Impact Evaluation of Improved Stove Use in Burkina Faso – FAFASO

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This impact evaluation report is part of an assignment by the Policy and Operations Evaluation Department (IOB) of the Netherlands Ministry of Foreign Affairs. It pertains to a series of impact evaluations of renewable energy and development programmes supported by the Netherlands, with a focus on the medium and long term effects of these programmes on end-users or final beneficiaries. A characteristic of these studies is the use of quantitative research techniques, in combination with qualitative techniques, to get insight in the magnitude of effects. The purpose of the impact evaluations is to account for assistance provided and to draw lessons from the findings for improvement of policy and policy implementation. The results of these impact evaluations will be input to a policy evaluation of the "Promoting Renewable Energy Programme" (PREP) to be concluded in 2014.

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1. Introduction

Today, around 2.7 billion people in developing countries rely on the traditional use of biomass, mostly firewood or charcoal, for cooking with severe implications for their well-being (International Energy Agency 2011). Biomass usage for cooking purposes induces respiratory diseases due to smoke emissions and heavy workloads if firewood has to be collected (World Health Organization 2009a). Both affect mainly women. In case the fuel has to be purchased, for example in most urban areas, this causes considerable financial costs. Not least, in many dry countries firewood and charcoal usage contribute to deforestation. Improved cooking stoves (ICS) potentially help to alleviate these negative implications of woodfuel usage since they increase the efficiency of the cooking process thereby reducing the woodfuel consumption per meal.

This report evaluates an ICS intervention in Burkina Faso against this objective of alleviating adverse effects of woodfuel usage. According to the Human Development Index (HDI), Burkina Faso is among the ten poorest countries in the world (United Nations Development Program 2011). Woodfuel consumption is one of the most important causes of deforestation in Burkina Faso (Ministère des Mines, des Carrières et de l'Energie 2007) and has serious health consequences related to the emitted smoke. According to WHO, in Burkina Faso 16,500 people die every year due to so-called household air pollution stemming from biomass based cooking fuels (WHO 2009b). The intervention is implemented by the *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ) and co-financed by the Netherlands Ministry of Foreign Affairs and the German Federal Ministry for Economic Cooperation and Development.

The intervention, called 'Foyer Amélioré au Burkina Faso' (FAFASO) differs from other earlier ICS promotion programmes in Burkina Faso in not providing direct subsidies. Instead, it rather focuses on the training of ICS producers (whitesmiths and potters), sensitization, and marketing campaigns. FAFASO started in 2005 to promote ICS in two cities, the capital Ouagadougou and Bobo-Dioulasso, Burkina Faso's second largest city. People in urban Burkina Faso use different cooking fuels, sometimes also simultaneously: Liquefied Petroleum Gas (LPG), firewood and charcoal – with the biomass fuels still being the dominating ones. The ICS disseminated by FAFASO is a simple metal stove called Roumdé. Both firewood and charcoal versions exist. The Roumdé improves the combustion process compared to traditionally used metal stoves (called Malagasy) and compared to three-stones stoves. Thereby, firewood and charcoal consumption is expected to be reduced. It is important to emphasize that the Roumdé is not designed to curb smoke emissions; it does not have a chimney nor can the combustion process be expected to take place in a cleaner way. Assuming a life-span of two years, at the time of the survey in March 2011 about 60,000 Roumdé stoves could be expected to be in use in the two cities. Since 2011, FAFASO has intensified its activities to rural areas. In addition, FAFASO disseminates improved brewing devices among small informal local beer breweries – one of the most important users of firewood in urban areas. While these commercial user activities are subject of a separate evaluation study, the present report focuses on the dissemination activities in urban areas.

In absence of adequate baseline data and given the project had been running for three years already when the study was planned, a cross-sectional approach is used to assess the impacts of ICS usage on households by, in principle, comparing ICS users to ICS non-users. For this purpose, in total 1,473 households were surveyed in Ouagadougou and Bobo-Dioulasso between January and March 2011.

The basic identification assumption behind this approach is that ICS non-users act like ICS users would do if they had not acquired an ICS. In order to substantiate this assumption, multivariate regression techniques in combination with matching processes are used to control for all observable differences between the two groups, for example, educational background and income. Unobservable factors such as being aware of smoke-related problems or an intrinsic tendency to safe woodfuels might pose a problem to the extent they are correlated with both ownership of an ICS and the outcomes of interest. The existence of such unobservable factors is scrutinized by qualitative interviews with key informants and ICS owning and non-owning households.

The principal impact indicator of this study is the household's woodfuel consumption. The rationale for this is that, first, a reduction of woodfuel has immediate implications for wood scarcity and deforestation pressures. Second, only if we can confirm a significant reduction in woodfuel consumption, it is plausible to assume that smoke emissions decrease and time savings or a reduction in energy expenditures materialize. Hence, a reduction in woodfuel consumption is a precondition for impacts on the health and the time use level. In addition, health, time use and expenditure impacts are also examined directly.

The literature rigorously evaluating ICS interventions is very thin. Existing studies almost exclusively focus on the related health impacts. Smith-Sivertsen et al. (2009) find a substantial reduction in exposure to indoor air pollution and a reduction in risk for respiratory symptoms in the course of a randomized controlled trial (RCT) for which chimney stoves were randomly assigned to replace traditional open fires in rural Guatemala. Masera et al. (2007) find similar results in rural Mexico and Diaz et al. (2007) observe a significant reduction in headaches and eye infections also in Guatemala, both following the introduction of chimney stoves. Yu (2011) examines the effects of behavioural interventions in which people are sensitized for harmful effects of smoke, for example, in combination with ICS interventions and find that this double treatment brings down respiratory diseases among children under five. This effect seems to be mainly triggered by the behavioural part, though.

The positive health impacts associated with the use of improved stoves have recently been challenged by an RCT undertaken in India (Hanna, Duflo and Greenstone 2012). A NGO offered improved cooking stoves to a randomly drawn group and not to another and followed both groups over a period of four years. Based on repeated surveys, the authors find no lasting health impacts. Neither do they find any substantial reductions in woodfuel consumption. They explain the absence of any effects by the failure of households to use and maintain the stoves regularly and appropriately. They conclude that "environmental and health technologies must be tested in real-world settings where behaviour may temper impacts." While the present study will also emphasize the importance of taking into consideration behavioural reactions and, hence, the importance of confronting lab tests with real world situations, it is important to note that a couple of specific features of this experiment actually do not necessarily reflect real-world settings, most importantly the low take-up of the randomly distributed ICS. The impacts found by Hanna, Duflo and Greenstone (2012) therefore have to be considered as lower bound estimates.

In Sub-Saharan Africa, only few rigorous evaluation studies have been conducted. Bensch and Peters (2012) and Burwen and Levine (2012) implemented RCTs on ICS impacts in Senegal and Ghana, respectively. As these studies took place in rural areas, the findings are likely not to be transferable to urban settings because different fuels and stoves are used. By contrast, Bensch and Peters (2013) apply quasi-experimental methods in order to examine the effect on charcoal consumption of a programme in urban Senegal similar to FAFASO. It is also implemented by GIZ and financed through the same funding window. The authors find that on average ICS using households save 25 percent of charcoal per stove utilization if compared to households using traditional stoves with this difference being statistical significant. They furthermore determine that, on the aggregate level, thanks to the intervention probably more than 4,500 tons per year or around 1.1 percent of the Senegalese charcoal consumption are saved. The virtue of this study is that their data provides detailed information on the level of dishes cooked by each household and, hence, allows accounting for the complex cooking behaviour in the urban African context with simultaneous usage of different fuel and stove types. In other words, it is possible to compare woodfuel consumption for the same dish prepared on two different stoves. The evaluation presented in this report follows the same approach.

The remainder of this report is structured as follows. In Section 2 the FAFASO intervention is presented in detail along with the broader context in which it is implemented. In Section 3 the evaluation methodology is described followed in Section 4 by a presentation of the data. In Section 5 the results are shown together with numerous robustness checks and a discussion of possible caveats. Section 6 gives a summary of the research questions related to the outcomes and impacts of the FAFASO programme. Section 7 concludes.

2. The context and the intervention

2.1. Energy and regional context

The vast majority of primary energy supply in Burkina Faso is provided by woodfuels (83 percent), followed by oil products (16 percent) and two renewables, water and solar energy (Wethe 2009; Briceno-Garmendia and Dominguez-Torres 2011). Woodfuels are used for multiple purposes, predominantly by households for cooking purposes. Woodfuel consumption is one of the most important causes of deforestation in Burkina Faso and has serious health consequences related to the emitted smoke. According to WHO, Burkina Faso alone counts 16,500 premature deaths per year due to household air pollution (WHO 2009b). In fact, woodfuels are by far the most often used energy source for cooking purposes. The most recent available census data (2006) reports that in Burkina Faso as a whole 88 percent of all households use firewood as the main source of energy for cooking, 3.6 percent charcoal. Electricity is only used by 0.2 percent. Even in Ouagadougou, the share of households that report to use firewood and charcoal is at 57 percent and 11 percent respectively. Liquefied Petroleum Gas (LPG) is the primary source for 23 percent and electricity for mere 0.8 percent of all households in the city (Ministère de l'Economie et des Finances 2009a).

If alternatives to biomass based cooking are considered, Burkina Faso is not endowed with domestic fossil energy reserves. As a consequence, the consumed oil is entirely imported (400,000-500,000 tonnes of oil annually; 40 percent of total imports; see Wethe 2009; Briceno-Garmendia and Dominguez-Torres 2011). The country's electricity supply is mainly generated from thermal sources using hydro carbons (about 80 percent) and to a lesser extent water power (about 20 percent), the latter being particularly volatile due to erratic rainfall conditions. Only about 18 percent of the population has access to electricity (about 40 percent in urban areas and 3 percent in rural areas)

Given its thermal-based generation and therefore the dependence on international oil prices and transport costs, electricity is with USD 35 cents per kWh very expensive also compared to otherwise similar countries (Briceno-Garmendia and Dominguez-Torres 2011).

The country's long term energy strategy is described in the policy document "*Vision 2020. De l'accès aux services énergétiques modernes*" (Ministère des Mines, des Carrières et de l'Energie 2007). The document outlines how the government envisages increasing the access to modern sources of energy. This encompasses, first, access to electricity and, second, the access to cleaner cooking stoves and fuels. It is anticipated that the use of woodfuels will remain to be the most important source of energy, but the objective is to increase efficiency with which woodfuels are used by the dissemination of ICS. The plan sets a penetration target for ICS in general of 63 percent of households using an ICS in 2015 and 80 percent in 2020 (in rural areas even 90 percent).

In addition to this energy strategy paper and in order to reduce deforestation pressures, the Government of Burkina Faso has elaborated a national strategy towards a sustainable and economically viable management of forest resources. The main tool is the set-up of special protected forest zones that are jointly managed by the government and local communities. In addition, the deforestation strategy envisages, in line with the "Vision 2020 document" reducing the woodfuel demand by increasing the use of LPG and kerosene as well as ICS.

At present, firewood is used in open fires (three-stone stoves) or simple metal stoves. In urban areas, the latter have widely replaced open fires. Charcoal is always used in simple metal stoves. One such simple metal stove type that is available in several Western African countries is the *Malagasy*, for which both a firewood and a charcoal model exist.[2] Since the 1980s, different ICS types have been developed and their usage has been tried to increase by subsidizing their production. The *Ouaga métallique* is a stove with a cylindrical shape. It is the only ICS that can only be fuelled with firewood. The *Burkina mixte* has a door and a more conical shape; it has a single pot size and uses wood or charcoal. The *Multimarmite*, for which two models exist, the *Burkina* and the *Malien*, is comparable to the Burkina mixte, but it can be used with different pot sizes. Illustrations of the different stove types can be found in Annex 1 and Annex 7.

All these ICS have been designed to reduce firewood or charcoal consumption. Smoke emissions cannot be expected to be substantially reduced. To put these ICS disseminated in Burkina into per-spectives in the international movement to promote cleaner cookstoves and fuels, they are definitely at the lower end of the spectrum of improved biomass stoves. For example, they are uniquely made of metal so that they do not dispose of components that better store the heat such as ceramic inlays. Furthermore, they do not have a chimney or improve the combustion process in a way that would substantially bring down particulate matter or carbon monoxide emissions. At the upper end of the spectrum, advanced biomass stoves exist that can reduce such emissions down to zero.[3]

[2] Strictly speaking, only the charcoal model can count as what internationally is called a Malagasy. The traditional firewood model will, however, in the following also be called Malagasy in accordance to the terminology used in the surveyed areas.

[3] There is no international commonly agreed measure for the exact amount of fuel savings that a stove needs to achieve to get the label improved stove. However, it is usually recognized that an improved stove should save about 40 percent of the fuel in a field test compared to a three-stone and/or reduce considerably the phenomenon

In the past, ICS programmes failed in Burkina Faso mainly because there were neither appropriate distribution channels nor systems in place to monitor the quality of such stoves. As the cheaper non-improved cooking stove models coexisted in the market, sales of whitesmiths producing quality ICS went down after the subsidies were stopped, which brought these whitesmiths to lower prices and quality and, eventually, caused the disappearance of ICS in the market.

2.2. Description of the FAFASO intervention

The intervention *Foyer Amélioré au Burkina Faso* (FAFASO) was established in mid-2005 and started in the two largest cities of the country, Ouagadougou and Bobo-Dioulasso. With 1.6 and 0.5 million inhabitants, respectively, the two cities account for about 15 percent of the country's total population. FAFASO is implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ, previously GTZ) under the umbrella of the Dutch-German energy partnership Energising Development (EnDev). EnDev receives funding from the Dutch PREP programme and is coordinated across 18 countries by GIZ in co-operation with the Dutch Agency for Sustainability and Innovation, Agency NL. The goal of EnDev is to actively promote and provide sustainable access to modern energy services for 6.1 million people by the end of its second phase at the end of 2012. The types of modern energy services EnDev focuses on are energy for cooking, energy for lighting and household applications, energy for social infrastructure, and energy for productive use.

FAFASO intervenes in the first area mentioned – energy for cooking. The project supports the dissemination of ICS in the country through the training of ICS producers (whitesmiths and potters), sensitization, and marketing campaigns. FAFASO differs from earlier ICS promotion programmes in the country, as it does not provide direct subsidies and puts particular effort into quality assurance. For this purpose, a special label has been introduced called *Roumdé*, which means "the preferred" in the national language Mooré. The label, a red humanized smiling stove (see Annex 2), is consistently used in all marketing channels including selling points and TV and radio spots. The reason for this strategy is that one of the major problems of former ICS programmes was that – after the subsidizing programmes had ended – ICS producers did not maintain the improved quality features of the stoves, which was partly due to the fact that these quality features were difficult to identify by the customers: higher-quality materials are used and the stoves are generally better manufactured. Notably, grills are bigger, spacers between stove and cooking pot exist for an optimal match and efficiency-enhancing aerodynamic features are respected in the design of the stove. For stove models with doors, these are typically precisely customized. Still today, cheaper stoves are available at the market, which resemble the Roumdé stoves but do not carry the Roumdé label because they do not exhibit all the mentioned quality features. In the following, we will therefore call these stoves "imitated Roumdé" or "imitated ICS", whereas the term ICS will be reserved for the Roumdé labelled stoves (see Annex 7 for a juxtaposition of the two types). Apart from these quality features, Roumdé stoves can be differentiated by means of a sticker with the Roumdé label affixed to the stove.

The stoves that have been chosen by FAFASO to qualify for the Roumdé label belong to three different types of simple metal stoves suitable for household use, the *Ouaga métallique*, *Burkina mixte*, and the *Multimarmite*, the most popular Roumdé stove (see also Section 2.1). These stove

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of indoor air pollution (Owsianowski and Barry 2008). This is also roughly the definition mentioned in the project documents of the FAFASO intervention.

have been all developed in the 80s by the "Institut Burkinabé de l'énergie (IBE)" presently named "Institut de Recherches en Sciences Appliquées et Technologies (IRSAT). Beyond the metal stoves, a ceramic stove Roumdé version exists as well, which is, however, virtually inexistent in the urban context and is rather intended to serve rural populations (see also Annex 1 for a depiction of the different stove types). The Roumdé is principally conceived to save woodfuel. Efficiency gains have so far only been determined in so-called controlled cooking tests, which are field laboratory tests in which local women cook typical meals under day-to-day conditions with both stove types. Furthermore, these tests have only been conducted with traditional three-stone open fire stoves as reference. According to these tests, the *Multimarmite* economizes 29 percent, the *Burkina Mixte* 35 percent and the Ouaga Métallique 43 percent (Sanogo 2008). Reductions in smoke exposure may only be triggered via these reductions in woodfuel consumption. As outlined in Section 2.2, the different Roumdé models do not have a chimney and are in general not designed to curb smoke exposure. Hence, the Roumdé does not necessarily qualify as a clean cookstove.

For commercial stove users, mainly small restaurants and producers of local beer ("Dolo") and shea butter, special stoves were developed and commercialized. According to the Ministry of Environment, the local beer producers alone account for 52 percent of the firewood consumed in Ouagadougou.[4] For these users, the improved stoves would economize 80 percent of the firewood consumed per application.

