepare breakfast on an LPG stove and lunch on two different stove types, an LPG and a charcoal stove, either traditional or improved. Thus, another set of dish-specific covariates Z_{ij} should be accounted for, where j refers to the different dishes throughout the day. Components of Z_{ij} are, for example, the distinction between main dish (rice mostly) and side dish (some sauce mainly), whether the dish is cooked for breakfast, lunch, or dinner, or the number of persons the respective dish is cooked for.

Different specifications S exist for including the X_i and Z_{ij} into our identification assumption. In formal terms, a valid specification S allows us to replace the right-hand side of equation (1) by the conditional expectation of the impact variable for the comparison group such that the mean treatment effect becomes

$$M_i = E(Y_i^{T_i=1} \mid S, T_i = 1) - E(Y^{control} \mid S, T_i = 0) \qquad (2).$$

The most straightforward specification is simply to control for X_i and Z_{ij} in a multivariate regression model (e.g. Ordinary Least Squares, OLS) for the total woodfuel savings indicator and the per dish indicator, respectively. Of course, X_i only allows for controlling for observable differences between the two groups. Implicitly, we therefore assume that there are no systematic unobservable differences beyond the observable X_i between the ICS owners and ICS non-owners that affect both the decision to buy an ICS and the impact variables at the same time. Examples of potentially unobserved heterogeneity that might violate the identification assumption in our case are the women's intrinsic propensity to save resources or their astuteness. Although one might argue that such differences can be well approximated by observable characteristics like education or membership in associations (which we both capture), some aspects might remain unobservable in the structured questionnaire. In order to further reduce the threat of a selection bias, we put much effort into scrutinizing the existence of such unobservable confounding differences by complementary qualitative interviews with households and key informants. The findings are presented in Section 4.

Besides the multivariate regression approach, another possibility to assess the *total woodfuel savings on the household level* is a specification based on propensity score matching

(PSM). We estimate propensity scores for households, in order to ensure that we limit the comparison to homogenous groups of households, this is, groups of observations that have the same probability to own an ICS based on the observable X_i. The assumption behind this is that the more homogenous the compared groups – ICS owners and matched non-owners – are with respect to observables, the more homogenous they may also be with respect to unobservables.

However, we do not include all X_i in PSM for this indicator. Instead, in addition to PSM we stratify the sample into two groups according to the covariate that differentiates between households using charcoal mainly to prepare the *main dish* and those that use it for *side dish* preparation. Descriptive statistics presented in Section 4.2 show that the proportions of these two groups considerably differ between ICS owners and non-owners and that the frequency of charcoal stove usage strongly differs between them: Those using the charcoal stove only for side dishes use charcoal less often. Including the side or main dish characteristic in a propensity score matching approach together with other covariates on household level would blur the strong effect that this household feature has on charcoal consumption. In other words, the predicted propensity scores of the two household types could be quite similar because of values other household covariates take on. This could lead to a direct comparison of total charcoal consumption of two household types, although we know that they are non-comparable in this regard due to completely different charcoal usage frequencies.

For the indicator *woodfuel savings per stove application* the additional challenge is that it has to be analysed on the level of individual stove applications. Here, a couple more factors than on household level strongly determine woodfuel consumption, most notably whether the dish is prepared for breakfast, lunch, or dinner and the duration of the cooking process. Exact matching as done on the household level would be an alternative in principle, but is not possible in light of the larger number of covariates to match on. Sample sizes for most cells would then become too small for a proper analysis.

We therefore proceed differently: In order to benefit from the improved comparison on the household level established by propensity score matching, we combine PSM with the regression-based specification using a propensity score weighted regression approach. Here, the propensity scores enter a weight that is used to balance treatment and control households. For the average treatment effect, BRUNELL AND DINARDO (2004) determine the weighting as specified in Table 1. Apart from the propensity scores, the weighting formula also includes the fraction of treatment and control observations. Both X_i and the Z_{ij} are included as control variables in the weighted regression.

Table 1: *Alternative specifications S to identify impacts (see equation (2))*

	Impact indicator	
	(a) Woodfuel savings per stove application	(b) Total woodfuel savings on the household level
Observation level	dish	household
Treatment	T_i = 1, dish being cooked with an ICS T_i = 0, dish cooked on a Malagasy stove in an ICS non-owning household	T_i = 1, household with ICS T_i = 0, without
Specification based on OLS	X_i, Z_i	X_i
Specification based on PSM	ω_i, X_i, Z_{ij} *with* $\omega_i^{T=1} = 1$ *and* $\omega_i^{Control} = \frac{Prob(T=1\mid X)}{1-Prob(T=1\mid X)} \times \frac{P^{Control}}{P^{T=1}}$	Prob(T_i = 1 | X_i), $\hat{x}_i$

Notes: The table refers to the specifications *S* to be plugged into equation (2). X_i and Z_{ij} are control variables for individual *i* on the level of the household (e.g. education) and dish *j* (e.g. main vs. side dish), respectively. Prob(T_i=1 | X_i) refers to the individual propensity score, $\hat{x}_i$ to the main vs. side dish user covariate used for stratification and ω_i to the household individual weight. $p^{T=1}$ to the fraction of treatment observations and $p^{Control}$ is the fraction of control observations.