Total funding of the FAFASO project between mid-2005 and end 2012 amounts to EUR 2.8 million (see Table 1). Within its first two phases funded under EnDev 1, according to its monitoring system FAFASO has disseminated over 68,000 ICS in this manner between mid-2005 and end 2009, thereby reaching almost 551,000 people (see also Table 1).[5] For the EnDev 2 phase, another 39,500 stoves have been disseminated as of March 2011 in the two cities of Ouagadougou and Bobo.

Table 1: Target-performance comparison for FAFASO

Phase	Objective		Realized		Project budget
	ICS	Persons	ICS	Persons	
EnDev 1					EUR 400,000
Phase 1 (07/05-06/07)	15,000	90,000	22,500	161,000	
Phase 2 (07/07-12/09)	24,500	175,000	45,708	389,635	EUR 900,000
Total EnDev 1	**39,500**	**265,000**	**68,208**	**550,635**	**EUR 1,300,000**
EnDev 2 Phase 3 (01/10-12/12)	- + 450 institutions + 4,500 prod. users	**300,000***	**39,492** (in 03/11; Ouaga and Bobo only)	-	**EUR 1,500,000**
Total EnDev 1 + 2		**565,000**	-	-	

[4] Personal conversation at the Ministry.

[5] Note that these figures imply an average size of households having acquired an ICS during EnDev 1 of 8.1. For the EnDev2 phase, FAFASO assumes an average household size of 7.8 persons in Ouagadougou and of 6.8 in Bobo-Dioulasso. The survey used in this analysis suggests that the average household size in Ouagadougou and Bobo-Dioulasso is in the order of 6.5 and 6.8, respectively. The average number of people cooked for found in the survey as an alternative measure for the number of beneficiaries is even slightly lower. Census data of 2006 indicates an average household size in urban areas in general of even only 5.0 (Sagnon and Sawadogo 2009). Hence, at least for Ouagadougou the estimated numbers of reached people provided by FAFASO are probably over-estimated by about 20 percent.

Source: FAFASO, March 2012.
Note: * = For the EnDev 2 phase, the objective in terms of people reached is defined as the "countable outcome of the current phase". It corresponds to the number of persons living in households who have bought an ICS within the assumed lifespan of two years minus the total sales figures of the previous phase (389,635 persons). All figures under "realized" are based on data from the FAFASO monitoring system. FAFASO assumes an average household size of 7.82 persons in Ouagadougou and of 6.83 in Bobo-Dioulasso. Regarding the institutions and productive users, it is assumed that each unit uses on average two stoves.

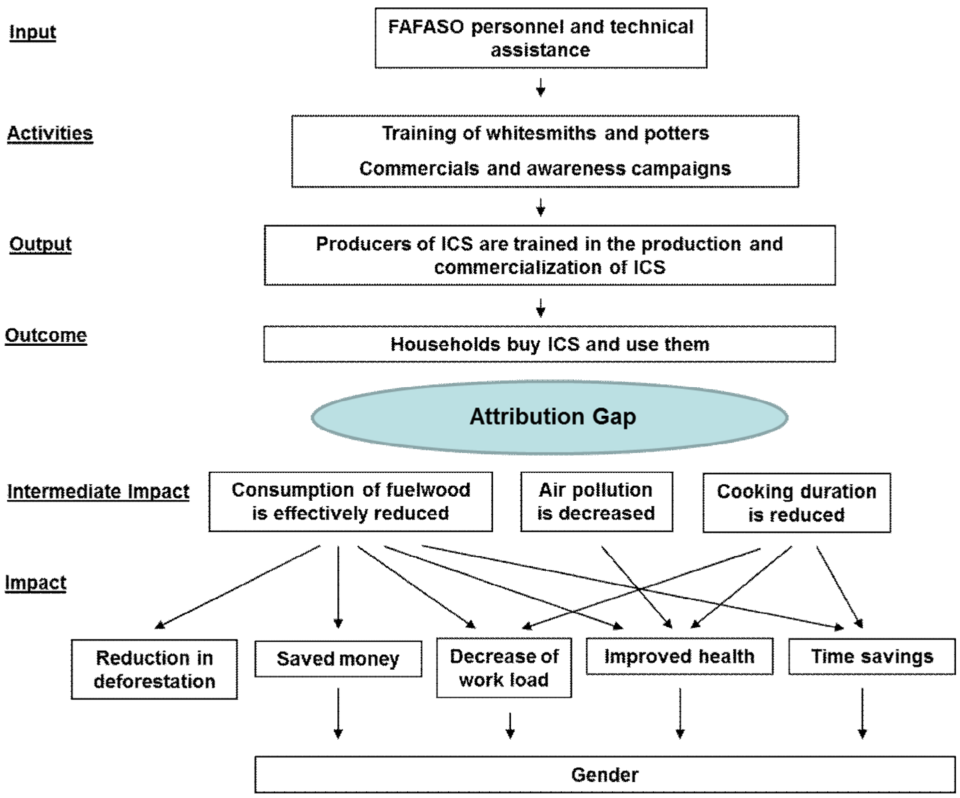
For this phase, it is furthermore envisaged to extend the target regions to rural areas. The strategy is to first concentrate on small cities in rural areas. It is expected that from there the ICS will also penetrate surrounding villages. As before, whitesmiths and potters will be trained, accompanied by awareness campaigns in the cities and surrounding villages. Correspondingly, training activities have started for instance in Koudougou and Kaya and will be extended substantially in the near future.

3. Methodology/Evaluation Approach

3.1. Evaluation objective

The intended outcome of FAFASO is to build up a sustainably functioning market for ICS in Burkina Faso so that households (customers) can buy ICS and use these stoves. Basically, the FAFASO approach is to create structures of the ICS supply side, complemented by sensitization measures among potential customers (demand side). Whitesmiths and potters are trained, awareness campaigns are run and radio commercials are broadcasted.

Figure 1: The FAFASO Results Chain



Source: Own illustration.

Looking at the results chain of the intervention (Figure 1), the crucial intermediate impact this evaluation is focussing on is the effective reduction of firewood or charcoal consumption. The reason for this focus is that a reduction of firewood or charcoal consumption is the pre-condition for all final impacts that are intended by the intervention: a reduction in household air pollution and, hence, in terms of respiratory diseases and eye infections, reducing the households' financial and workload burden and reducing deforestation. Furthermore, firewood or charcoal consumption can be expected to be quite responsive to the interventions so that an effect of a plausible magnitude can in principle be detected with a sample size that can be realized within the budgetary limits that are imposed by this kind of evaluation. Note that gender aspects are a cross-cutting element in our evaluation. The literature on gender and energy emphasizes two specific aspects related to the use of improved cook stoves: time-use, with its links to reduction in drudgery and improvements in health due to reduced household air pollution (Clancy et al., 2013). Hence, wherever it is possible and adds to the understanding of the overall evaluation questions, the study will investigate differences of impacts by gender and focus on women in particular.

Although laboratory results from controlled cooking tests for fuel savings exists for the ICS under evaluation here, the large sample size assessment of the woodfuel savings is required, because the effective reduction in firewood consumption might deviate from the theoretically possible reduction. The reason is that households may make sub-optimal use of the stove and may adjust their cooking behaviour as the relevant prices of cooking and the cooking technology change and this may lead to a different woodfuel savings rate.

More precisely, this evaluation will focus on the following outcomes and impacts.

Outcomes:

- How many households own an ICS? How many use the ICS and in which frequency?
- What socio-economic groups own an ICS?

Impacts:

- How much woodfuel is effectively saved per meal per household (taking into account cooking behaviour)?
- What is the effective usage (per week or month) of ICS taking into account simultaneous usage of other stoves and LPG?
- How much firewood is saved in total (per week or month)?
- What are the time savings of persons responsible for woodfuel provision? For which purpose the 'liberated' additional time is being used for?
- What are the changes in household expenditures for energy in total and cooking energy in particular? For which purposes are the potential savings being used?
- What are the changes in health related outcomes (respiratory disease symptoms, eye infections)?
- How are these impacts distributed across different household members (women vs. men, children vs. adults)?

Both positive and negative outcomes – intended or not – are included in the assessment. Given the broad coverage of the evaluation questions, a specific household survey had to be designed to collect the necessary information. A further requirement was to include in the survey both customers and non-customers and to make sure, to the extent possible, that both groups are comparable.

3.2. Identification strategy

In this sub-section, the strategy to identify causal impacts of the programme is outlined in detail, in particular concerning the central evaluation question that relates to the reduction in woodfuel consumption in households using an ICS. In this context, we use two impact indicators: (a) woodfuel savings per stove application for cooking[6], where stove application is synonymous with the term dish, which in the context of this analysis refers to a component of a meal prepared on a single stove; and (b) total woodfuel savings on the household level in the course of one week. In principle, a straightforward approach to obtain this information could be to undertake a controlled cooking test (CCT). Here, a cook prepares the same meal on both a traditional stove and an ICS. Afterwards, the woodfuel consumption in both cases is compared. Such tests are internationally approved and have been conducted in Burkina Faso by GIZ in cooperation with the *Institut de Rechereche en Sciences Appliqueées et Technologies* (IRSAT). These tests showed a reduction in firewood consumption of 29 to 43 percent if a three-stone stove was compared with the various types of ICS provided by FAFASO. However, such tests cannot provide more than an estimate of the *potential* savings associated with the use of an ICS, since the *effective* savings in real-life households might deviate from such laboratory field tests for various reasons. First, households typically use simultaneously different cooking stoves (three-stone, charcoal, LPG) for different meals and sometimes even for one meal. Second, savings depend on the type of dish (e.g. breakfast, lunch or dinner), while CCTs are typically conducted for the lunch meal. Third, it is unlikely that a cook in a CCT under observation behaves as she would behave under day-to-day conditions (known as the Hawthorne effect); in real-life kitchens, for example, the cook tends to do a number of activities simultaneously and, hence, cannot dedicate the same attention to their stoves as a cook in a cooking test. Fourth, the effectiveness of a stove may decline over time due to inappropriate maintenance. Fifth, a CCT, being conducted only with few households, can obviously not account for the heterogeneity across households. Savings may vary with income, education, age and so on. Sixth, the cook in a CCT cannot be expected to be equally habituated in cooking with the different stove types. In addition, for total woodfuel savings, another reason why CCT cannot capture the real-world effects occurs: 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 woodfuels for certain dishes or meals. Hence, the only way to accurately assess the woodfuel savings in the real world is to conduct a large representative household survey which captures the diversity of real life cooking practices (see Bensch and Peters 2013).

[6] Apart from cooking, in cold periods heating water can become another relevant source of wood consumption. Yet, first, cooking in any case remains the dominant purpose and, second, heating water generally takes little time, whereas savings potentials of stoves tend to be stronger when it is cooked for longer time.

In formal terms, an ideal evaluation framework would be to calculate the mean treatment effect on the treated *M* as follows

$$M = E\,(Y\,(T = 1) \mid T = 1) - E\,(Y\,(T = 0) \mid T = 1). \quad [1]$$

Here, *M* is simply the difference of the conditional expectations *E* for the impact variable *Y* (e.g. woodfuel consumption) under treatment (*Y(T = 1)*) and under the counterfactual of not receiving treatment (*Y(T = 0)*) amongst those who actually received the treatment (| *T = 1*). In our case, treatment refers to ICS ownership. Obviously, this counterfactual situation does not exist. Households can only be observed in one of both situations, either with or without a cooking stove.

Given the absence of data before the roll-out of the program the only solution to this evaluation problem is thus to compare owners and non-owners of ICS, hence to replace the subtrahend in equation [1] by data from non-users (| T = 0). However, it must be recalled that FAFASO is a market-based approach and households make their own decision to obtain an ICS or not. In other words, they select themselves into the groups of users and cannot be considered as a random sample. Such dissimilarities compromise the unbiasedness of estimated impacts, if household characteristics that determine the decision to buy and use a stove may also influence the extent of woodfuel savings, the occurrence of respiratory diseases or expenditure patterns. Therefore, one has to account for as many relevant factors as possible by eliciting the respective household information in the structural questionnaire.

Such confounding factors might occur on the household level and on the level of dishes. Therefore, we gathered information on all levels, for example, the educational level of the household head or household income on the household level and the number of persons cooked for or the type of dish being prepared on the dish level.[7] This allows us accounting for differences like dish types (breakfast, lunch, dinner), side dish or main dish, dish-specific cooking durations or the number of persons the dish is cooked for. Households may prepare the breakfast on an LPG stove and the lunch on two different stoves, for example an LPG stove and a charcoal stove, either traditional or improved. Hence, in order to approximate the counterfactual we need to ask on which stove type a meal that is cooked on an ICS would have been prepared if there had been no intervention. Here, it is assumed that in the absence of the intervention an ICS meal would have been cooked on a traditional woodfuel stove. The difference of the conditional expectations for the level of dishes can then be rewritten as:

$$M = E\,(Y\,(T = 1) \mid X, Z, T = 1) - E\,(Y\,(T = 0) \mid X, Z, T = 0). \quad [2]$$

This equation ensures accounting for observable confounding effects, X_i, that all dishes in household *i* share, but also for confounding effects, Z_{ik}, that vary for every dish *k* prepared throughout the day by household *i*. Given the detail of available information that has been collected about households and dishes (see next section), potential unobservable sources of selection bias that are not already captured by observable characteristics are limited to only a few suspects. For example, women that have an intrinsic tendency to safe woodfuels may be both more likely to buy an ICS and be more

[7] In fact, confounders may also occur on the level of individual household members (e.g. age or educational level), which is why we also gathered respective information. In our final analysis, there is, however, only one model in Annex 8 where we actually make use of it. We therefore focus the presentation of our methodological approach on the household and dish level.

economical in using woodfuels. Not controlling for this characteristic may lead to attribute impacts to the ICS that are in fact due to having an intrinsic tendency to safe woodfuels. In order to further reduce the threat of a selection bias, much effort has been put into scrutinizing the existence of such unobservable confounding differences by complementary qualitative interviews with households and key informants.

While Equation [2] can be implemented by means of standard Ordinary Least Squares (OLS), we moreover apply the propensity score weighted regression approach.[8] The basic idea here is to combine a propensity score matching approach with a regression-based specification in order to benefit from their respective advantages: the matching estimator ensures that the comparison is limited to very homogenous groups, this is, groups of observations that are equally likely or – given observable characteristics – have the same propensity to own a stove. While matching is therefore supposed to yield an improved comparison on the household level compared to OLS, it does less well in accounting for covariates of unequal importance for the outcome, for which OLS is more appropriate. In our case, this is the case for the particularly important dish-level covariates, most notably whether the dish is prepared for breakfast, lunch, or dinner and the duration of the cooking process. One may hope that the more homogenous the groups to be compared are with respect to observables, the more homogenous they may also be with respect to unobservables. Hence, being more prone to save woodfuels would then not anymore bias the results. However, whether this is really the case, cannot be tested.

The propensity scores determined by means of a binary response model (probit) enter a household-individual weight μ^C (see Annex 3) that is used to balance treatment and control households, such that the difference of the conditional expectations for the *woodfuel savings per dish* indicator can then be rewritten as

$$M = E\,(Y\,(T = 1) \mid X, Z, T = 1) - E\,(Y\,(T = 0) \mid X, Z, \mu^C, T = 0). \qquad [3]$$

Since the unit of comparison for the *total charcoal savings* indicator is the household, we can apply conventional propensity score matching (PSM), i.e. simply match treatment and counterfactual households based on their observable characteristics:

$$M = E\,(Y\,(T = 1) \mid X, Z_{,}\, Prob(T = 1 \mid X'), T = 1) - E\,(Y\,(T = 0) \mid X, Z_{,}\, Prob(T = 1 \mid X'), T = 0). \qquad [4]$$

Key to the application of this approach is the co-called common support condition, i.e. there should be enough non-owners of stoves that share the same characteristics than the stove-owners. This ensures having untreated matches for the treated observations for every *X*. Note that matching needs to be based on characteristics that are not affected by the treatment, hence X_i', which included in the computation of the propensity score, may only represent a subset of X_i.

Altogether, while some uncertainty about unobservable differences and, thus, selection biases cannot be ruled out, the unique level of detail of the collected data, the mixed methods approach and the combination of statistical methods in analysing the data can be expected to eliminate large

[8] The propensity score weighted regression approach was initially proposed by Hirano, Imbens and Ridder (2003) and is further discussed in Hirano and Imbens (2001). A detailed description of the PSM approach can be found in Annex 3. Besides PSM, the literature proposes a number of other matching estimators (see e.g. Cameron and Trivedi 2009).

parts of any selection bias. The present cross-sectional approach might in this case even be preferable to a difference-in-difference approach since doing a follow-up survey two to three years after the baseline in an urban set-up, which in principle is required to apply a difference-in-difference estimator, is very difficult and bears the risk of losing many observations due to attrition.

In addition to total and per dish woodfuel savings, the assessment also includes an analysis of the impacts of ICS usage on weekly cooking expenditures, time use and health. These assessments are either undertaken on the household or the individual level (household member); hence they rely on a framework that corresponds to Equation (1). The treatment variable is then defined as a dummy that takes the value one if the ICS is the "most often used stove by the household" or as a ratio depicting the household's share of dishes that is prepared with an ICS. The first treatment definition allows assessing the impact that materializes when the frequency of ICS usage is higher than for any other stove type in the household – the treatment variable either assumes the value 0 or 1. The second treatment definition is slightly different in that is defined as a continuous variable, where – for example – the impact of preparing two-thirds of dishes with an ICS can be compared with not cooking with an improved woodfuel stove at all.