Hence, we determined for our two impact indicators two specifications each (Table 1). It can be concluded that – while the OLS-based specification for the per stove application savings indicator at least serves as a valid robustness check – the OLS-based specification for the total woodfuel savings indicator is clearly inferior in to the matching estimators.

We therefore apply all other three specifications in the impact analysis presented in Section 5.

3.2. The Data

In light of the methodological considerations presented in the previous section, the purpose of data collection was to obtain information on ICS owning and non-owning households. Before survey implementation, we had expected the share of ICS owners in the intervention areas of the project to be around 20 to 30 percent . We therefore chose simple random sampling as the most appropriate sampling approach to reach both representativeness and a sufficient number of ICS owning households in the sample for the intended statistical analysis. During fieldwork preparations in August 2009, we then selected 16 quarters of Dakar and 4 quarters of Kaolack, in which FASEN stoves had been available previously, to be included in the survey. Enumerators were recruited among students from the *Ecole Nationale d'Economie Appliquée* (ENEA), a faculty specialized in the education of rural development agents familiar with field and survey assignments. After enumerator training and pre-tests in collaboration with local researchers, the survey started in early September 2009 and ended a month later. The enumerators were accompanied during the whole survey by a junior researcher from our team. In total 624 households were interviewed – 508 in Dakar and 116 in Kaolack.

The main survey tool was a structured questionnaire covering virtually all socio-economic dimensions that characterize the household's living conditions. A particular focus of the questionnaire is on cooking energy, cooking behavior and patterns of fuel provision. The core impact variable, the charcoal consumed per stove used for dish preparation, was elicited from the person responsible for cooking. She was asked to enumerate all stoves used for meal preparation throughout a typical day as well as information on the cooking duration and the number of persons cooked for. In case the stove was fuelled with charcoal, she was further asked to specify the amount of fuel used with the specific stove for the specific dish. The enumerators were equipped with weigh scales to weigh the amount of charcoal shown by the woman. Yet, households most often were able to accurately indicate the weight of the fuel in kilogram themselves, because they usually buy charcoal for each meal individually in grams or kilograms. For this reason, they are very familiar with quantifying the amount of charcoal they use. We used the information on charcoal consumption for all prepared dishes and the frequency with which the respective stove is used throughout a typical day to determine the houshold's charcoal consumption per week.

In addition to cooking-related questions, the questionnaire also covers income sources, time use, and gender related issues. The interviews took, on average, around 45 minutes. The structured questionnaire delivers data for quantitative analysis and is complemented and cross-checked by qualitative information from semi-structured interviews among selected key informants such as women groups, ICS producers, or local chiefs, so-called chefs du quartier.

4. Cooking behavior and living conditions in the survey regions

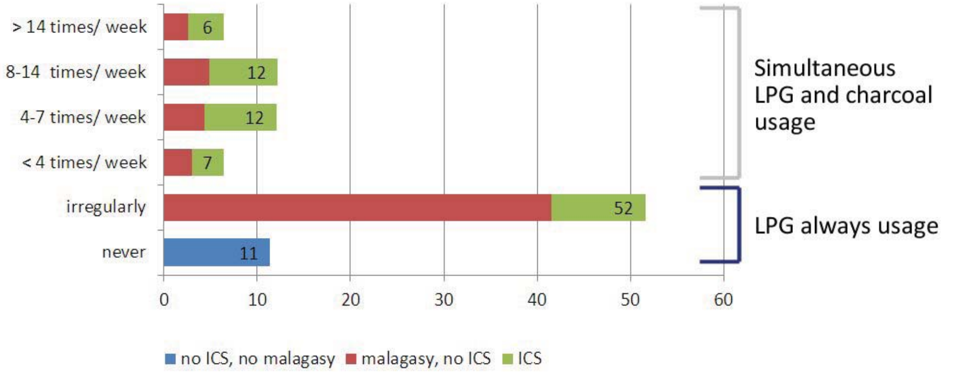
This section's objective is first, to discuss the comparability of the ICS owners and non-owners. This is crucial in order to assess if our identification assumption is appropriate and, hence, whether we will be comparing comparables. For this purpose, we scrutinize in this section to what extent differences in household characteristics exist and whether they have been captured in our structured questionnaires. The second objective of this section is to present the environment and the living conditions in the survey regions, the households' structure, educational and occupational background, financial situation, and, in particular, the cooking behavior.

4.1. Cooking behavior

The dominant cooking fuel in Dakar and Kaolack is LPG. Around 93 percent of interviewed households in Dakar and around 53 percent in Kaolack state that their principal cooking stove is an LPG cooker. They appreciate LPG as a clean, fast and easily manageable cooking fuel. The remaining households principally use charcoal. Firewood is almost never used in urban Senegal. Only 2 percent of the surveyed households use firewood at all, which is why we focus our analysis on LPG and charcoal. 92 percent of households own more than one stove and – with few exceptions – stoves for the different fuel types.

There are four principal reasons why households do not use LPG exclusively: First, people sometimes prefer the taste of meals cooked on a charcoal stove. Second, LPG is not constantly available. Supply shortages occur frequently, but are unpredictable. Households in these situations resort to charcoal. Third, although LPG is not more expensive than charcoal on a per dish basis, households have to invest in an LPG bottle, which lasts for around ten days. The price of a 6 kg bottle was at 2700 FCFA in Dakar and 3400 FCFA (4-5 EUR, around 1 percent of the average monthly household income) in Kaolack at the time of the survey. Households with little and unstable income prefer charcoal that can be purchased in small quantities on a day-to-day or even meal-to-meal basis. Fourth, even if people are able to buy the LPG bottle, they are likely not to have more than one. Yet, the typical Senegalese meals that are also prevailing in the survey regions are based on two dishes, mostly rice and sauces, for which two stoves are required.

Figure 1: *Frequency of charcoal stove use per week, as share of households in percent*



We can see from Figure 1 that 11percent of our sample households do not have a charcoal stove and therefore never use charcoal – they only cook with LPG. Another 53 percent predominantly use LPG in their every-day life and use charcoal irregularly, for example for celebrations, specific dishes, or in case of LPG shortages. Even among the ICS owners, a considerable share of 37 percent does not use the ICS regularly (Table 2). Since this has implications for the following impact analysis of ICS ownership, we distinguish between two groups: (1) the 63 percent of sample households that employ charcoal never or only in exceptional cases, which we will call *LPG always* users in the following, and (2) the remaining 36 percent of households, the *simultaneous LPG and charcoal* users, who use both LPG and charcoal on a regular basis.

Table 2: *Frequency of ICS use among ICS owners, as share of households in percent*

Simultaneous LPG and charcoal usage	> 14 times/ week	8%
	8-14 times/week	25%
	4-7 times/ week	17%
	< 4 times/ week	13%
LPG always usage	irregularly	37%

Among the *LPG always* households with ICS, we cannot expect strong impacts, since they simply do not use the ICS on a regular basis. This is also the reason for which no data on every-day charcoal usage patterns can be obtained from that group. Therefore, we will in the following focus the comparability assessment on the 210 *simultaneous LPG and charcoal* users and calculate stove and meal-specific charcoal savings based on this subsample only.

4.2. Comparing the comparable?

Virtually all *simultaneous LPG and charcoal* user households are connected to the electricity grid and water access is widely available as well. Most of the households (83 percent) even dispose of a private tap at home. Housing conditions, the composition of households, and their financial situation suggest a better status of ICS owners. We perform *t*- and *chi-squared* tests to find out whether statistically significant differences between our two comparison groups exist. These can only be found in the number of rooms inhabited and bank account ownership, which is a common proxy for both the regular reception of income and access to credits. Table 3 also shows the primary occupation and, hence, the main income source of the household heads. No substantial differences between ICS owners and non-owners can be seen. This supports qualitative findings from our field work, suggesting that income is not a decisive variable in driving the decision to obtain an ICS.

Beyond income, it is frequently argued that the probability of ICS adoption depends on the ability of a household to understand the advantages of ICS usage. Among the observable variables, this can best be grasped by the educational level of the women. Table **4** therefore contains information on the education of the household's mother.