4. Data

4.1. Survey tools

In order to obtain the information that is needed to implement the identification strategy described in Section 3.2, a large representative household survey was conducted in Ouagadougou and Bobo-Dioulasso. A household in our survey was defined as the group of persons sharing common meals. Several households living together in one compound were treated as separate households. The focus of the employed structured questionnaire was on cooking behaviour and energy usage. Socio-economic aspects of the households' lives were also widely covered encompassing housing conditions, education, revenues, activities, assets as well as gender and health issues. Retrospective questions were asked to ICS owners to determine the durability of ICS and replacement rates in case ICS had broken. In addition, information on the level of neighbourhoods was collected, for example on firewood and charcoal prices, basic infrastructure, and ICS availability.

Moreover, during both the survey preparation and the implementation phase, a large number of experts have been interviewed, for example stove producers and sellers, programme implementers and the administrations of the surveyed sectors, the lowest administrative level in urban Burkina Faso. These interviews served to provide contextual information that is typically difficult to grasp through a structured questionnaire such as the relations between the market and the public sector, about local habits that influence the ownership and use of an ICS, and the local developments in the firewood and charcoal markets. Using transect walking techniques[9], a team of RWI/ISS researchers elicited data on the level of sectors that could be fed into the household dataset, for example related to basic infrastructure, availability of improved stoves and woodfuel prices.

[9] The researcher conducts a walking tour through areas of interest, here the sectors, to observe, to listen, to identify different zones and conditions and to ask questions to identify problems and possible solutions. With this method the outsider can quickly learn about community assets (Grenier 1998: 59f.).

School staff was interviewed to get insights into their cooking behaviour, as FAFASO also aims to increase the usage of ICS at schools. Women groups would have been another relevant key informant group to understand the diffusion of ICS. Unlike the case of the EnDev stove dissemination project in Senegal, though, they do not constitute an active partner in FAFASO's dissemination approach and, in fact, even refused to participate in the intended focus groups discussions, since they were upset with FAFASO for not giving them ICS for free as former projects did.

Reference information as useful inputs to the questionnaire could be drawn from studies conducted by FAFASO in the past. In 2005 for instance, FAFASO conducted a small (although non-representative) survey documenting mainly the usage of different fuels and stove types (Yameogo 2005). Market studies examining the brand awareness of Roumdé ICS were implemented in 2007 and 2008 and some interviews among ICS users were done in 2009.

4.2. Sampling method

Power calculations suggested that a sample size of 1,500 would be enough to detect induced woodfuel savings as small as 15 percent.[10] This is in principle sufficient, as the literature shows that savings with comparable ICS are typically much higher. However, with this sample size it is unlikely to detect more secondary effects on, for example, health and time use, which must be expected to be much smaller. The limits of the budget made available for this evaluation did however not allow an even larger sample size in order to detect these more secondary effects with more precision.

Based on the following procedure the sample of, eventually, 1,473 households, was drawn. First, the sample was distributed among the two surveyed cities proportional to the respective population size. In a second step, sectors as first stage sampling units were stratified into six different classes ranging from poor over mixed to wealthy, which represent the socio-economic status of the resident population of the respective sector. This classification was based on an ad hoc assessment by GIZ/FAFASO staff given that census information could not be consulted for this exercise as it was not sufficiently disaggregated. The classification was corroborated by own inspections at the beginning of the preparatory mission.

In a third step, sectors were drawn randomly from each of the six socio-economic classes such that the number of sectors drawn per class was proportional to the total number of sectors in each class (see Annex 4). In addition, in each city one "non-lotis" area was drawn, i.e. an area located just outside the administrative borders of the city that is not connected to the basic urban infrastructure. Hence, in total, ten sectors in Ouagadougou and nine in Bobo-Dioulasso have been selected.

In a fourth step, the sampling within each sector was realized in two stages. Within each sector, 88 households in Ouagadougou and 30 households in Bobo-Dioulasso have been randomly interviewed. This was done by selecting every third to fifth household (depending on the sector size) along a pre-defined path, which was determined during the preparatory mission using maps of Ouagadougou and Bobo-Dioulasso. This random sample of 1,158 households was then complemented by a targeted

[10] The envisaged power and the statistical significance were set to conventional levels (beta=0.8, alpha=0.05) for a two sided test). Further parameters that affect the required sample size to meet these statistical requirements (e.g. before and after level and standard deviation of the impact indicator) were determined based on a comparable study in urban Senegal (see Bensch and Peters 2013).

sampling of ICS users in a second stage. This *oversampling* procedure was applied, since the number of households owning an ICS in the random sample was expected too low for a rigorous comparison between owners and non-users. For every third household without an ICS an additional interview was conducted with an ICS-using household from the same sector; only in few cases the replacement households had to be searched in other sectors. The replaced households without an ICS were nonetheless interviewed, but only using a short 5-pages questionnaire that elicited basic information, which we use for the analysis of ICS uptake. This procedure allowed us to interview a much larger number of ICS users carrying the relevant information for the effects of ICS usage.

This procedure of replacing every third household without an ICS bears some momentum of insecurity on the effective final sample size. At the outset of the study, we assumed an ICS penetration rate of between 5 and 20 percent. This would imply a total sample size in the range of 1,460 to 1,510 households (see Annex 5). The actual *full sample* of 1,473 households comprehends two subsamples relevant for the subsequent analysis (cf. Table 2): First, a *representative sample* comprising all sampled households, but excluding the purposively oversampled ICS owners. Second, a sample with all households that had to answer to the long questionnaire, the *long questionnaire sample*. This sample of households is the basis for most of the subsequent impact analyses. In order to ensure representativeness of the findings, weighing factors are applied throughout the analyses that were computed based on the representative sample.

Table 2: Composition of survey population

Sampling	**Pre-oversampling**				**Oversampling**	**Total**
Sampled households	ICS non-owners		ICS owners	**Total (*representative sample*)**	ICS owners	
Questionnaire	long	Short	always long	long and short	always long	
Ouagadougou	568	240	76	884	248	1,132
Bobo-Dioulasso	172	67	35	274	67	341
Total (*long questionnaire sample*)	**740**	**-**	**111**	**-**	**315**	**1,166**
Total (*full sample*)	**740**	**307**	**111**	**1,158**	**315**	**1,473**

Source: Improved Stove Data set 2011.

4.3. Survey implementation

The data was collected in the urban areas of Ouagadougou and Bobo-Dioulasso from February to March 2011 (see Annex 6 for a timeline of the survey preparation and implementation). For the implementation of the survey, RWI/ISS cooperated with the local research institute *Bureau d'Etudes des Géosciences, des Energies et de l'Environnement* (BEGE) based in Ouagadougou. BEGE has many years of experience in the field of energy surveys and already worked with RWI/ISS on the IOB evaluation of the Yeelen Ba project in the province of Kénédougou (Grimm et al. 2011). Throughout the survey, BEGE was supported by a junior RWI/ISS researcher.

The general setup and organisational issues of the study were discussed in a first meeting with RWI/ISS, BEGE and FAFASO in October 2010. During a four-day pre-test phase in December 2010 the household questionnaire was tested in Bobo-Dioulasso and Ouagadougou. The results then served as a basis for a revision. The key issue that came up in the pre-test phase was the fact that a considerable number of households used different types of ICS imitations, i.e. metal stoves that roughly look the same as ICS, but are cheaper and are supposed to be less efficient than the FAFASO stoves. This has to do with the lower quality of the materials used as well as the design and precision of certain features such as the ventilation holes. The initial questionnaire was adapted accordingly in order to allow for the distinction between households without any ICS (i.e. those who only use the three-stone fires, Malagasy stoves or LPG stoves), households with an ICS imitation and households with a FAFASO stove. Enumerators and supervisors were thorough trained by FAFASO staff to detect the differences and equipped with an instruction sheet (see Annex 7). In the field, enumerators encountered high quality ICS imitations that closely resembled Roumdé ICS only in exceptional cases.

This introduction was part of a four-day workshop during the preparatory mission for the survey and also included field trips to the survey areas and visits to stove producers to reassure that all important issues could be incorporated in the questionnaire. The workshop was held by ISS/RWI research members and attended by the seven enumerators recruited by BEGE and three BEGE data entry operators in Ouagadougou and also included two days of pre-tests. The same workshop was organized with six further enumerators in Bobo-Dioulasso right after the interview period in Ouagadougou (February 1st to March 3rd 2011). The survey in Bobo-Dioulasso then took from March 11th to March 22nd 2011. The junior RWI/ISS research member who accompanied the field teams supervised the proper implementation of the survey and collected additional qualitative information on the sector level. A final version of the data was handed over to RWI/ISS in April 2011.

4.4. Data quality

Based on the research team's experience and with support from the local partners including the GIZ, the questionnaire was designed in a way that prevented many of the classical problems frequently observed in data sets collected under difficult conditions. The most critical remaining issues are the length of the interview and the collection of sensitive information, for instance on income. The latter is also complicated by the fact that various household members engage in different non-regular activities; for example selling homemade fruit juices on one day and hand-woven clothes on the market on the other day. Each long interview lasted on average 45 minutes; the short interviews were considerably shorter (15-20 minutes). Almost all questionnaires were filled out completely. There was also no major problem of finding the respondents, although most households in the surveyed areas have some income generating activity and can be expected to be away during daytime. The enumerators were instructed to revisit households where no person knowledgeable about the household's circumstances was available or arrange alternative appointments where necessary. Regarding the income-related questions, enumerators were trained in asking these questions very carefully and to first establish trust. Moreover, information about the main expenditure categories as well as information about asset ownership was collected considering that both are generally seen as good proxies for income. Regarding expenditures the level of detail that households could provide was surprising, many respondents even voluntarily provided water and electricity bills as a proof. Overall the reported information on expenditure, income and asset ownership is highly correlated suggesting that reporting errors are very limited and the quality of the provided information is good.

In the specific context, during the preparatory phase doubts were discussed whether it is possible to collect detailed information about cooking behaviour and woodfuel consumption. In the field, though, it turned out that the enumerators managed to reliably elicit the necessary information in a smooth way from the person responsible for cooking. She was asked to give the frequency with which the different stoves in the household are used throughout a typical week. In addition, she was requested 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 woodfuels, she was further asked to specify the type and amount of fuel used with the specific stove for the specific dish. The enumerators were equipped with weigh scales to weigh the amount of woodfuel shown by the woman. In the less frequent case where no woodfuel was available in the household at the time of the interview, the fuel weight used for individual meals was elicited on the basis of the amount of fuel usually bought by the household and information on the dishes this particular fuel is used for. Households typically buy cooking fuels on a daily basis and were therefore able to give precise information on this quantity. In case the household could only specify the price of the fuel in CFA Francs, this value has been converted to kilograms based on local firewood and charcoal prices. We checked the plausibility of the reported woodfuel consumption figures by looking at the consumption for specific dish patterns. In line with expectations, reported woodfuel consumption is – ceteris paribus – on average lower for breakfast compared to lunch and dinner. It is also lower for side and quick dishes (cooking time less than 30 minutes). Cooking expenditures are on average higher in Ouagadougou, for households that cook outside and they increase with the number of prepared meals.

5. Impact assessment

5.1. Distribution of ICS and determinants of ownership

In this section, we present socio-economic characteristics of the ICS owners and non-owners in our sample. This allows for a first assessment of what type of households adopts this technology. For this purpose, the *long questionnaire sample* is used. As described in Section 4.2, it is reweighed to ensure representativeness. Hence, data from 1,166 households is used of which 9.6 percent are users (after the sample has been weighted to be representative). 892 of these households were interviewed in Ouagadougou and 274 in Bobo-Dioulasso. Table 3 shows that the aggregate penetration rate is surprisingly similar in both cities. They considerably differ, though, when we disaggregate according to per capita household expenditure quintiles. In Ouagadougou, the penetration rate is strictly increasing along the household expenditure per capita distribution, i.e. the richer the households are the more likely they are to own an ICS.[11] In Bobo-Dioulasso, the penetration rate is very low in the lowest quintile with around 4.5 percent, whereas it does not differ considerably among the rest of the expenditure distribution (10.7 to 11.7 percent). The robustness of these results is checked by computing ICS ownership rates by asset index quintiles, which can be seen as another acceptable proxy for income. The asset index is based on the reported ownership of a large number of assets other but cooking devices (see the note of Table 3). The aggregation into a single metric index is done

[11] Recall, that our survey does exclude the very rich neighbourhood of Ouaga 2000 in Ouagadougou which is mainly inhabited by international expatriates and high government officials. These inhabitants usually live in large houses, where cooking is usually done either with electricity or LPG.

using principal component analysis.[12] Similar to expenditures per capita, one can note a clear gradient, i.e. except for the second quintile ICS ownership increases with asset ownership.[13]

The penetration rate of around 9 to 10 percent is clearly less than what one may expect given the number of sold stoves provided by FAFASO (see Section 2.2). If they all had remained in either of the two cities and actually attained the assumed lifespan of two years and taking the average amount of Roumdé per Roumdé-owning household observed in this study, which is 1.12, the penetration rate would correspond to some 20 percent (as of March 2011). However, it is quite likely – although difficult to verify – that many stoves are sold in Ouagadougou and Bobo-Dioulasso, but are then immediately transferred to the country side, either as gift or to be sold there. Moreover, some stoves may not survive the average life time assumed by FAFASO of two years. Stoves may break earlier due to inappropriate use or a lack of care or might get lost. It can, however, be excluded that the low penetration rate is the result of a biased sampling, since the sample is representative along other household characteristics as a comparison with census data shows.[14]

Table 3: Distribution of ICS owners and ICS non-owners, by expenditure quintiles (quintiles specific for both locations)

		Quintiles					Total
		1	2	3	4	5	
Total	**By per capita expenditure quintile**	6.3	8.3	9.5	12.3	11.5	9.6
(N=1,166)	**By asset quintile**	7.7	6.3	9.3	11.7	12.9	9.6
Ouagadougou	**By per capita expenditure quintile**	6.5	7.8	8.6	11.6	13.0	9.5
(N=892)	**By asset quintile**	7.6	5.5	9.7	11.7	13.1	9.5
Bobo-Dioulasso	**By per capita expenditure quintile**	4.4	11.0	11.7	10.7	11.7	9.9
(N=274)	**By asset quintile**	8.4	7.1	11.0	8.2	14.9	9.9

Note: This sample comprises all ICS users and non-users that had to answer the long questionnaire. Representativeness is ensured through reweighing, i.e. results are representative for the population in both cities (except the top-end neighbourhoods, for details, see data section). Expenditures refer to total yearly household expenditures per capita and include expenditure for food (both consumed at home and in restaurants), clothing, health, energy, rent, telecommunication, transportation, education, ceremonies and remittances sent to other households. Self-produced food consumption has not been collected and is therefore not included in the expenditure aggregate. The asset indicator has been computed using information about the ownership of a bicycle, a scooter, a car, a house, a fridge, an air-conditioning system, a fan, landline phone, a mobile phone, a dvd player, a black and white television, a colour television, a personal computer and livestock.
Source: Improved Stoves dataset 2011.

In Table 4 the basic socio-economic characteristics of the sampled households are shown and compared across ICS owners and non-owners. This gives a first idea what type of households adopts ICS. Households comprise on average 6.5 members, of whom about a third is below the age of 15. Almost 85 percent of all households are headed by men, who are on average 46 years old. About 67

[12] This method is today widely used in the literature, in particular in cases where no expenditure data, but information on asset ownership is available (see e.g. Filmer and Pritchett (1999 and 2001) and Sahn and Stifel (2000 and 2003)).

[13] However, this higher correlation is partly driven by the fact that the asset index cannot be expressed in per capita terms but is measured in per household terms.

[14] In addition, it can of course not completely be ruled out that Roumdé ICS have been falsely recorded as imitations even though the intensive training of enumerators and their feedback from the household visits indicate that this should be less of a problem. On the other hand, given that households were asked questions related to ICS in different parts of the interview, it seems highly unlikely that they forgot to mention them in case they are not used.

percent of all household heads belong to the ethnic group of Mossi, which is particularly dominant in Ouagadougou. More than 40 percent do not have any formal education. Only 35 percent of all household heads have the level of secondary schooling or more. About 48 percent of all household heads are independent workers, mostly informal self-employment and 13 percent are employed in the public sector. In most cases the household heads, usually a man, are also the ones who decide on household expenditure in general. The monthly per capita household expenditure is about 24,350 CFA Francs, which is evaluated at market exchange rates about 37 Euro or 1.25 Euro a day (of course significantly more if purchasing power parities instead of exchange rates are used). Note that this expenditure aggregate does not include auto-consumption, which, however, is relatively low in urban compared to rural areas. About a quarter lives in houses built of clay, half the houses are cemented. 68 percent have electricity. Hence, to summarize, the surveyed areas are characterized by little educated and poor households for which even an ICS can be expected to be an expensive good, in particular if households do not have access to formal savings and credit instruments.