Table 3: *Housing conditions and household composition*

Variable	ICS owner		No ICS		
	Mean	S.D.	Mean	S.D.	
Number of observations	118		92		-
Housing Conditions					
Number of rooms inhabited	5.8	2.8	5.0	2.5	**
Household shares kitchen (= 1)	0.14		0.18		-
Household composition					
Household size	8.0	2.9	8.3	3.3	-
Female head of household (= 1)	0.21		0.23		-
Financial situation					
Household receives remittances (= 1)	0.30		0.28		-
Monthly household income per working age household member (in 1,000 FCFA, excl. students)	80.5	7.7	74.6	8.2	-
Monthly household income (in 1,000 FCFA)	273.3	235.6	237.9	170.0	-
Bank account ownership (= 1)	0.37		0.24		**
Primary occupation of household head					-
managers, professionals, technicians	0.21		0.17		
services and commerce	0.23		0.29		
agriculture and crafts	0.23		0.23		
elementary occupations	0.07		0.09		
emigrant (not further specified)	0.04		0		
household, child care and retirement	0.18		0.17		
unemployed	0.04		0.06		

Note: The grouping of employed heads of households into the top four occupation categories is based on an adaptation of the ILO occupation classification ISCO-88 by Elias and Birch (1994) according to so-called skill levels. S.D. refers to the standard deviation. Differences between the two groups at a significance level of 10 %, 5 % and 1 % are pointed out by *, ** and *** respectively in the very right column. They are tested by means of *t*- and chi-square tests.

In fact, we find some statistically significant differences between ICS owners and non-owners in terms of both years of schooling and highest level of education. Yet, when regressing the ICS adoption decision on the different characteristics mentioned in the two tables, we do not find joint significance for them, which rather refutes the notion of two systematically different comparison groups.

Table 4: *Gender-related variables*

Variable	ICS owner		No ICS		
	Mean	S.D.	Mean	S.D.	
Highest education of mother in the household					***
no education	0.33		0.56		
up to secondary school	0.65		0.43		
university	0.02		0.01		
Years of schooling of mother in the household	4.7	0.4	2.9	0.4	***
Any household member responsible for cooking has at least secondary school level (= 1)	0.44		0.35		-
Household member responsible for household budget					-
Father	0.55		0.53		
Mother	0.31		0.28		
Both	0.14		0.19		

Note: Differences between the two groups at a significance level of 10 %, 5 % and 1 % are pointed out by *, ** and *** respectively in the very right column. They are tested by means of t- and chi-square tests.

The patterns of charcoal stove usage can, however, be identified as a major driver of the decision to buy an ICS: Households that only use a charcoal stove for side dishes are less likely to buy an ICS than those that also use it for main dishes. Among ICS non-users, the proportion of side dish users is 49 percent whereas it amounts to only 33 percent among ICS users. This is due to two reasons: First, households that use charcoal stoves for main dishes use it more often than those that use charcoal for side dishes (Table 5). Second, the main dish requires longer cooking time and, hence, bears higher potentials for charcoal savings. Since we have detailed data on the usage of each stove individually, we can easily control for these factors.

Table 5: *Weekly frequency of stove use differentiated by stove use for main and side dishes*

	ICS non-owners				ICS owners			
	Malagasy only used for side dishes		Malagasy mainly used for main dishes		ICS only used for side dishes		ICS mainly used for main dishes	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
ICS	-		-		6.6	3.3	13.4	5.2
Malagasy stove	6.1	3.9	13.6	5.3	0.7	1.4	0.2	0.6
LPG stove	18.8	3.0	8.5	6.5	19.3	2.9	8.9	5.3
Total	24.9	3.2	22.1	2.9	26.6	3.0	22.5	3.8

Note: For irregularly used stoves, no information was available on whether they are only used for side dishes or mainly used for main dishes. The average values therefore refer to regularly used stoves only.

Apart from these observable differences between ICS owners and non-owners one might suspect unobservable differences such as astuteness and intrinsic propensity to save resources. While we can control for observable differences in the estimation models, unobservable differences could bias our cross-section comparison in case they also affect the outcome of woodfuel consumption. During the field work, we put much effort into understanding the process underlying the decision to purchase an ICS by many open and qualitative interviews. The insights and results are extensively presented and discussed in BENSCH, PETERS, AND ZIMMERMANN (2011).

The basic message is that no indication for a distorting effect of unobservable variables could be found. Overall, ICS adoption seems to be mainly driven by personal relations: If a neighbor or a friend buys an ICS, this clearly affects the inclination to buy one. Social proximity to women groups that market the ICS also plays a role. We capture this in the structured questionnaire by asking whether the woman is member in a women group or any other association. For other potential network characteristics, we did not find any hint in qualitative interviews that such networks are formed by women, for example, with a particular intrinsic inclination to save resources. Only if this were the case, i.e., only if the participation in such a social network would be per se associated with a lower charcoal consumption, our impact assessment would be biased.

5. Impact Assessment

5.1. Charcoal consumption per dish

The descriptive survey results presented in Section 4 have revealed that households in urban Senegal in principle use LPG and charcoal simultaneously and employ different stoves for different meals with different frequencies. These findings underpin the relevance of accounting for features of cooking customs in our analysis by examining the charcoal consumption on stove usage level.

In a first step, we examine the mean values of charcoal consumption for these two stove types. We account for two basic particularities that affect charcoal consumption for dish preparation and, consequently, the savings potentials: First, we account for the number of people a meal is prepared for and, second, whether it is a breakfast, dinner, or lunch meal. Accordingly, Table 6 shows charcoal consumption per dish and per capita for the different meals to determine the efficiency gain.

Table 6: *Per capita charcoal consumption per dish and savings rates*

Variable	Malagasy Stove		ICS		Savings Rate (in %)
	Mean	S.D.	Mean	S.D.	
Breakfast	0.079	0.04	0.072	0.06	9.4
Lunch and dinner	0.220	0.15	0.153	0.07	30.5
All dishes	0.205	0.15	0.146	0.07	28.6

Note: The values for breakfast are based on only 12 and 14 observations, respectively.

The average savings rate across all applications is 28.6 percent. Depending on the particular dish prepared, stark differences can be observed. For breakfast, the savings rate amounts to mere 10 percent. This has to do with the fact that people usually do not prepare a complete meal but – if they use a stove – rather prepare porridge. Because of a very short cooking duration charcoal savings cannot materialize. On the other hand, the savings rate is highest if the ICS replaces the Malagasy for main dish at lunch (not shown in the table). Here, almost 37 percent of the charcoal is economized, which confirms the results from the CCT.

Employing two different models based on OLS, we regress charcoal consumption per dish on ICS usage and control for relevant characteristics in order to further increase the accuracy of our impact assessment (Table 7). The central variable, ICS usage, is a dummy variable taking the value one if the respective dish is prepared on an ICS and zero otherwise. In Model 1, we control in a simple OLS setup for both dish- and household-specific characteristics. While dish-specific characteristics may differ from dish to dish, this is, obviously, not the case for household-specific characteristics, which are the same for all dishes prepared in a household. In Model 2, we combine this approach with propensity score weighting. The covariates included in the probit regression that generates the propensity score are the household variables already included in the pure OLS regression Model 1.[7]

These household level control variables, first, include the *sex of the head of household* as well as the *education of the woman responsible for cooking*. We try to capture potential social network effects through a dummy indicating whether the *mother is member of an association*. Furthermore, we include the logarithm of *household income*, a dummy for *bank account ownership* reflecting the household's access to credits and ability to pay as well as housing conditions represented by whether the *floor is tiled* in the household as a wealth indicator. Another dummy specifies whether a *FASEN partner* (either women group or whitesmith) is located in the quarter of the respective household. Finally, a dummy is included indicating whether the household is located in *Dakar* or Kaolack.

[7] The only slight difference is that – in line with the considerations presented in the methodological chapter – on the household level we account for main vs. side dishes via a dummy for distinguishing between households using their charcoal stove mainly for main dishes and others using their charcoal stove (far less often) only for side dishes.

Table 7: *OLS and weighted OLS results for charcoal consumption per dish, standard errors in parentheses*

Estimator	OLS	OLS + propensity score weighting
Variable	Model 1	Model 2
Dish variables		
Dish is cooked on ICS	-0.365***	-0.360***
	(0.093)	(0.113)
Number of people the meal is cooked for (in terms of adult equivalents)	0.059*	0.039
	(0.033)	(0.039)
Squared number of people the meal is cooked for (in terms of adult equivalents)	-0.002	-0.001
	(0.002)	(0.002)
Main dish	0.003	-0.123
	(0.148)	(0.124)
Lunch	0.513***	0.452***
	(0.118)	(0.121)
Dinner	0.131	0.052
	(0.113)	(0.118)
Multiple stoves	-0.125	-0.111
	(0.142)	(0.102)
Short cooking (< 30 min)	-0.539***	-0.568***
	(0.104)	(0.114)
Cook outdoors	-0.065	-0.132
	(0.087)	(0.121)
Household variables		
Female head of household	-0.081	-0.035
	(0.090)	(0.105)
Educational level of cooking person	0.066	0.066
	(0.068)	(0.085)
Mother member of an association	-0.111	-0.213*
	(0.081)	(0.119)
Household income (log)	0.022	0.029
	(0.045)	(0.060)
Bank account ownership	0.158	0.156
	(0.102)	(0.122)
Tiled floor in household	-0.026	-0.076
	(0.076)	(0.104)
Quarter with FASEN partner	-0.086	-0.100
	(0.068)	(0.073)
Dakar	0.165**	0.123
	(0.077)	(0.090)
Constant	0.743	0.944
	(0.564)	(0.681)
Observations used for estimation	257	257
Adjusted R-squared	0.459	0.431
F-Test	15.97***	13.08***

Note: Only charcoal stoves used at least one time per week are included. *, ** and *** indicate significance levels of 10 %, 5 % and 1 %, respectively. Standard errors are clustered by household.