Overall, it turns out that user and non-user households do not differ much in terms of demographic characteristics, while most socio-economic characteristics – notably, education, housing conditions and the sector of activity – show significant differences. These characteristics are obviously also directly related to household income. ICS owners have on average a higher education level, are more likely to be employed in the public sector, live more often in houses built of bricks or cement and have more often access to electricity. Despite these differences, the difference in household expenditure per capita is relatively small between both groups; ICS owners' spending are on average 11 percent higher. Who takes in general the decision on household expenditures does not differ a lot across ICS owners and non-owners. Households in which women decide on expenditures are slightly underrepresented among the owners.

The structure in the present sample was also compared with statistics from the census, to check whether representativeness is indeed given. It turned out that the sample matches quite closely the official statistics in terms of household size and the gender and education of the household head. Household size and education are slightly lower in the given sample which can be explained by the fact that the top end of the income distribution was not sampled, i.e. the very rich neighbourhoods. Hence it can be concluded that the sample is indeed representative of the target population of the project in these two cities.

To analyse the correlations in a multivariate setting, a binary response model (probit) of ICS ownership has been estimated using as explanatory variables basically the variables shown in Table 5. We estimate two specifications which differ slightly with respect to the set of included explanatory variables and a third specification in which we exclude those households who only use LPG as these households tend to stem from a more affluent section of the population that consequently represents a less accurate counterfactual and is less likely to buy an woodfuel stoves at all (including ICS). It is interesting to see that in a multivariate setting, i.e. simultaneously controlling for a number of factors, only the education of the household head's spouse (often the person who cooks), access to electricity and the identification of the person who takes the decision on expenditures in the household remain significant. Although users and non-users differ along several dimensions as Table 4 shows, the many insignificant variables in Table 5 in conjunction with the relatively low pseudo-R^2 suggest that a non-neglectable part of the variation in ownership cannot be explained by the observable variables at hand. This is also the case in the third specification which excludes LPG-only users. The remaining variation can now be caused by random selection processes or due to self-selection driven by unobservable characteristics. For the latter, the question with regards to the used identification assumption is whether these unobservables are correlated with impact indicators under investigation. In conjunction with the fact that most socio-economic characteristics are significantly different between ICS owners and non-owners in bilateral tests (see Table 4), we have indeed reason to suspect that unobservable factors are driving ICS ownership that might also affect the impact indicators we look at (e.g. fuel consumption).

Table 4: Household's characteristics and ICS ownership

	ICS owners (sd)	ICS non-owners (sd)	*p*-values for *t*-test/ chi-2-test (ICS vs. non-ICS)
Household size	6.3 (3.3)	6.6 (3.5)	0.13
Share of children 0-14 years (in %)	32.3	34.4	0.09*
Hh's ethnicity is Mossi (in %)	64.2	67.0	0.34
Hh head is male (in %)	81.6	83.5	0.19
Hh head is public employee (in %)	19.1	11.3	0.00***
Education of hh head (in %)			0.01**
No formal education	37.8	46.9	
Primary education	20.2	21.9	
Secondary education and more	41.1	32.1	
Educ. of hh head's spouse (in %)			0.13
No formal education	35.9	44.6	
Primary education	30.7	25.5	
Secondary education and more	32.0	29.1	
Share of children aged 7-12 attending school	88.9	86.5	0.26
Material of the house is cement (in %)	64.8	61.2	0.23
Electricity in the house (in %)	79.3	66.7	0.00***
Who in the hh takes the decision on expenditures			0.29
Hh head (male or female)	76.1	74.4	
Spouse of the hh head (female)	7.1	9.6	
Head and spouse together	11.6	9.6	
Several hh members together	5.2	6.4	
Per capita monthly expenditure (in CFA Francs)	27,120 (26,460)	24,050 (27,900)	0.06*
Number of observations	420	746	

Notes: * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent.
Source: Improved Stoves dataset, 2011.

Table 5: Probit estimates of using an improved stove

Dependent Variables	Coefficient (Std. Err.)	Coefficient (Std. Err.)	w/t LPG only users Coefficient (Std. Err.)
Head of the household is male (=1)	-0.170*	-0.158*	-0.140
	(0.098)	(0.095)	(0.103)
Age of the head of the hh	0.002	0.001	-0.001
	(0.003)	(0.003)	(0.004)
Household size	-0.002	-0.008	-0.010
	(0.012)	(0.012)	(0.013)
Share of children aged 15 or less in the hh	-0.019	-0.030	-0.230
	(0.185)	(0.182)	(0.202)
Share of people aged 65 or more in the hh	-0.211	-0.251	-0.011
	(0.484)	(0.487)	(0.610)
Mossi – Ethnicity (=1)	0.031	0.040	-0.016
	(0.077)	(0.077)	(0.086)
Head of the hh has primary education (=1)	-0.025	-0.026	-0.025
	(0.092)	(0.082)	(0.088)
Head of the hh's spouse has primary education (=1)	0.157*	0.131	0.079
	(0.092)	(0.084)	(0.089)
Head of the hh has secondary education (=1)	0.025		
	(0.092)		
Head of the hh's spouse has secondary education (=1)	0.070		
	(0.096)		
Head of the hh employed in independent activity (=1)	-0.029	-0.032	-0.055
	(0.070)	(0.069)	(0.074)
Ouagadougou (=1)	-0.059	-0.072	-0.013
	(0.087)	(0.088)	(0.093)
Owner of the house (=1)	-0.056	-0.069	-0.090
	(0.078)	(0.078)	(0.087)
Electricity in the house (=1)	0.272***	0.238**	0.202*
	(0.086)	(0.117)	(0.123)
Head of the hh (male or female) is responsible for the budget	Ref.	Ref.	Ref.
Spouse of the head of the hh (female) is responsible for the budget	-0.162	-0.159	-0.214*
	(0.113)	(0.112)	(0.124)
Head and spouse together are responsible for the budget	0.189*	0.199*	0.119
	(0.115)	(0.115)	(0.126)
Several hh's members together are responsible for the budget	-0.266*	-0.270*	-0.299*
	(0.145)	(0.146)	(0.156)
Log of per capita monthly hh expenditure	0.069		
	(0.052)		
First asset quintile		Ref.	Ref.
Second asset quintile		-0.086	-0.060
		(0.110)	(0.113)
Third asset quintile		-0.015	0.008
		(0.136)	(0.142)
Fourth asset quintile		0.109	0.172
		(0.138)	(0.148)
Fifth asset quintile		0.165	0.172
		(0.142)	(0.152)
Constant	-2.090***	-1.307***	-1.065***
	(0.555)	(0.203)	(0.230)
Pseudo R^2	0.021	0.023	0.025

Number of observations	1128	1128	972

Notes: 38 observations are lost due to missing information for explanatory variables. Observations are weighted. p<0.10, ** p<0.05, *** p<0.01.
Source: Improved Stove Data set 2011.

Table 6 depicts the persons responsible for the purchase decision for the different stove types that could be found in the households. It can be observed that stove purchase in general is woman's business – except for LPG. In particular, imitated ICS are often bought by female heads or spouses of the household's head. The picture for ICS more closely resembles that of Malagasy. A particularity of ICS is that non-household members more often than for the other stove types brought the stove into the family as a gift. This probably both has to do with availability and the higher price compared to other wood-fuel stoves.

Table 6: Decision maker on stove purchase, in percent by stove type

	Malagasy	ICS	Imitated ICS	LPG
Male head of hh	13.0	12.6	5.2	58.6
Female spouse of head of hh	58.2	56.5	71.4	19.8
Female head of hh	11.1	11.5	9.3	10.4
Other hh member being relative of head of hh	7.0	5.2	8.7	6.2
Non-household member	8.7	13.2	4.5	3.1
Other*	2.0	1.1	0.9	1.9
Number of observations	759	459	234	578

Note: 'Other' refers to non-relative hh members, male spouses of female heads of hh and the case where several hh members decided.
Source: Improved Stove Data set 2011.

When asked for their motivation for buying an ICS, the most frequent response was quick cooking. Fuel savings were only the second most often mentioned motivation followed by smoke reductions, the cleanliness of the kitchen and the mobility of the stove. This ranking both holds for Roumdé ICS and imitated ICS. The largest difference between the two stove types in terms of the households' motivation lies in the appreciation of the beauty of the stove. Significantly more households with ICS have been encouraged to buy the stove due to its beauty compared to households with imitated ICS. In general, interviews in Roumdé ICS-owning households revealed a high customer loyalty. Households often themselves proudly pointed out the different advantages of ICS and advertise the ICS in their circle of acquaintances. It can, hence, also be expected that ICS owners persuade friends or neighbours to obtain an ICS, so that social networks are likely to play a role in diffusing the idea of ICS.

On the other hand, ICS non-owners who regularly cook with woodfuel were asked for why they do not own an ICS. Lack of Information seems to be less a problem. FAFASO seems to have succeeded in raising awareness for the ICS. 80 percent are in principle aware of ICS, of which 59 percent heard about them on TV and 9 percent on the radio. The FAFASO selling points and word-of-mouth from friends, neighbours or relatives also seem to be highly effective advertisement channels with 41 and 33 percent respectively. In consequence, only 18 percent of non-owners do not know at all where to find ICS selling points.

Considering that around 85 percent of traditional metal stoves encountered in the survey have been bought later than 2005, which is the year the FAFASO project started, the majority of ICS non-owning households purposefully decided not to buy an ICS. Most non-owning households (60 percent) stated that ICS are simply too expensive compared to the existing alternatives. Further data and complementary qualitative interviews suggest that there are a couple of other reasons both behind and beyond this price argument. While only few people mentioned not to be convinced of the efficiency (3 percent of respondents) and the durability (as well 3 percent) of the ICS, the investment character of ICS acquisition does not seem to be understood or acknowledged by most ICS non-owners. This also has to do with the fact that – while ICS may already be well-known and their advantages may already be well communicated – households often do not relate substantial fuel savings to them. Instead, cooking stoves are considered by many household as a homogenous good and, as a consequent, many households prefer going for the cheaper options. Of course, the existence of similarly looking ICS imitations aggravates this situation. Yet, only in very exceptional cases households stated that they intended to buy a Roumdé ICS, but mistakenly took an imitated version. At the time of the survey, many households further explained the absence of ICS in their household by the fact that they already own other types of stoves and therefore do not need an additional stove. In addition, even if the investment character of buying an ICS is understood and acknowledged by the household, many are cash and credit constrained at the time a new stove needs to be purchased.

A cultural aspect that, in principle, might affect ICS ownership and usage is the tradition of the largest ethnic group in Burkina Faso, the Mossi: the mother-in-law is supposed to build a three-stone stove in the household as a traditional welcome present for the bride after a marriage. From this perspective, destructing the three-stone stove can be perceived as divorce. As a consequence, three-stone stoves can even be found in wealthier households. The data reveals that Mossi and non-Mossi households neither differ in terms of the frequency of three-stone usage nor in terms of ICS ownership. This aspect therefore does not seem to affect ICS ownership and usage.

To conclude, apart from the economic situation of the household no other major drivers of ICS ownership could be detected. Instead, a myriad of other less tangible, but also less prominent influencing factors exist.

5.2. Cooking behaviour of ICS users and non-users

The stoves used in the urban centres of Burkina Faso can be classified into six groups that can be ordered according to their degree of being an efficient and clean cooking facility: Three-stone open fires as the most inefficient and polluting one[15], followed by simple metal stoves called *Malagasy*, imitated ICS, *Roumdé* ICS, LPG stoves and electric stoves (for details on these stove types refer to Section 2.1 and 2.2). The penetration of these different stove types among the surveyed population can be taken from Table 7. It has to be noted here that these figures can only give a first rough picture of the stove portfolios of households, since these values also include stoves that typically are not used but rather serve as a back-up. The table therefore also presents the share of households

[15] A slightly improved version of three-stone open fires exists as well. They make up around 20 percent of all three-stone fires found in the surveyed households.

regularly using the various stove types – either for cooking or for other purposes like heating up water, ironing or for their business.

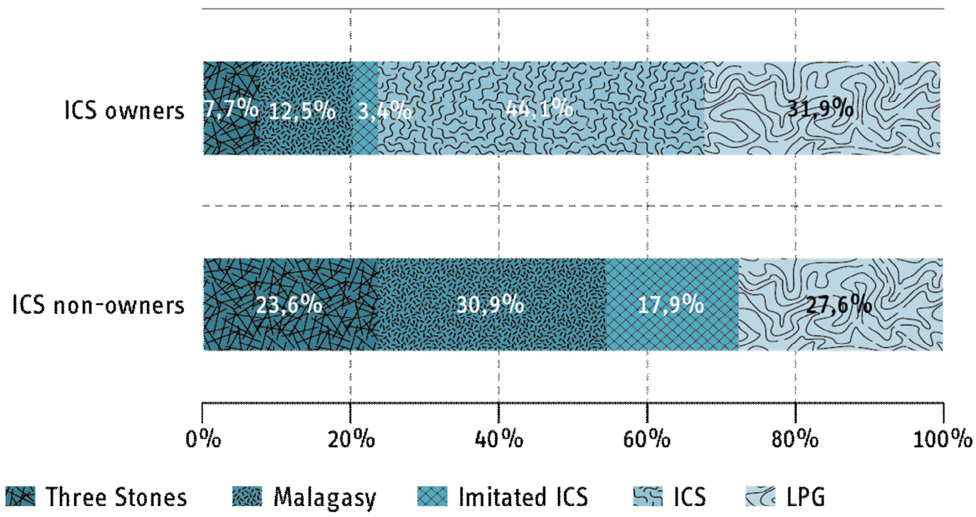
Table 7: Ownership rates of different stove types differentiated by ICS ownership

	ICS owners		ICS Non-owners	
	Mean number of stoves owned per household	**Share of regular users (in %)**	**Mean number of stoves owned per household**	**Share of regular users (in %)**
Three stones	0.34	16.8	0.65	40.5
Malagasy	0.62	27.2	0.96	50.6
Imitated ICS	0.07	6.4	0.31	24.3
Roumdé ICS	1.12	84.3	-	-
LPG stove	0.72	50.3	0.64	43.1
Electric stove	0.03	<1	0.01	<1

Source: Improved Stove Data set 2011.

For the analysis of cooking customs of surveyed households, the unit of observation will be the number of stove applications – or put in other words, the number of dishes, which are prepared with a particular stove. Dishes, in the context of this analysis, refer to the different parts of a meal, where each dish is prepared on a different stove. While households cook up to three meals throughout a day, i.e. breakfast, lunch and dinner, the number of dishes may, of course, well exceed this number, for example, because for dinner two dishes, rice and sauce, are prepared. To get an impression on the households' cooking patterns, Figure 2 presents the usage share of different stove types, differentiated by ICS owners and non-owners. Roughly half (44 percent) the dishes prepared in ICS households are actually cooked on an ICS, followed by LPG stoves (32 percent). Only around 20 percent of dishes in ICS households are cooked on three-stone and Malagasy stoves, another three percent are cooked on imitated ICS. Among ICS non-owners, more than half of the dishes are cooked on three-stone and Malagasy stoves. Here, mere 18 percent of dishes are prepared with imitated ICS. LPG stoves are employed to a similar degree in ICS owning and non-owning households. In both groups, only 1 percent of households possess electrical stoves (hence not shown in Figure 2). This suggests that mainly traditional woodfuel stoves and imitated ICS are replaced by an ICS, which will be further elaborated in the subsequent data analysis. Obviously, this is an important question in the analysis of the effectiveness of ICS, since potential savings on woodfuel consumption crucially depend on the stove type they replace.

Figure 2: Usage share of different stove types

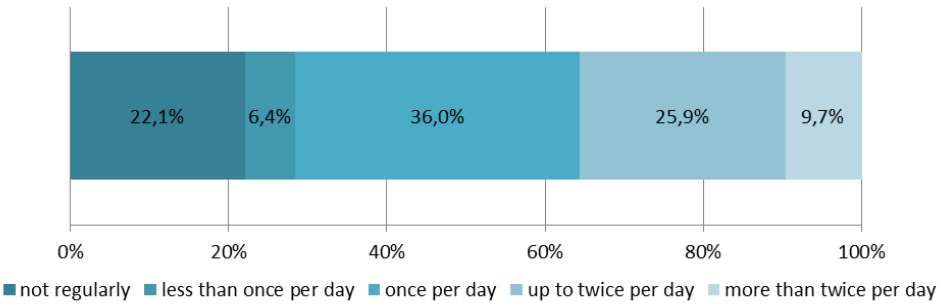


Note: The shares depicted in the figures are calculated as a ratio between the number of times the respective stove is used per week and the total number of times stoves are employed per household. Example: Household uses two stoves cooking 21 meals a week, would lead to a denominator of 42. The total may not sum up to 100 percent due to other stove types (mainly electric stoves). N=1,108.
Source: Improved Stove Data set 2011.

Figure 3 depicts the usage frequency for ICS. On average, each ICS is used to cook 8.3 dishes per week (out of 20.3 dishes that are prepared in an average ICS household). Typically, ICS-owning households own no more than one ICS. Only 8 percent of households own two ICS and 1.5 percent own three or more ICS. Based on the information on stove usage, the most frequently used stove type can be determined both for ICS-owning and non-owning households: Among ICS non-owners, a traditional woodfuel stove (Malagasy or imitated ICS) is the most frequently used stove in 65 percent of cases, followed by 26 percent of households using an LPG stove most frequently. The remaining 9 percent use both a woodfuel stove and LPG most frequently. In 37 percent of ICS-owning households, the ICS has become the sole most often used cooking stove. Another 16 percent of ICS owners employ both their ICS and another stove (LPG, Malagasy or imitated ICS) most frequently. With 28 percent, the share of households preferring to use LPG is almost the same as for ICS non-owners.