Coming to the control variables on the dish level used in the OLS regression, we first control for the number of persons the meal is cooked for. Different from Table 6, we do so in terms of *adult equivalents* in order to account for differences in household size and composition – consumption needs of young children, for instance are less than those of prime age adults.[8] Since adult equivalents can be expected to influence charcoal consumption in a non-linear decreasing way, they also enter the equations in squared terms. Furthermore, we include a dummy taking the value one if the charcoal stove is used for a *main dish*. We also differentiate between breakfast, dinner, and lunch meals by including two dummies (*lunch* and *dinner*). In addition, we add another dummy indicating whether the respective meal is prepared on *multiple stoves* or on one single stove only. Sometimes Senegalese households just warm up a meal; we control for this by including a *short cooking* dummy. Obviously, charcoal consumption for such dishes is lower than for proper meals. In addition, by means of this dummy we account for the fact that ICS first need some time to heat up and cannot realize their efficiency advantage in such quick dishes.[9] Although it is rather uncommon in urban Senegal to cook outdoors, we also include a dummy for whether the dish is prepared *outdoors* or inside.

The results depicted in Table 7 show a highly significant effect of using an ICS on the charcoal consumed per dish that proves to be very robust across the two applied methods. The coefficient for the ICS utilization variable can be transferred to absolute terms by inserting 1 and 0 for this variable for ICS and Malagasy usage respectively, while setting the covariates in this regression at their average value. Accordingly, a Malagasy stove consumes around 1.42 kg of charcoal and an ICS only around 1.05 kg per stove utilization, which yields a savings rate of 25.9 percent or 25.1 percent for the simple OLS and the weighted OLS respectively. The comparison with the savings rate calculated in Table 6

[8] The scale used to determine adult equivalents distinguishes between age and sex of household members. For example, kids aged 4 to 6 years are counted as 0.76 adults, so that a family of two adults at the age of 20 to 39 years and two kids between 4 and 6 years counts as 3.5 adult equivalents (MCKAY AND GREENWELL 2007).

[9] We do not include cooking duration itself as covariate on dish level, simply because ICS cook faster except for quick dish applications. The cooking duration variable therefore is affected by the treatment (see also the discussion in KING 1991).

shows that controlling for further potential influences in a regression model leads to an attenuation in the rate.

Table 8: Charcoal savings rates based on OLS

Estimator	OLS	OLS + propensity score weighting
	Model 1	Model 2
Charcoal consumption per dish of ICS	1.41 kg	1.43 kg
Charcoal consumption per dish of Malagasy	1.04 kg	1.07 kg
Savings rate	25.9%	25.1 %

Among the dish-specific variables, statistically significant outcomes can be detected for *lunch* (positive influence) and *short cooking* (negative influence), which is both in line with expectation. Table 7 furthermore shows that most household variables do not have a significant influence. Only whether the household is located in Dakar or Kaolack is significant in the simple OLS regression. This effect, however, vanishes as soon as the data is reweighted by means of the propensity score. On the other hand, the weighted OLS delivers a significant coefficient for the *mother is member of an association* indicator supporting our assumption that this indicator captures such unobservable characteristics as social network effects or astuteness.

The success of the weighting exercised in Model 2 can be tested by the Hotelling's T-squared test that scrutinizes the differences in means for the joint set of all included covariates between the treatment and control group. The test shows a significant difference before the weighting (p-value 0.026), which vanishes completely after weighting (p-value 0.974).

Altogether, we confirm the existence of a strong and significant effective efficiency increase reflected in a reduction in charcoal consumption per dish of 25 to 26 percent if the household switched from a traditional charcoal stove to an ICS. However, the savings are lower than one would expect from the results from CCT.

5.2. Total charcoal savings

At the end of the day, the decisive question with regard to the effectiveness of the FASEN project is how much charcoal is economized in total. In this section we gauge the total charcoal savings – taking into account potential rebound and fuel switching effects. In a first step we subtract the *LPG always* group, from the amount of ICS that have replaced Malagasy stoves due to the FASEN intervention, simply because they hardly use charcoal and, hence, the ICS. As displayed in Table 9, we differentiate by whether the household is located in Dakar or Kaolack in order to account for the distinct charcoal usage patterns in the two cities. The project's monitoring system shows that in total 71,600 ICS have been disseminated by FASEN in Dakar and 6,900 in Kaolack. As delineated in Section 2, the system is quite meticulously implemented and the figures were found to be credible after scrutinizing the system on the ground. With a share of irregular users of half the ICS owners in Dakar and 11 percent in Kaolack, we come up with 35,800 ICS owners in Dakar and 5,520 ICS owners in Kaolack that use charcoal regularly.

For these households, we calculate in a second step the absolute savings that accrue to an ICS using household because it changes from Malagasy stove to ICS usage. For this purpose, we compare the mean weekly charcoal consumption of an ICS using household to the weekly charcoal consumption of a comparable Malagasy using household. As outlined in Section 3.1, we apply a matching approach in two stages: we first stratify the households into households that use their charcoal stove mainly for main dishes and those who use it for side dishes bearing in mind that the two differ considerably in terms of frequency of charcoal usage (see also Table 5 in Section 4.2). Within the two strata we use propensity score matching to identify comparable households. As covariates, again the household variables from the OLS estimation on dish level (Table 7) are used. Different matching quality indicators suggest that the matching was successful in improving the balancing between the treatment and the comparison group.[10]

In line with our expectation, we observe substantial charcoal savings among the *main dish* group. Households in the *side dish* group, in contrast, do not save very much in absolute terms. This is caused by the rebound and fuel switching effect, i.e. households use charcoal more frequently after obtaining an ICS because it becomes relatively cheaper due to the efficiency increase. The absolute savings in Kaolack are considerably higher at 185 kg per year than in Dakar where the average ICS household saves 94 kg annually, simply because households in Dakar more often use the ICS only for side dishes.

Table 9: Calculation of total charcoal savings

	Dakar		Kaolack	
Total number of regularly used FASEN ICS				
▪ ICS disseminated by the project (between 2006-2009)	71,600		6,900	
▪ share of ICS owners among the *simultaneous LPG and charcoal users*	50%		89%	
	35,800		5,520	
Average annual charcoal savings due to ICS per household	**Main Dish**	**Side Dish**	**Main Dish**	**Side Dish**
▪ share of households belonging to the groups *ICS mainly used for main dishes* and *ICS only use for secondary dishes* respectively	43%	57%	86%	14%
▪ total charcoal savings per week in a household that regularly uses its ICS	4.13 kg	0.03 kg	4.13 kg	0.03 kg
▪ weeks per year	52.2	52.2	52.2	52.2
	94 kg		185 kg	
Total charcoal savings	**3,375 t**		**1,145 t**	

Taking into account the total number of ICS disseminated by FASEN and the fact that a considerable share does not use the ICS regularly, this yields a total annual amount of

[10] P-values of the likelihood-ratio test of the joint influence of all the covariates before and after matching goes up from 0.32 to 0.79 and from 0.21 to 0.83 for the two strata, respectively. At the same time, the mean absolute standardised bias for all covariates goes down from 18.9% to 12.3% and 22.3% to 12.6%. Looking at individual covariates, for each of the two strata we do not find statistically significant differences for the ten included covariates.

saved charcoal due to the FASEN intervention in both cities of 4,520 tons (see Table 9). For comparison, Senegal as a whole consumes around 470,000 tons and Dakar around 94,000 tons, so that 1.0 percent of the Senegalese and 4.8 percent of the Dakar charcoal consumption are saved.

Due to the discounting in first step, these saving figures so far do not include the savings of *LPG always* households possessing an ICS. Although these households use the ICS only irregularly, their savings will not be zero and may sum up to a sizeable amount, simply because 36,600 ICS owners belong to this group. Without having detailed individual information about their irregular usage patterns in our data, we try to gauge their contribution based on our contextual knowledge from the field work: Taking into account the frequency of LPG shortages and family celebrations – the most important, but also erratic reasons for ICS usage among *LPG always* people – ICS might be used on average for 1.5 to 2 meals per week (out of 21 potential meals). If we, furthermore, assume that the savings per dish correspond to the *simultaneous charcoal and LPG* users, this yields an additional total charcoal saving of 562 and 24 tons for Dakar and Kaolack respectively when the *LPG always* households are included. We can take these values including the *LPG always* households as an upper bound for the impact assessment. According to this upper bound FASEN can claim a reduction in total charcoal consumption amounting to 5.5 percent of Dakar's and 1.1 percent of Senegal's total consumption.[11]

6. Conclusion

This paper presented an impact evaluation of the improved cooking stoves (ICS) dissemination project FASEN implemented by GIZ in Senegal. The extent to which woodfuel consumption is reduced by the introduction of ICS was the focus of the analysis.