Here, we also observe that 15.1 percent of ICS-owning households in Ouagadougou and 1 percent in Bobo-Dioulasso usually do not use their ICS. Asked for the reason why they tend not to use their ICS, most households stated to resort to the woodfuel ICS only in case of LPG shortage. Another more frequent explanation is that the ICS is only used in case of ceremonies and other exceptional occasions. Further reasons are that the ICS is, in principle, obsolete – for example with a broken grill – but is being kept as backup stove. Other households state that they want to prevent the ICS from deteriorating and, hence, do not use it frequently. Another 3.1 percent of ICS-owning households in Ouagadougou and 6.9 percent in Bobo-Dioulasso, respectively, do not use the ICS for meal preparation in the household, but only for other purposes like for ironing. The corresponding share of 84 percent of households using their ICS regularly for cooking is, though, considerably higher than for an ICS intervention in urban Senegal, where LPG is far more dominantly used (see Bensch and Peters 2013). Considering that the majority of households (63 percent) with more than one ICS do only use one of them, the share of individual ICS not regularly used is slightly higher with 22 percent (see Figure 3).

Figure 3: ICS usage frequency, categorized



Source: Improved Stove Data set 2011.

With 53 percent of all ICS in our sample, the multimarmite Burkina is the most popular Roumdé stove. The second most popular model is the Ouaga métallique accounting for 19 percent of the ICS. The multimarmite Malien and Burkina mixte each have an ICS market share of 12.5 percent. The céramique is virtually inexistent in the urban areas. Users are highly satisfied with their respective ICS. The vast majority of 89 percent do not see any inconvenience in using the stove. Among the remaining households, most lament on the price (4 percent) and that the woodfuel does not fit into the stove (3 percent). Comparing the ICS with their traditional stove, the vast majority considers usage as easier, whereas 7 percent see no difference and mere 3 percent consider the usage of the ICS as more difficult. Another more specific comparison criterion is taste: Here, 31 percent mention not to notice any difference, contrasted to 46 percent who like the taste of food cooked on an ICS better and 23 percent of ICS-owning households who see a difference in taste, which they, however, would neither classify as better or worse.

Table 8 lists all perceived advantages of ICS in comparison to traditional stoves mentioned by house-holds. The table also presents the same data for owners of ICS imitations. For both stove types, fuel savings and a quicker cooking process are the most valued advantages. Large differences in the perception of advantages can be observed when it comes to durability, money savings, appearance of the stove and comfort, which only a minority of ICS imitation users declared as advantages.

Table 8: Advantages of ICS and imitated ICS in comparison to traditional stoves, in percent

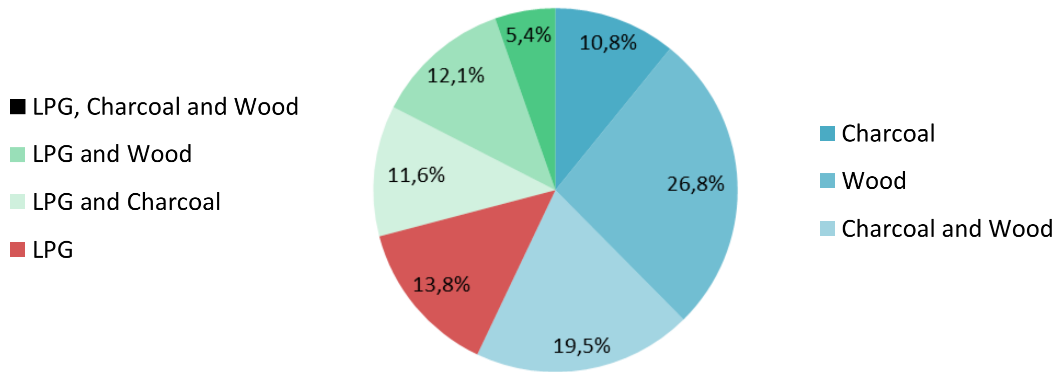
	ICS owners	Owners of imitated ICS		ICS owners	Owners of imitated ICS
fuel savings	93.4	80.7	beauty of stove	69.4	36.8
quick cooking	89.4	80.7	increased comfort	66.9	44.3
smoke reductions	85.6	60.6	durability of stove	65.2	39.4
mobility of stove	77.1	62.3	less respiratory diseases	60.4	50.0
cleanliness of kitchen	72.6	59.2	less eye diseases	60.3	55.1
money savings	70.7	47.7	less accidents/ burns	58.8	49.7

Note: Households were asked whether they perceive these aspects as advantages of their stove. They were additionally openly asked to mention further advantages they might see.
Source: Improved Stove Data set 2011.

Data on the purchasing date of the respective stoves somehow underpins the lower durability of imitated ICS – also taking into account that Roumdé ICS are marketed since shorter time: 46 percent of imitated ICS have been bought within the last two years whereas this share is only 28 percent for the Roumdé. The quality improvements of Roumdé stoves compared to imitated ICS are also reflected in a higher price: While households usually pay between 1,000 and 2,000 CFA Francs and on average 1,400 CFA Francs for an imitated ICS, the average price of a Roumdé stove is twice as high, with prices typically ranging between 2,000 to 3,500 CFA Francs. For comparison: at the time of the survey, the firewood price was around 50 and 100 CFA Francs per kg in Bobo-Dioulasso and Ouagadougou, the charcoal price between 150 and 300 CFA Francs. It thus depends on the saved woodfuels induced by the Roumdé and its durability if it is a more profitable investment than the imitated ICS. We will analyse this in Section 5.3.2. According to qualitative interviews, though, in many cases neither producers nor users of imitated ICS are aware of differences in quality and woodfuel consumption between imitated ICS and Roumdé ICS.

Concerning the fuel type used with the respective stove, three-stones are usually applied with firewood, while Malagasy stoves are available for both charcoal and firewood – charcoal models are more common representing around 65 percent of all Malagasy stoves. Three of the Roumdé ICS models, namely Burkina mixte and the two multimarmite models, can be fired with charcoal and firewood, while the Ouaga métallique and céramique only run with firewood. Half of the households only use biomass to fire their stoves – the right-hand side of Figure 4 –, 19 percent only LPG and 29 percent use LPG and woodfuels simultaneously for cooking.

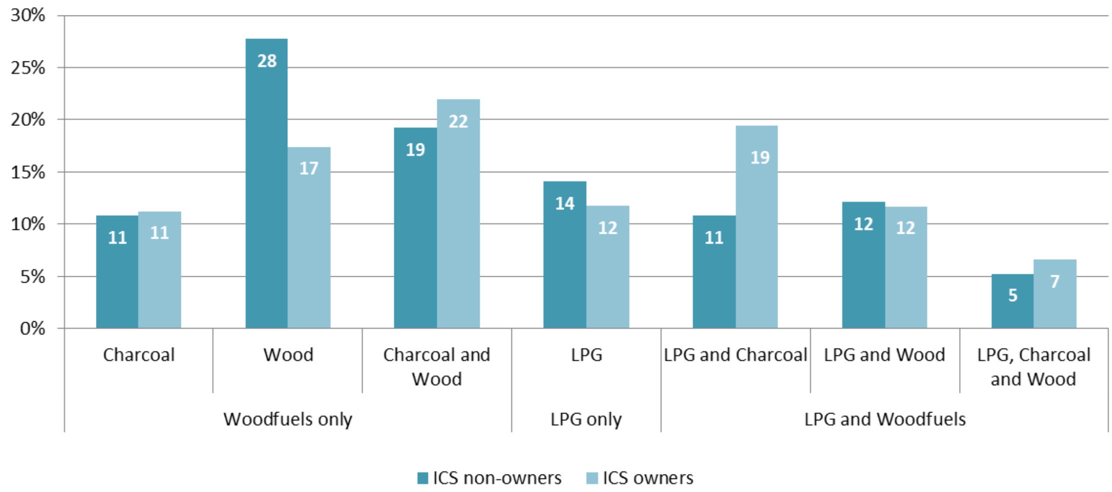
Figure 4: Fuel usage of households, in percent of households



Note: N=1158, for eight households no information about their fuel usage could be retrieved, among whom five stated that they do not cook at all in the household.
Source: Improved Stove Data set 2011.

Differentiating fuel usage by ICS owners and non-owners, it can be seen that a higher share of households without ICS only uses firewood for cooking, while ICS owners more often use LPG and woodfuels simultaneously (Figure 5). Virtually all woodfuel-consuming households buy the fuel. Only 0.4 percent of the households mentioned that they collect at least part of their firewood.

Figure 5: Fuel usage of ICS owners and non-owners, in percent of households



Note: N=1158.
Source: Improved Stove Data set 2011.

Table 9: Stove and cooking related characteristics

	All	ICS owners	ICS non-owners	
	mean (sd)	mean (sd)	mean (sd)	***p*-value**
Stove usage in times per week	18.3 (8.4)	20.3 (8.4)	18.1 (8.4)	0.00***
Number of observations (households)	1,108	396	712	
Share of meals prepared with more than one stove	25.9%	28.3%	25.6%	0.15
Number of people meals are cooked for	6.3 (3.3)	6.1 (3.4)	6.3 (3.3)	0.21
Number of observations (meals)	2,618	1,021	1,597	
Firewood consumption per dish				
Three-stones	3.8 kg (2.6 kg)	4.0 kg (3.1 kg)	3.8 kg (2.6 kg)	0.67
Malagasy	4.3 kg (3.4 kg)	3.0 kg (2.2 kg)	4.3 kg (3.5 kg)	0.00***
ICS	2.8 kg (1.9 kg)	2.8 kg (1.9 kg)	-	-
Imitated ICS	†	†	3.1 kg (2.6 kg)	†
Number of observations (dishes prepared with firewood)	1,025	358	667	
Charcoal consumption per dish				
Malagasy	1.6 kg (1.6 kg)	1.3 kg (1.3 kg)	1.6 kg (1.7 kg)	0.13
ICS	1.5 kg (1.5 kg)	1.5 kg (1.5 kg)	-	-
Imitated ICS	†	†	1.7 kg (1.4 kg)	†
Number of observations (dishes prepared with charcoal)	840	375	465	

Note: sd – standard deviation; † = there are too few observations to provide the given statistics for dishes prepared with firewood on imitated ICS in ICS owning households. * significant at 10 percent, ** significant at 5 percent, *** significant at 1 percent.
Source: Improved Stove Data set 2011.

Table 9 shows stove and cooking related characteristics differentiated for ICS-owners and ICS non-owners. The two groups differ significantly in their stove usage: ICS owners prepare more hot meals in total and, hence, use significantly more often their stoves (20 and 18 times per week, respectively). Additionally, they apply more often two or three stoves simultaneously to prepare a meal, although this difference is only weakly statistically significant (p-value of 0.15). Multiple stoves are particularly used for lunch preparation – among ICS owners, around 53 percent of lunch meals are prepared with more than one stove (43 percent for ICS non-owners). The average number of people cooked for does not differ significantly between the two compared groups.

Regarding woodfuel consumption of the different stove types, the comparison of crude descriptive figures in Table 9 indicates that ICS on average consume considerably less firewood than three-stone and Malagasy stoves, while the difference to their imitated counterparts is less pronounced. Furthermore, the table shows two particularities: First, Malagasy stoves on average consume more firewood than three-stones and ICS owners need significantly less firewood when cooking with a Malagasy stove compared to ICS non-owners. For charcoal, differences across the three stove types are almost undetectable. These findings suggest the necessity of controlling for certain characteristics that co-determine the amount of fuel consumed in meal preparation such as whether the meal is breakfast or dinner or whether multiple stoves are being employed. Since these characteristics may occur with varying frequency among the compared subgroups, differences observed on this level may be rather due to these background characteristics. To give another example, for the preparation of certain dishes some households could not specify the amount of woodfuel needed, since only fuel leftovers from a previous dish have been used. While this is the case for around 15 percent of dishes prepared with Malagasy and ICS stoves, this share is twice as large for imitated ICS. In the following section the saving potentials on woodfuel consumptions of ICS stoves will therefore be analysed in more detail using multivariate regression analysis in conjunction with matching techniques allowing controlling better for confounding factors.[16]

Box 1: Cooking behaviour and stove use at schools

Among twenty randomly chosen schools that were surveyed in the two cities, only one institution cooked with Roumdé stoves. As far as Ouagadougou and Bobo-Dioulasso as a whole are concerned, no statistics exist on the total number of Roumdé stoves used in schools. There are two major reasons for the limited utilization of ICS in the educational field: first, there was never any comprehensive project with the aim of disseminating modern stoves to schools in the urban areas. FAFASO itself rejects the idea of passing them to schools for free because this goes against the underlying philosophy of the project – namely to work according to free-market principles. Second, despite a newsletter circulated by the Ministry of Education in 2010, in which all elementary schools (both private and public institutions) were summoned to prepare

[16] Of course, only observations (dishes) enter the regression analyses for which woodfuel consumption values are reported. To account for the case where no such consumption figures are reported, because the dish is prepared with fuel leftovers from a previous dish, a dummy is included in the regression that takes on the value one if the respective fuel is also used to prepare another dish and zero otherwise.

a lunch meal for their students, and to prioritize the use of Roumdé stoves for this undertaking, most schools can simply not afford the stoves with their everyday budget. In principle, it is the school administration who decides on the purchase provided the consent of the parents association. Many of the schools continue to prepare meals on three-stone fires. In the majority of Burkinabé schools, rice with green beans is the one and only meal offered to the students every day of every week. Those schools that are privately run and attended by students from comparatively wealthy families predominantly use gas to prepare meals.

In nine of the visited primary schools, cooking habits and needs have been examined in more detail. In seven out of them a canteen exists. The meal is provided for all pupils free of charge, while three schools charge a rather symbolic contribution of 1,000 CFA Francs (1.5 EUR) per year. In addition, most schools ask pupils to bring one to three bundles of firewood each month. The usual meal is rice and beans, sometimes couscous. While one better-off private school uses LPG for cooking, all other visited schools cook on three-stones, four of them complemented with imitated ICS. These four schools confirmed that the imitated ICS consume less firewood than for the three-stone stoves. Considering the small sample of schools, differences in firewood consumption between schools additionally using imitated ICS and those only cooking on three-stones could not be detected. Based on extrapolations from samples of the firewood consumed for cooking, the amount of firewood used in the nine schools per month and pupil can be gauged to range between 500 and 650 grams. For the firewood that they additionally have to buy schools incur monthly costs of 30 to 180 CFA Francs (0.05 to 0.30 EUR) per pupil enrolled.

5.3. Econometric identification of impacts

Using the identification strategy outlined in Section 3, this section now analyses the causal effects of using an ICS compared to alternative types of stoves on firewood and charcoal consumption, on firewood and charcoal expenditures, on health outcomes, and on time use patterns. In the following, only firewood- or charcoal-using households were included, since LPG-only households are already on a higher step of the energy ladder and cannot serve as a benchmark to assess the effectiveness of ICS. In case we examine individual dishes, only observations are included for which either firewood or charcoal was used.

5.3.1. Impact on firewood and charcoal consumption

Laboratory cooking tests in Burkina Faso have only been conducted for firewood and showed a reduction in firewood consumption of 29 to 43 percent if a three-stone stove was compared with the various types of ICS provided by FAFASO. As summarized above, the complexity of the households' day-to-day cooking habits likely have the effect that the actual savings rate will differ. We now first analyse the savings per dish and therefore look at woodfuel consumption with the observational unit not being the household but the dish prepared on a stove. Table 10 shows regressions where the kg consumption of firewood and charcoal, respectively, per dish is regressed on the type of stove used for this dish and control variables on the household level as well as cooking related characteristics.[17] The included variables seem to explain quite substantial parts of the variation in the dependent

[17] Note that all standards errors are estimated in way that they are robust to potential heteroscedasticity, i.e. an increasing variance of the errors with the level of predicted woodfuel consumption. The Breusch-Pagan Test in the lower part of Table 10 indicates that heteroscedasticity might be a problem in columns (1) and (2).

variables, firewood or charcoal consumption. This is indicated by the R^2 ranging between around 25 percent and up to almost 40 percent for the six regressions.

Column (1) shows the basic Ordinary Least Squares (OLS) specification for dishes that are cooked on stoves using firewood. Firewood consumption is expressed in logarithms such that the estimated coefficient can be interpreted as a semi-elasticity. This feature is convenient for interpretation, since it approximates the percentage change in firewood consumption following an increase by one unit in the respective right-hand side characteristic, which implies changing from ICS non-ownership to ICS ownership in the case of the *ICS* dummy variable, for example.

The reference stove is the three-stone stove. The results suggest that dishes that are prepared on an ICS consume roughly 30 percent less firewood than dishes that are prepared on a three-stone stove. The coefficient is highly significant at the 1 percent level, but the savings are about a quarter less than in the cooking experiment. The regression results also suggest that the firewood model of the Malagasy does not save firewood compared to the three-stone stove. In other words, the ICS also saves around 28 percent compared to the Malagasy. The imitated ICS seems to save around 15 percent compared to the three-stone, but the difference is barely statistically significant (15 percent level). Also the difference between ICS and imitated ICS, the savings rate of the "real" ICS seems to be 12 percentage points higher than that of the imitated one, is not statistically significant (the corresponding *p*-value is 0.25, see tests at the bottom of Table 10). Overall the results are robust to the inclusion of a large set of control variables that account for cooking and household related characteristics. The estimated signs of these controls are almost all as expected. No significant difference in firewood consumption is found between male and female-headed households. The education level of the cook does also not seem to matter, although, as shown above, education mattered for adoption of an ICS. Wealthier households as measured through housing conditions and ownership of a bank account seem to consume more firewood per dish than poorer households, possibly because they do not need to save on cooking expenditures. Note that cluster effects within households are accounted for, i.e. the fact that some households prepare different dishes with different stoves and thus enter the estimation with several – presumably correlated - observations. The distribution of the number of stoves per households that enter the estimation are also shown at the bottom of Table 10.

Table 10: Estimated impacts of ICS usage on firewood and charcoal consumption per dish (kg, standard errors in parentheses)

	Firewood total Basic OLS (1)	Firewood total OLS PS weighted (2)	Firewood per cap. Basic OLS (3)	Charcoal total Basic OLS (4)	Charcoal total OLS PS weighted (5)	Charcoal per cap. Basic OLS (6)
Three-stone	Ref.	Ref.	Ref.			
Malagasy stove	0.004	-0.074	0.012	Ref.	Ref.	Ref.
	(0.079)	(0.075)	(0.081)			
ICS	-0.277***	-0.284***	-0.262***	-0.149*	-0.126	-0.150*
	(0.083)	(0.076)	(0.084)	(0.089)	(0.083)	(0.091)
Imitated ICS	-0.155	-0.204**	-0.137	0.151	0.159	0.162
	(0.099)	(0.103)	(0.099)	(0.103)	(0.117)	(0.105)
Breakfast	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Lunch	0.229**	0.258***	0.208**	0.249**	0.183*	0.225*
	(0.102)	(0.097)	(0.105)	(0.113)	(0.099)	(0.115)
Dinner	0.253***	0.248***	0.194**	0.106	0.098	0.032
	(0.086)	(0.081)	(0.088)	(0.087)	(0.077)	(0.091)
One full meal per day	0.190***	0.162**	0.211***	-0.098	0.013	-0.124
	(0.069)	(0.065)	(0.070)	(0.089)	(0.084)	(0.091)
Side dish	-0.119	-0.125	-0.124	-0.053	0.013	-0.068
	(0.087)	(0.076)	(0.088)	(0.096)	(0.084)	(0.101)
Quick dish (<30 min)	-0.475***	-0.512***	-0.418***	-0.568***	-0.638***	-0.546***
	(0.088)	(0.081)	(0.089)	(0.091)	(0.089)	(0.092)
Outdoor cooking	0.090	0.044	0.088	0.021	0.028	-0.004
	(0.077)	(0.073)	(0.078)	(0.093)	(0.084)	(0.097)
Several stoves used per meal	-0.041	-0.131**	-0.034	-0.156	-0.236**	-0.168
	(0.072)	(0.064)	(0.074)	(0.109)	(0.095)	(0.115)
Fuel used for several dishes	0.022	0.033	0.013	0.222**	0.174*	0.177
	(0.077)	(0.069)	(0.079)	(0.108)	(0.103)	(0.109)
Number of adult equivalents meal is cooked for	0.029	0.052	-0.226***	0.013	0.044	-0.328***
	(0.033)	(0.032)	(0.034)	(0.053)	(0.050)	(0.058)
Squared number of adult equivalents meal is cooked for	0.002	-0.001	0.009***	0.001	-0.001	0.013***
	(0.002)	(0.002)	(0.002)	(0.004)	(0.003)	(0.004)

Table continues next page

Table continued

	Firewood total Basic OLS (1)	Firewood total OLS PS weighted (2)	Firewood per cap. Basic OLS (3)	Charcoal total Basic OLS (4)	Charcoal total OLS PS weighted (5)	Charcoal per cap. Basic OLS (6)
Household head female	0.005	-0.022	0.030	0.004	-0.009	0.040
	(0.081)	(0.069)	(0.081)	(0.102)	(0.094)	(0.106)
Cook at least secondary school	-0.015	0.058	-0.056	-0.056	-0.009	-0.074
	(0.072)	(0.067)	(0.072)	(0.085)	(0.081)	(0.087)
Household has bank account	0.259***	0.185***	0.280***	0.179**	0.107	0.236**
	(0.067)	(0.064)	(0.069)	(0.090)	(0.081)	(0.092)
Floor is soil	-0.382***	-0.384***	-0.383***	-0.692***	-0.652***	-0.697***
	(0.083)	(0.079)	(0.084)	(0.112)	(0.101)	(0.116)
Household has electricity	-0.108	-0.053	-0.090	-0.085	0.022	-0.108
	(0.069)	(0.065)	(0.070)	(0.106)	(0.091)	(0.110)
Sector effects	yes	yes	yes	yes	yes	yes
Number of observations	982	982	977	776	776	772
Number of households	662	662	660	516	516	515
Distribution of stoves per household						
1 stove	419	419	419	320	320	320
2 stoves	181	181	179	148	148	148
3 stoves	50	50	50	40	40	39
4 and more stoves	12	12	12	8	8	8
Breusch-Pagan (Heteroscedasticity)	0	0	0.036	0.738	0.738	0.194
t-Test ICS vs. Malgache (*p*-value)	0.003	0.013	0.004			
t-Test ICS vs. Imitated ICS (*p*-value)	0.240	0.438	0.232	0.025	0.038	0.023
R-squared	0.288	0.269	0.298	0.325	0.268	0.422

Note: Own estimations. Standard errors are clustered within households. * p<0.10, ** p<0.05, *** p<0.01
Source: Improved Stove Data set 2011.

As explained in Section 3, to account better for the fact that the measured difference in firewood consumption between three-stone users and ICS users might be due to unobserved household characteristics that determine both stove choice and firewood consumption, a propensity score weighting approach was used. The basic underlying idea is to compare households that are equally likely to have an ICS, but only some of them indeed have one and others not. Given that standard matching was not an option, as explained above, the observations are weighted by a transformation of their propensity score to have an ICS (see Annex 3 for more details). The results are almost identical to those presented in column (1). In column (3) then the regression is estimated measuring firewood consumption in per capita terms. Again, it is found that an ICS relative to a three-stone stove reduces woodfuel consumption by about 27 percent and that imitated ICS seem to perform worse than ICS, even though differences in the savings rate between the two stove types are not statistically significant.

In columns (4) to (6) the regressions are repeated for all dishes that were cooked using charcoal. Given that charcoal is, in principle, not used on three-stone stoves, the charcoal version of the Malagasy stove is now used as the reference stove. The OLS results in columns (4) and (6) suggest that an ICS consumes about 15 percent less charcoal than a Malagasy stove with this difference being statistically significant at the 10 percent level. In column (5), where propensity score weighting is used, the saving rate decreases to around 13 percent and the significance level goes down to 13 percent. Partly this may also be driven by a somewhat smaller sample size. Technically, though, a lower saving rate for charcoal compared to firewood is plausible, mainly due to the fact that the charcoal reference stove is more efficient than the firewood reference, the three-stones. For imitated ICS, no savings but rather a higher charcoal consumption than that of the Malagasy is indicated (although the significance levels are clearly above 10 percent). In consequence and in contrast to the firewood stoves, the Roumdé charcoal ICS consume significantly less fuel than the imitated versions (as indicated by *p*-values between 2 and 4 percent).[18] Apparently, the more precise and accurate fabrication of the Roumdé as compared to the imitated ICS is more important for charcoal usage than for firewood.

To summarize: we find quite substantial savings that are also in the range of statistical significance, partly highly significant. Although the findings on savings rates are somewhat lower than it has been found in controlled cooking tests, savings rates between 15 and 30 percent are not negligible. Based on the estimated savings rate we could now estimate the potential monetary savings that can be attributed to the use of an ICS. However, this also requires taking into account changes in the cooking behaviour associated with the use of an ICS such as the frequency of use. Therefore, we provide this estimate below in Section 5.4.

[18] The results are confirmed if we further include control variables for the four metal stove models, for which both ICS and imitated ICS exist (Ouaga métallique, Burkina mixte, Multimarmite Burkina and Multimarmite Malien).

5.3.2. Impact on firewood and charcoal expenditures

Conditional average impact

In this section, it is examined whether the use of an ICS also results in lower cooking expenditure. The simultaneous usage of different stove types in many households is accounted for by two different specifications. First, one specification where households are distinguished on the basis of which stove types are used most frequently: (a) a three-stone, Malagasy or imitated ICS, (b) an ICS or (c) an ICS in combination with other stoves. Second, one specification where households are compared on the basis of the shares of dishes that are prepared on a three-stone or a Malagasy stove, an imitated ICS or an ICS respectively. For each specification, one model is estimated that focuses just on firewood consumption (and hence firewood expenditure) and one that focuses on woodfuel consumption in general controlling for charcoal use. In each case, an OLS model is estimated, but also again a propensity score weighted regression. In order to examine whether savings are differently affected in the lower part of the income distribution, these estimations are also separately run for the three lowest quintiles of the household expenditure per capita distribution.

A crucial issue in this analysis is whether to condition the estimated savings on cooking frequency (i.e. the number of cooked meals per week). Given that in this cross-sectional approach different households with similar characteristics with and without an ICS are compared (and not the same households before and after), one would like to control as many as possible observable differences between ICS users and non-users. In particular, one might suspect that cooking behaviour patterns determine whether a household is more inclined to obtain an ICS. For example, households that typically cook for more persons or prepare dishes that take longer might amortize the investment costs faster. Since these cooking characteristics are also correlated with savings potentials, this calls for including them as a control variable. However, if in practice households change their cooking behaviour once they use an ICS then controlling for cooking behaviour implies that we attribute only the hypothetical changes in cooking expenditure to the stove that would be achieved if cooking behaviour would not change. This, in turn, means if households cook more once they realize that their (new) ICS consumes less than a traditional stove the actual savings are in fact lower than the hypothetical or potential ones. In different words, in that case the household could save more by maintaining its initial cooking behaviour. However, from an economic point of view, the fact that the household can now afford to cook more has a value for the household in its own right and this is paid for with the forgone savings. In a cross-section it is impossible to quantify exactly to what extent cooking behaviour is affected by the adoption of an ICS, because no information is available on the pre-ICS situation for ICS-adopting households from which to identify changes. Altogether, though, we consider the risk of an omitted variables bias induced by not controlling for cooking patterns to be much more severe than the distortion that would occur if control variables are affected by the treatment. Table 11 therefore shows the results for models that control for cooking behaviour, in particular the number of all stove usages per week. Regressions without these control variables are conducted for robustness checks. The results without these controls are briefly discussed but will not be shown in detail.

The results suggest that the effects on monthly firewood and cooking expenditure associated with frequent ICS usage are negative throughout. However, they are statistically significant only in the case where total cooking expenditures are considered (not for expenditure on firewood only, which might be due to a higher standard deviation for firewood because of measurement problems). Columns (3) and (4) suggest that households that use frequently an ICS have cooking expenditure that are on average about 12 percent lower than households that use mostly other types of stoves. There are no significant savings for households that constantly use ICS in combination with another stove. Evaluated at the sample mean (still excluding LPG users) 12 percent savings in cooking expenditures correspond to 930 CFA Francs or EUR 1.42. This estimate is in line with our estimate derived from the saved firewood in Section 5.3.1., but far below the savings of 5 Euros per months that had been expected by FAFASO in 2007 (FAFASO 2007). With reference to the discussion above, the estimated saving rate in column (4) declines by about one percentage point if the number of applications is not controlled for (not shown in Table). This suggests that ICS users indeed cook more often, which offsets some of the potential savings that can be realized with an ICS. Here, we are unable to disentangle to what extent this is due to ICS users that increase their number of hot dishes after ICS acquisition or if households that cook more hot dishes have self-selected into ICS ownership. In most urban households, food is prepared twice a day and during times of social or economic distress, a family might even cook only one single time per day and warm up the leftovers for the remaining meals. Hence, cooking frequency is, in principle, relatively elastic. Still, there is also qualitative indication for self-selection of households cooking more often with woodfuels.

If the model is estimated for the three lower quintiles of the expenditure distribution only, the saving rate is rather lower and, again, not statistically significant, probably due to the smaller sample size. Overall, the regressions explain about 20 to 30 percent of the total variance in cooking expenditure. In the case of expenditure for firewood only, about 35 percent can be explained. Finally, if the shares of dishes that are prepared on an ICS are used as “treatment variable”, the results are almost identical to those presented in Table 11, therefore they are not shown.

Table 11: Estimated impacts of ICS usage on monthly firewood and cooking expenditure (in CFA F, standard errors in parentheses)

	Firewood expenditure		Cooking expenditure			
	households using only firewood		households using only firewood and/or charcoal			
			all households		lower three quintiles	
	Basic OLS	PSM-w	Basic OLS	PSM-w	Basic OLS	PSM-w
	(1)	(2)	(3)	(4)	(5)	(6)
Most often used stove						
Non-ICS	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
ICS	-0.059	-0.112	-0.119*	-0.121*	-0.079	-0.076
	(0.092)	(0.084)	(0.065)	(0.065)	(0.070)	(0.071)
ICS and non-ICS	-0.000	0.095	-0.005	0.000	-0.095	-0.070
	(0.449)	(0.444)	(0.150)	(0.146)	(0.190)	(0.180)
LPG	.	.	0.204	0.216	0.245***	0.230***
			(0.164)	(0.194)	(0.086)	(0.081)
Household only uses charcoal			-0.098	-0.086	-0.093	-0.072
			(0.074)	(0.082)	(0.081)	(0.084)
Ln number of usages of woodfuels per week	0.456***	0.447***	0.342***	0.360***	0.358***	0.383***
	(0.112)	(0.089)	(0.070)	(0.068)	(0.087)	(0.079)
Outdoor cooking	0.144	0.071	0.002	0.074	-0.042	0.011
	(0.107)	(0.092)	(0.077)	(0.083)	(0.090)	(0.085)
AE meal is cooked for	0.041	0.025	0.067**	0.053*	0.084**	0.082**
	(0.044)	(0.034)	(0.033)	(0.028)	(0.041)	(0.038)
AE meal is cooked for squared	-0.001	0.001	-0.002	-0.001	-0.004	-0.003
	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Any person responsible for cooking has secondary education	-0.079	-0.054	-0.020	-0.014	0.034	0.056
	(0.111)	(0.093)	(0.069)	(0.071)	(0.076)	(0.073)
Household head secondary education	0.052	0.017	0.105	0.140*	-0.001	-0.040
	(0.125)	(0.106)	(0.075)	(0.078)	(0.087)	(0.079)
Household head female	0.164*	0.155*	0.168**	0.107	0.203**	0.094
	(0.094)	(0.087)	(0.081)	(0.081)	(0.087)	(0.084)
Household has bank account	-0.233*	-0.250**	-0.125	-0.170**	-0.091	-0.118
	(0.140)	(0.106)	(0.083)	(0.079)	(0.093)	(0.078)

Table continues next page.

Table continued						
	Firewood expenditure		Cooking expenditure			
	households using only firewood		households using only firewood and/or charcoal			
			all households		lower three quintiles	
	Basic OLS	PSM-w	Basic OLS	PSM-w	Basic OLS	PSM-w
	(1)	(2)	(3)	(4)	(5)	(6)
Floor is soil	0.092	0.011	0.014	0.017	0.006	-0.025
	(0.080)	(0.079)	(0.061)	(0.060)	(0.072)	(0.069)
HH has electricity	0.118	0.126	0.171***	0.235***	0.211***	0.252***
	(0.092)	(0.077)	(0.059)	(0.057)	(0.069)	(0.063)
Ouagadougou	0.618***	0.474***	0.400***	0.357***	0.421***	0.441***
	(0.091)	(0.083)	(0.062)	(0.061)	(0.074)	(0.069)
Ln total monthly household expenditure	0.165***	0.135***	0.148***	0.117***	0.175**	0.193***
	(0.052)	(0.051)	(0.041)	(0.041)	(0.073)	(0.069)
Constant	4.740***	5.344***	5.498***	5.767***	5.109***	4.797***
	(0.567)	(0.499)	(0.474)	(0.500)	(0.716)	(0.629)
Number of households	222	219	533	524	400	392
Breusch-Pagan (Heteroscedasticity)	0.422	0. 422	0.135	0.135	0.012	0.012
R-squared	0.392	0.428	0.274	0.263	0.311	0.339

Note: Own estimations. Standard errors are clustered within households. * p<0.10, ** p<0.05, *** p<0.01

Source: Improved Stove Data set 2011.

Distribution of actual and potential savings across the income distribution

So far, the assessment of the savings induced by ICS usage has focused on conditional averages, i.e. it has only been controlled for a number of household characteristics in order to come up with a single average figure – without probing into differences in the saving rates for different levels of the control variables. In this sub-section, this assessment is refined in order to show how savings are distributed across different income groups, given that households of distinct income levels may exhibit different ICS adoption patterns and saving rates. For this purpose, first the ICS adoption (and the adoption of alternative cooking technologies) is explored across the entire distribution of household expenditures per capita ('income distribution' hereafter). Second, it is assessed how the monetary savings that are associated with the use of an ICS are distributed across the entire income distribution. Hypothetical cooking expenditures are simulated assuming that all ICS users would still cook on a traditional stove (including imitated ICS). Obviously, the shape of this counterfactual distribution does then not only depend on the saving rates estimated in the first part of this section, but also on the penetration of ICS across the income distribution. Hypothetical savings can be expected to be higher in those parts of the distribution in which penetration is higher.