[11] Looking at FASEN's impact on charcoal consumption of stoves disseminated in Dakar only, the savings rate amounts to 4.8 to 6.0% of Dakar's total consumption for the two ways of calculating the savings.

By the time of the evaluation, FASEN had concentrated mainly on urban and suburban areas, namely Dakar and Kaolack, where nearly 80,000 ICS had been disseminated by supporting whitesmiths, potters, traders, and women groups within the first three years of project implementation. Assigned by the *Independent Evaluation Unit* of GIZ, we conducted a representative household survey among 624 households in those parts of the two cities where FASEN was active. One first important finding is that Liquefied Petroleum Gas (LPG) is the dominant fuel in our sample. While it had been well-known that LPG is widely used in Dakar, it came as a surprise that also the surveyed suburbs use LPG predominantly. More than half of the interviewed households always use LPG and only occasionally resort to charcoal, for example for family celebrations or in case of LPG shortages. Also, around one third of the ICS-owning households in our random sample rely almost exclusively on LPG. As a consequence, we cannot expect many impacts to emerge among the mostly LPG-using households, simply because a switch from a traditional charcoal stove to an ICS cannot change very much if charcoal is hardly used.

Accounting for this feature of the sample, we used the remaining households that use LPG and charcoal *simultaneously* to cross-sectionally evaluate the effect on charcoal consumption if the household switches from a traditional stove to an ICS. We strongly benefit from the detailed data that we collected on each cooking process in the household. This allows us to evaluate charcoal consumption on the level of each individual stove application, so we cannot only control for household characteristics but also for dish-specific cooking behavior. In fact, these dish-specific characteristics have turned out to be highly relevant for the charcoal consumption per dish. We find significant reductions in charcoal consumption if an ICS is used to prepare a dish instead of a traditional charcoal stove, with an average savings rate per dish of 25 to 26 percent. Taking into account this savings rate and the different stove and fuel usage patterns among the FASEN beneficiaries, we obtain an amount of saved charcoal of 4,520 to 5,100 tons per year for the totality of stoves disseminated by the intervention. This corresponds to around 1.0 to 1.1

percent of the amount of charcoal consumed in the whole country or around 4.8 to 5.5 percent of Dakar's total consumption.

It can therefore be concluded that the savings triggered by the project constitute a relevant contribution to alleviate pressure on forests in Senegal. They can as well clearly be considered a success of the FASEN project given its rather short intervention period and its comparatively limited scope. These charcoal savings also have to be valued against the background of the simplicity of the promoted technology: The ICS are locally produced low-cost devices that – using our savings rate – amortize already after two to three months for an average charcoal-using household. The challenge for the project, of course, is to institutionalize the established structures on the ICS market in order to assure the sustainability of the approach beyond the project cycle. In any case, the importance of ICS for the household energy sector in urban Senegal is beyond discussion: Cooking with charcoal will remain a widespread bridging and backup technology, most importantly because of LPG shortages and because it can be purchased in small amounts on a day-to-day basis.

In spite of the successes in terms of charcoal savings, it has to be noted that we found stark differences between households that use their charcoal stove for side dishes only and those who also use it for main dishes. Among the first group, rebound effects could be observed of such a magnitude that the efficiency gains of ICS were almost completely negated. Correspondingly, the reduction in charcoal consumption among the group of households who also used the stove as main dish was considerably larger. These households, moreover, tend to be less well-off.

This observation leads over to the recommendation to ICS dissemination projects to thoroughly verify the targeting of their activities. If the real energy-poor people are supposed to benefit from the project, urban areas with a widespread usage of LPG in combination with readily available charcoal might better be avoided. The classical benefits of ICS usage on health or gender related outcomes due to reduced smoke emissions and fuelwood collection time cannot materialize in such an environment. It is therefore recommendable to extend the project activities to rural areas where virtually all households still use firewood for their cooking purposes that they have to collect in a time-consuming way. Furthermore, exposure to cooking-related smoke is much higher. This rural target group thereby bears substantially more potentials for socio-economic impacts beyond reducing deforestation pressures, in particular in terms of gender and health.

From a methodological point of view, our analysis has to rely on a cross-sectional comparison of ICS users and non-users. Although we include a number of control variables that afford reasonably broad coverage of the determinants of charcoal consumption, the possibility of omitted variable bias can never be completely ruled out. Yet, the complementary qualitative interviews indicate that the control variables we have at hand in the quantitative analysis succeeded in capturing the relevant heterogeneity. With regards to future research this clearly suggests applying mixed methods approaches that combine quantitative and qualitative methods. Thereby, the robustness of cross-sectional comparisons can be increased, making possible the evaluation of relevant policy issues for which experimental methods or panel approaches are difficult or impossible to implement.

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