Given the relatively low overall penetration rate of ICS of 9.6 percent as well as the rather moderate expenditure savings of about 12 percent (cf. Table 11), which furthermore do not accrue to households that only use LPG, the effect on cooking expenditures across all households estimated in this first simulation is likely to be very small. Hence, a second simulation is performed in order to assess the savings potential that could be tapped in case of full ICS penetration. Now, the hypothetical cooking expenditures are simulated for the scenario that all households that are not yet, or not yet fully, using an ICS switched to full ICS usage.

For the first counterfactual, the regression in column (4) of Table 11 is used to predict cooking expenditures for each single household conditional on its characteristics including its cooking behaviour. This provides a distribution of (predicted) actual expenditures. The counterfactual distribution is then obtained if for all ICS users the variable ICS use is recoded from one to zero (they are hypothetically switched to the group of non-users) and cooking expenditures are predicted again. This is then the distribution that could be expected if all ICS users of today would still cook with a traditional cooking stove, would they not have bought an ICS (backward-looking). The alternative forward-looking counterfactual is obtained if it is assumed that all non-ICS or only partly-ICS users of today would switch to ICS use only.[19]

Before discussing the results of these two counterfactuals, it is useful, as mentioned above, to first focus on the usage patterns by stove type across the income distribution as these largely influence the shape of the counterfactual distributions. This is shown in

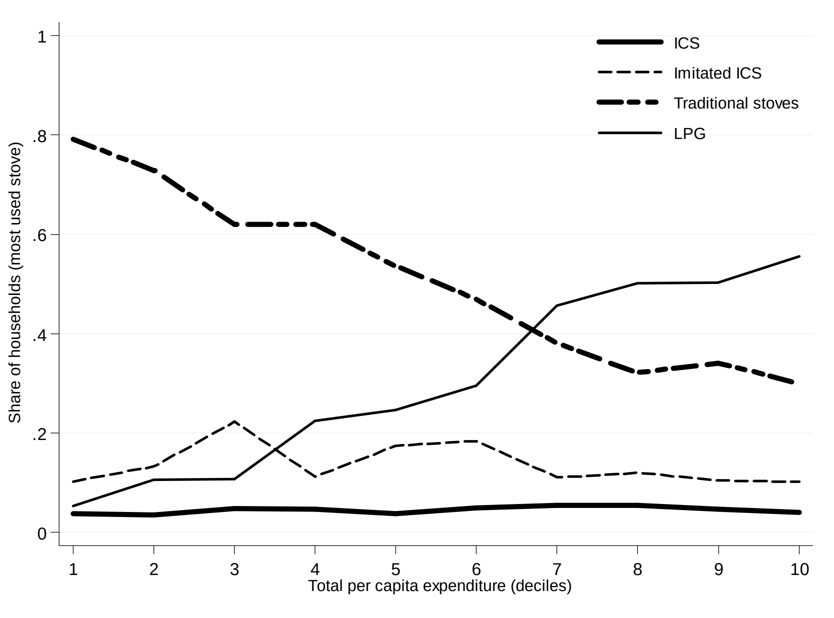
[19] Note that for households that use LPG and woodfuels simultaneously no change in cooking expenditures is simulated.

Figure 6. Two trends are striking: The robust decline of traditional stoves (three-stone stoves and Malagasy) and the significant increase of LPG usage across the income distribution. In contrast, the penetration of ICS is relatively low and does only evolve little with income. Usage rates are just a little bit higher around the fourth and between the seventh and ninth decile of the income distribution. The actual and the two simulated counterfactual expenditure distributions are shown in Figure 7. Monthly cooking expenditures increase strongly across the first four deciles of the income distribution, first linearly and then with a slightly decreasing rate. In the poorest decile households spend about 5,500 CFA F per month. In the fourth decile it is about 7,000 CFA Francs, i.e. almost 30 percent more. From the fourth to the sixth decile cooking expenditures are relatively flat before they decline again around the seventh decile and then stay around 6,500 CFA Francs per month. This decline is mainly driven by the lower usage rate of three-stones and also the higher usage rate of LPG stoves. LPG users spend less on cooking energy than charcoal and firewood users.[20]

The comparison with the backward-looking counterfactual suggest that across the entire income distribution there are not yet any significant savings that can be attributed to ICS usage. The curves of actual and hypothetical cooking expenditures more or less fully overlap. This is obviously due to the low penetration rate of ICS and the relatively moderate savings that are achieved by ICS users. However, a low actual penetration rate means in turn that at least theoretically the potential for savings is still significant. Indeed as the second – forward looking – counterfactual shows, if all non-ICS users switched to the use of ICS as their most often used stove, about 500 CFA Francs per month (about EUR 0.75) could be saved on average by all households up to the fifth decile. Beyond, given the higher penetration of LPG, the savings are on average lower, rather around 250 CFA Francs. Whether these savings are achieved through the dissemination of ICS or another technology will depend on whether ICS non-users indeed adopt in the near future a different cooking technology and if so whether this will be an ICS or rather LPG. In Dakar, for instance, many households seem to have switched directly from traditional stoves to LPG, which is likely due to long-standing LPG marketing and subsidisation programmes (see Bensch and Peters 2013).

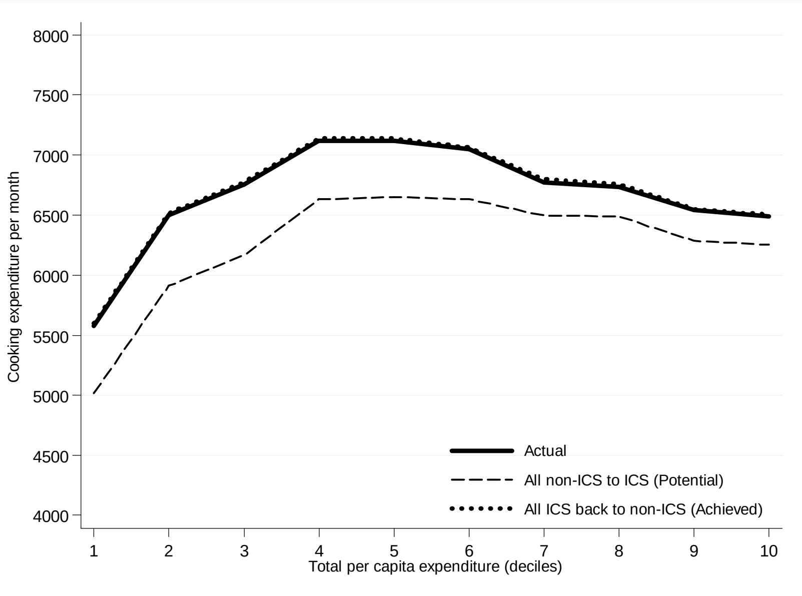
[20] The reason why poorer households do not opt for LPG even though they might end up spending more on cooking with charcoal in the course of a month lies in the investment character of the LPG stove. Households have to invest in an LPG stove and an LPG bottle – potentially including an initial deposit for the LPG cylinder. Households with little and unstable income therefore prefer charcoal that can be purchased in small quantities on a day-to-day or even meal-to-meal basis.

Figure 6: Stove usage across the income distribution (most frequently used stove)



Source: Improved Stove Data set 2011.

Figure 7: Monthly cooking expenditure across the income distribution (actual and hypothetical)



Source: Improved Stove Data set 2011.

5.3.3. Impact on health outcomes

Cooking with solid fuels such as firewood and charcoal is expected to have detrimental impacts on health, mainly through the emission of particulate matter and carbon monoxide evoked by unclean burning processes – referred to as household air pollution (WHO, 2006). There are also other less-reported health risk of open fires and stoves, such as burns and scalding. Children are particularly prone to accidents in the kitchen. They are for instance also at risk of paraffin poisoning (Clancy et al., 2013). Several studies exist that demonstrate the relationship between exposure to particles and serious respiratory diseases such as lung cancer, pneumonia, or asthma.[21] According to the World Health Organization (WHO 2009), two million people die every year due to household air pollution – more deaths than are caused by malaria (Martin et al. 2011). Especially children are vulnerable to smoke emissions. Acute respiratory infections rank among the leading causes of child mortality, inducing up to 20 percent of fatalities among children under five, primarily in developing countries (WHO 2002).

There is still an on-going debate about the effectiveness of ICS in eliminating household air pollution (see Duflo et al. 2008). Although they are expected to reduce woodfuel consumption in general, the degree by which they actually reduce smoke emissions differs greatly across the various types of ICS. Chimney stoves or advanced biomass stoves, for example, can reduce emissions or at least emission exposure almost down to zero. The design of the Roumdé stove, however, is oriented towards fuel efficiency relative to traditional stoves rather than towards emission reductions. A priori, there is less reason to expect that the Roumdé stove yields emission reductions that – all else equal – lead to an improved health situation. Even if the firewood and charcoal savings ranging between 10 and 30 percent translate proportionally into emission reductions – which is not a matter of course and, so far, has not been measured in the laboratory – this is likely not to be sufficient to improve people's health status. However, ICS usage might alter the cooking behaviour in a way that increases health effects beyond what could be expected from the mere reduction of smoke. In Senegal, for example, a very basic ICS (also mostly targeted towards fuel consumption rather than emission reductions) apparently induces health benefits. The reason seems to be that it is more frequently used outdoors, the cooking duration is reduced and cooking is clearly facilitated, since virtually all households formerly cooked on a three-stone stove, so that women spend less time next to the cooking spot (Bensch and Peters 2012).

Of course, the availability of ICS might as well induce changes in the cooking behaviour that aggravate the health situation. For example, the usage of ICS may come at the expense of cleaner stoves such as LPG. As shown in Section 5.2, there is evidence that in the case of FAFASO mainly traditional stoves have been replaced by ICS. Finally, the households' individual cooking behaviour has an influence on smoke exposure. This not only refers to the proper usage and maintenance of the ICS, which are critical for the stove to unfold its potentials in reducing smoke emissions. Cooking behaviour is also dynamic and may adapt to the new situation of owning a cleaner stove with implications for smoke exposure, e.g. by cooking more often inside the house or by staying more time close to the stove. In line with the rebound effect concept (see Section 3.2), this pattern can be called *risk rebound*.

In order to measure effects on health outcomes, most empirical studies investigate indicators that are likely to be affected in the short-term after smoke emissions are reduced. Such indicators are eye irritations and eye infections as well as cough, asthma or difficulties in breathing used as proxy variables for serious respiratory diseases. A shortcoming of these variables is that the symptoms can also be induced by other causes than kitchen smoke, which makes it more difficult to detect a

[21] See, for example, Diaz et al. (2007), Smith-Sivertsen et al. (2004), (2009) and Smith et al. (2000), (2011) on results of the RESPIRE study in Guatemala. Further sources are Hosgood et al. (2010), Masera et al. (2007), Hanna, Duflo, and Greenstone (2012), Smith and Peel (2011) and Yu (2011).

potential change related to increased ICS usage. We therefore particularly focus our analysis on household member responsible for cooking who, for obvious reasons, are most intensively exposed.

Among woodfuel-using households, virtually all persons responsible for cooking are women (97 percent). In 82 percent of households a single person bears this responsibility, the average amounts to 1.2 persons per household. Their exposure may be increased if cooking takes place inside and if they stay close to the stove while cooking. Altogether, 24 percent of the households mentioned to usually only cook inside, most of them in a separate kitchen building. Only 3 percent cook in a room also used as living room and bedroom. On the other hand, 71 percent tend to only cook outside. During the rainy season almost all households are forced to cook inside. In combination with a higher humidity of the woodfuel leading to a more unclean combustion process, smoke exposure temporarily increases in that time period. Air circulation can reduce the exposure to smoke – more than 85 percent of the households reported to keep windows or doors open while cooking inside. In half of the households the person engaged in cooking activities stays next to the stove most of the cooking time. In 14 percent of the households, additionally a baby is carried and in 29 percent of the households a child under 6 years often stays close to the stove while it is cooked.

Table 12 gives a first impression of the incidence of health problems potentially related to smoke exposure as reported by the household members. In the lower part of Table 12 the analysis is restricted to only those members responsible for cooking. First of all, on the aggregate, respiratory diseases and eye problems are relatively rare, which already complicates the quantitative analysis of these incidents: Less than 6 percent of cooks in the interviewed households stated to suffer from these diseases. Furthermore, these descriptive statistics clearly suggest that richer households more often declare the assessed illnesses even though they tend to use cleaner cooking fuels. This might, first, be due to the fact that the self-selection of households into the ICS treatment leads to an overrepresentation of less healthier people (be it perceived or factual) among ICS owners (see Pitt, Rosenzweig and Hassan 2006). Second, and probably more importantly, this result is a typical finding in the context of low and middle income countries and can be explained by reporting heterogeneity: given the same objective health status, poorer individuals tend to underreport their health problems, because they are less aware of health problems have lower health expectations (Bonfrer et al. 2012; Bago d'Uva et al. 2008; Lindeboom and Van Doorslaer 2004; Salomon et al. 2003). While this problem is not unique to low and middle income countries, it is likely to be of greater importance in settings where awareness of health care needs is less widespread and more likely to be correlated with socio-economic status than in developed countries. This may also explain why we – counter intuitively at a first glance – find that ICS owners perceive the air quality to be worse than non-owners (also when taking into account indoor cooking and complementary LPG usage).

Table 12: Incidence of health problems potentially related to smoke exposure among woodfuel-using households as reported by household members, in percent

	ICS owners			ICS non-owners		
	Mean	Bottom Quintile	Top Quintile	Mean	Bottom Quintile	Top Quintile
Household member variables						
Number of observations	2081	371	365	3601	1005	427
Household member suffers from respiratory diseases	3.6	0.8	6.1	2.6	1.3	3.3
Household member suffers from eye problems	3.2	1.1	3.9	2.9	0.5	4.5
Variables on the level of the household member responsible for cooking						
Number of observations	478	73	100	757	185	111
Household member responsible for cooking suffers from respiratory diseases	5.6	2.8	7.0	3.2	1.6	3.8
Household member responsible for cooking suffers from eye problems	5.3	1.4	5.1	5.2	0.5	7.9

Source: Improved Stove Data set 2011.

Hence, in order to investigate the link between ICS ownership and health problems, we need to control for socio-economic characteristics in a multivariate setting. Given the binary outcome of the analysed health proxies, we estimate a probit model – unlike in Section 5.1 with the person responsible for cooking as the unit of observation. As covariates, we use the same variables as for cooking expenditures in Section 5.3.2, completed by the cooking person's age. The results from these regressions are shown in Annex 8. Even if we control for a large set of household characteristics, we still find a rather positive association between the use of an ICS and self-reported health problems. Both ICS usage and income (proxied by expenditures and flooring) are positively correlated with health problems. Nevertheless, overall the results are not conclusive. For respiratory diseases, all three models show significant positive effects (i.e. health deteriorating effects). For eye problems, if the focus is on households that use only firewood, the estimated effect is negative (i.e. health improving), but the corresponding coefficient is far from being significant (p-value 0.67). Finally, across all stove types, the unique use of charcoal significantly reduces the probability of eye problems, which is plausible.

Altogether, these analyses underpin that there is little substance to expect positive health-improving effects associated with Roumdé usage. Our findings at least suggest that – even if there are positive health impacts – they are unlikely to be large.

5.3.4. Impact on time use patterns

Improved cooking stoves may affect time allocations of household members and between them through two different channels: first, ICS may have an effect on the cooking duration by speeding up the cooking process. Second, a reduction of fuel consumption may imply time savings in obtaining the fuel, be it in terms of collecting or buying it. In case, ICS have thereby triggered time savings, households may then reallocate the freed up time to other activities in a second-round effect (Blackden and Wodon, 2006). This second aspect, though, cannot be expected to be very strong given that the ICS have been disseminated in urban areas where the woodfuels are bought in the neighbourhood rather than being collected and carried from far away. In rural areas of course firewood collection is much more important and is typically carried out by women (Clancy et al., 2013).

For the analysis of cooking duration, the OLS regression model for woodfuel consumption on the dish level is applied, now with cooking duration per dish (in minutes) as dependent variable. The analysis is restricted to full meals, thereby excluding quick dishes of less than 30 minutes duration. Since main dishes in most cases determine the cooking duration of the respective meal, the presented results on the dish level are based on estimations that are restricted to main dishes prepared for lunch or dinner. To assess the sensitivity of the results and to check for potential heterogeneity between different meals, separate regressions, including those with side dishes, have as well been performed. The results do not change substantially. Behavioural adaptations, such as an increase in the number or alteration on the type of dishes cooked are accounted for when looking at the total cooking duration per day. The results for the weighed propensity score model are presented in

Table 13.

The findings suggest no time savings of charcoal ICS compared to the Malagasy reference stove, whereas some indication for time savings associated with the use of an ICS for dishes prepared with firewood exists. The reduction is statistically significant and on average amounts to about 13 minutes per main dish prepared for lunch or dinner. These dish savings, however, do not necessarily proportionally translate into savings in total daily cooking duration. For total duration of all meals cooked throughout a typical day on household level, the OLS regression model for cooking expenditures is employed. As for cooking expenditures, we compare values for households with non-ICS as their most often used stove with households where the most often used stove is an ICS or, alternatively, both an ICS and a non-ICS. Economically, the impact turns out to be rather weak. The suggested time saving amounts to mere 7 minutes per day for households who most often use an ICS for cooking and 18 minutes for the group of households who use both ICS and other stoves most frequently. These results do not seem to be driven by the number of full meals prepared, since ICS-owning and non-owning households do not differ in this domain (1.35 times per day for both groups). Instead, it has to be considered that among ICS users, not necessarily all of these meals are prepared with an ICS. Furthermore, the ICS is – in part for side dishes – used in combination with traditional stoves, which may extend the duration of meal preparation. In fact, running an OLS regression for the cooking duration per meal, where meals that are prepared only with ICS are compared with meals with at least one of the dishes being cooked on a traditional stove, yields far lower estimates than on the dish level. Overall, the effects for ICS users are too small to embark on an analysis how households allocate this freed time. Restricting the analysis to the subgroup of households who use both ICS and non-ICS most frequently is not reasonable in light of the low subsample size of 52 households.

Table 13: Cooking duration per dish and per day

	Main dishes, lunch and dinner only			All meals, per day	
	Firewood only	Charcoal only			
	PSM-w	PSM-w		Basic OLS	PSM-w
	(1)	(2)		(3)	(4)
			Most often used stove		
Three-stone	Ref.		Non-ICS	Ref.	Ref.
Malagasy stove	-1.054	Ref.	ICS	-6.542	-7.757*
	(4.655)			(4.628)	(4.539)
ICS	-12.845***	-2.054	ICS and non-ICS	-17.841**	-19.409***
	(4.282)	(4.371)		(7.139)	(6.818)
Imitated ICS	-3.462	14.277**	LPG	-10.289	-11.900**
	(5.766)	-5.931		(6.251)	(5.001)
Lunch	Ref.	Ref.	One full meal per day	Ref.	Ref.
Dinner	-21.608***	-32.318***	Two full meals per day	83.969***	81.214***
	(3.729)	(4.983)		(5.060)	-3.780
One full meal per day	-0.141	1.928	Three full meals per day	127.570***	125.670***
	(3.508)	(5.314)		(13.748)	-9.023
Outdoor cooking	2.696	-6.245	Outdoor cooking	-4.159	-6.052
	(3.859)	-5.429		(4.828)	(3.962)
Several stoves used per meal	-27.702***	-26.895***	Household only cooks with charcoal	17.119***	15.211***
	(3.385)	(4.632)		(5.248)	(5.360)
Fuel used for several dishes	-4.070	-4.066	Household only cooks with wood	13.321***	15.020***
	(3.390)	(5.433)		(4.512)	(4.423)
AE meal is cooked for	-1.560	1.552	AE meal is cooked for	-1.028	1.591
	(2.403)	(3.516)		(2.754)	(2.080)
AE meal is cooked for squared	0.189	-0.045	AE meal is cooked for squared	0.219	0.037
	(0.155)	(0.253)		(0.190)	(0.133)
Household head female	-2.541	0.679	Household head female	-0.653	-2.190
	(4.551)	(6.892)		(4.719)	(4.275)
Cook at least secondary education	3.625	-6.223	Cook at least secondary education	3.153	6.136*
	(4.089)	(4.508)		(4.338)	(3.707)
Household has bank account	0.012	-2.077	Household has bank account	5.446	-1.143
	(3.970)	(4.912)		(4.449)	(3.656)
Floor is soil	-4.808	0.450	Floor is soil	-9.091**	-5.590
	(4.070)	(6.464)		(4.514)	(4.583)
HH has electricity	4.412	4.496	HH has electricity	2.566	6.285
	(3.908)	(5.415)		(4.539)	(4.699)
Sector effects	yes	yes	Sector effects	yes	yes
Constant	131.246***	107.454***	Constant	112.081***	101.337***
	(11.148)	(19.972)		(11.682)	(10.864)
Number of observations	687	315	Number of obs.	923	911
R-squared	0.200	0.243	R-squared	0.484	0.485

Woodfuel collection does not play any role in our urban setup. Only seven households (!) among the 1,166 households interviewed with the in-depth questionnaire report to collect their firewood (including for example waste wood). As for the time that the totality of household members spend on buying woodfuels per month, ICS owners report significantly lower figures for firewood than non-owners (5 hours and 6 minute vs. 4 hours 4 minutes), whereas for charcoal both groups take three and a half hours. The difference of about one hour in case of firewood means a time saving rate of about 20 percent. This is roughly consistent with the savings in firewood consumption reported above, assuming that there is something like a linear relationship between the quantity of firewood bought and the time that takes. Against this, one may argue that household members in charge of buying cooking fuels (for charcoal on average 1.1 and for firewood on average 1.2 household members) usually combine this task with the purchase of other goods. Hence, the determined difference is not necessarily a net reduction in purchasing time.

5.4. Estimation of aggregate annual firewood and charcoal savings attributable to FAFASO

The objective of this part of the analysis is to estimate the aggregate savings of firewood and charcoal consumption that can be attributed to the FAFASO intervention in the past twelve months preceding the survey, i.e. roughly for the calendar year 2010, in the two cities Ouagadougou and Bobo-Dioulasso. The analysis takes place in two steps: first, it has to be approximated how many stoves have exactly been sold in these two cities and also stayed there, i.e. those which were not brought to the country side, and are still in use. Second, plausible counterfactual woodfuel consumption figures have to be derived, i.e. it has to be answered how much firewood and charcoal would have been consumed in the absence of FAFASO?

For the number of ICS used in the two surveyed cities, the approach followed here is to take the sample of interviewed households as the starting point and then to derive an *expansion factor* to extrapolate the amount of ICS found in the representative survey sample into the target population. In accordance with the sampling design, the target population is located in the two surveyed cities excluding the very rich quartiers, since cooking energy is essentially provided by LPG and electricity there. The National statistics institute (INSD) provides the 2006-census-based estimate of population size in the different quarters of both cities.[22] Using these estimates and given that in these sampled and interviewed households reside 5,731 people in Ouagadougou and 1,865 people in Bobo-Dioulasso, it is possible to compute the share of the population that has been surveyed in the respective quarters of both cities. The reciprocal of this share is then the expansion factor. For instance in Ouagadougou around 0.5 percent of the population has been surveyed such that every interviewed household represents on average 234 real households. For Bobo-Dioulasso, this value amounts to 316. Accordingly, it can be concluded that around 28,800 ICS have been sold in the two cities and also stayed there such that they are still at the households' disposal, 17,800 in Ouagadougou and 11,000 in Bobo-Dioulasso. In order to come up with figures of ICS effectively used as presented in Table 14, it has to be additionally accounted for the share of households only using LPG among ICS owners (18 percent in Ouagadougou and 8 percent in Bobo-Dioulasso) as well as the shares of households fuelling the ICS with charcoal or firewood (between 53 and 67 percent). This results in 24,700 ICS being effectively used in the two cities of Ouagadougou and Bobo-Dioulasso.

Firewood and charcoal savings of an individual household are estimated separately using the standard propensity score matching approach described in Section 3.2 thereby also accounting for potential dynamic behaviours such as rebound effects and fuel switching (e.g. from LPG to charcoal). For the probit model used to determine the two propensity scores, the same covariates are included

[22] See www.insd.bf.

that are used in the construction of the weights applied in the propensity score weighted regressions in Section 5.3.1 (see Annex 3). The matching in both sub-groups was successful as indicated by various balancing checks.[23] The results are shown in Table 14. Households that use the Roumdé ICS with firewood save around 3.5 kg of firewood per week. Those households using the Roumdé with charcoal save 1.9 kg.

Hence, the weekly firewood savings attained on average in a firewood-using household that owns a Roumdé amount to about 3.5 kg relative to a comparable household equipped with traditional stoves. Evaluated with the price of firewood observed in our survey (between 50 and 100 CFA Francs per kilo) the weekly savings are around 200 CFA Francs or EUR 0.30 (EUR 1.28 per month). This means that the investment in a Roumdé with costs ranging between 2,000 to 3,500 CFA Francs is on average earned back after two and a half to four months.

Table 14: Estimated aggregate yearly savings in firewood and charcoal that can be attributed to FAFASO

		Ouagadougou	Bobo-Dioulasso	Total
Number of ICS (long questionnaire, reweighted)		76	35	111
Number of ICS up-scaled		17,784	11,049	28,833
Share of households only using LPG among ICS owners		18%	8%	
Number of ICS effectively used		14,546	10,183	24,729
Share of ICS-using households using their ICS with firewood and charcoal respectively	Firewood	53%	67%	
	Charcoal	67%	59%	
Number of ICS effectively used, differentiated by firewood and charcoal	Firewood	7,750	6,824	14,574
	Charcoal	9,772	5,958	15,730
Savings per week and stove (in kg, derived through Propensity Score Matching)	Firewood	3.50	3.50	
	Charcoal	1.87	1.87	
Total annual savings (in 1000 kg)	Firewood	1,415	1,245	2,660
	Charcoal	955	580	1,535

Source: Improved Stove Data set 2011.

In order to assess the total savings in the two target cities of the FAFASO intervention, Table 14 merges these weekly savings with the estimates for the number of ICS effectively used derived above. Altogether, 1,535 tons of charcoal and 2,660 tons of firewood are saved per year. In absolute terms, this is certainly far from negligible. Total woodfuel consumption figures that may help to put these figures into perspective are difficult to obtain. Most reliable, yet, potentially outdated figures are provided by the Ministère de l'Environnement et du Cadre de Vie (Ministère de l'Environnement et du Cadre de Vie 2004). In relative terms, the estimated savings are quite moderate: For charcoal, they make up 0.26 percent and for firewood even only 0.06 percent of total consumption. If we accounted for the reported number of ICS sold according to FAFASO reports, and not only for those

[23] P-values of the likelihood-ratio test of the joint influence of all the covariates before and after matching go up from 0.000 and 0.031 to 0.997 and 0.998 for the two matching applications, respectively. At the same time, the mean absolute standardised bias for all covariates goes down from 19.4 and 11.7 percent to 2.0 and 2.9 percent. Looking at individual covariates, for each of the two strata no statistically significant differences are found.

we could locate in Ouagadougou and Bobo-Dioulasso, the total estimated savings would be higher, but then also not only concern the two major cities.

As a robustness check, savings can be calculated based on the per dish figures determined in Section 5.3.1 and the up-scaling factor used above. This provides in some sense an upper bound estimate, as (i) it ignores the above mentioned behavioural responses, i.e. if a household that switches from a three-stone stove to an ICS, for example, increases the number of hot meals per week and (ii) as it is assumed that ICS have completely replaced existing traditional stones (i.e. either three-stone or Malagasy). The resulting savings are however identical for charcoal (0.26 percent) but indeed significantly higher, at least in relative terms, for firewood (0.09 to 0.13 percent).

6. Summary: Answers to the evaluation questions

In this section we summarize the findings of the impact evaluation by providing point by point answers to each evaluation question on the level of outcomes and impacts as they are formulated in the Terms of Reference underlying this study. For details we refer in every case to the corresponding section in the report.

6.1. Outcomes

Who (gender specific) in the household has made the decision to buy an ICS?

In two-thirds of the cases, the female spouse or female head of household made the decision to buy the ICS (see Section 5.1). Only in 12.6 percent of the cases, the male head of household decided on the acquisition of the Roumdé ICS. A particularity of ICS is that non-household members more often than for the other stove types brought the stove into the family which probably both has to do with availability and the higher price compared to other woodfuel stoves.

How many households own an ICS? How many use the ICS and in which frequency?

The presented data reveals that about 9.6 percent of all households in the surveyed areas of Ouagadougou and Bobo-Dioulasso, respectively own an ICS. Given that our sample is not representative for the very top end of the income distribution representing around 5 to 10 percent of the total population, the figures for the two cities as a whole may be slightly lower. 15.1 percent of ICS owners in Ouagadougou and 1 percent in Bobo-Dioulasso do not regularly use their ICS. Still, on average, ICS are used 8.3 times per week, which implies that the average among regular ICS users is 10.6 (for details the reader can refer to Section 5.2). The survey revealed that in total around 25,000 Roumdé ICS can be expected to be effectively used in the two cities, which is clearly less than the number of Roumdé stoves sold according to FAFASO. Part of this difference may be explained by the fact that many stoves are sold in Ouagadougou and Bobo-Dioulasso, but are then immediately transferred to the country side, either as gift or to be sold there. Moreover, some stoves may not survive the average life time assumed by FAFASO of two years. Stoves may break earlier due to inappropriate use or a lack of care or might get lost. While the data on those stoves that are still available in the surveyed households suggest a good quality and sufficient lifespan of the improved stoves, we obviously cannot infer from this information that this is the case for all ICS sold, since discarded and lost stoves do not appear in the data. Yet, it is unlikely that these factors can fully account for the missing ICS. Hence, it is recommended to undertake a follow-up survey that investigates how many stoves sold in Ouagadougou and Bobo-Dioulasso can actually be found in in other places.

What socio-economic groups own an ICS?

Overall there is only little variation across commonly observable characteristics such as age, education and income. There is a weak positive correlation with income and the use of ICS is slightly more likely if the spouse of the head has at least completed primary education. Usage is also slightly more frequent (relatively) in female headed households. However, ceteris paribus, usage is slightly more frequent in those households in which the household head decides on expenditure.

6.2. Impacts

How much woodfuel is effectively saved per meal per household (taking into account cooking behaviour)?

Households that cook their dishes with an ICS and firewood use about 26 to 28 percent less firewood than households that cook with a three-stone. This reference scenario – the three-stone stove – had also been taken by FAFASO to determine the expected savings rate in laboratory tests, in so-called controlled cooking tests. Yet, our survey has revealed that three-stones are not the most common alternative used in urban Burkina Faso, used for less than 25 percent of all dishes prepared in interviewed households without ICS. If the Roumdé is compared to a Malagasy stove, the saving rate amounts to about 20 percent to 25 percent and – if compared with an imitated ICS – to about 10 percent. However, given the relatively small sample size, the latter difference is statistically not anymore significant. Charcoal users save about 15 percent of charcoal if they use an ICS compared to a Malagasy stove. Roughly the same amount is saved if the comparison is made with an imitated ICS.

What is the effective usage (per week or month) of ICS taking into account simultaneous usage of other stoves and LPG?

For 53 percent of the ICS owners, the ICS is the most often used stove they have, partly together with one other stove type. In terms of usage shares, this is the share of a particular stove among the totality of stove applications, with 44 percent ICS are clearly the preferred stoves among ICS owners. Another 32 percent of them mainly use an LPG stove. Only around 20 percent of the stoves regularly applied by ICS owners are traditional ones such as three-stone and Malagasy stoves. Taking all stoves together, ICS owners significantly more often prepare a hot meal than non-owners (20 and 18 times per week, respectively). Additionally, they apply significantly more often two or three stoves to prepare a meal, especially for lunch. For details the reader can refer to Section 5.2.

How much firewood is saved in total (per week or month)?

As shown above, given the large share of households that still cooks on a traditional stove including three-stones, the potential for further savings is substantial. The transition to LPG still seems to be very slow. Based on a matching approach that accounts for potential dynamic behaviours such as rebound effects and fuel switching (e.g. from LPG to charcoal), an annual firewood savings figure for

Roumdé ICS used in the two cities of Ouagadougou and Bobo-Dioulasso of 2,660 tons could be derived. Yet, only around 60 percent of ICS are used with firewood. Roughly the same share of ICS is fuelled with charcoal as some households use both woodfuel cooking types. For charcoal, additional annual savings of 1,535 tons were found. Given that charcoal can be said to require roughly twice as much raw wood as does cooking with firewood, the effective consumption of biomass resources is likely to be larger for charcoal than for firewood. While sound data on national woodfuel consumption is hardly available, existing data indicates that these savings make up clearly less than 0.5 percent of total demand in Burkina Faso.

What are the time savings of persons responsible for woodfuel provision? For which purpose the 'liberated' additional time is being used for?

Firewood collection is virtually inexistent in the urban target areas of the project. Both firewood and charcoal are purchased near the house. For charcoal, we have not observed a difference in charcoal purchasing time between ICS owners and non-owners. For firewood, a difference of around one hour per week can be seen. It is difficult to obtain a net time savings number, though, since purchasing firewood is partly combined with the purchase of other goods. Apart from the time it takes to collect woodfuels, the time spent on cooking is another impact dimension potentially affected by more efficient cookstoves. For the Roumdé stoves, reductions in the order of 5 to 20 minutes per day have been detected. While – in the long rung – this can be seen as a noticeable relief for those household members who are responsible for cooking, it is not reasonable to examine for which activities the liberated time is used for as the overall time savings are quite modest.

What are the changes in household expenditures for energy in total and cooking energy in particular? For which purposes are the potential savings being used?

The analysis above (ref. to Section 5.3.2.) suggests that ICS users save about 12 percent in household expenditure for cooking (around 10 percent if we focus on firewood users only). Given that ICS users cook more hot dishes than users of traditional stoves, they could in principle save more. This has been discussed in length above. Cooking expenditures represent about 16 percent of total expenditure in the lowest decile of the income distribution, about 8 percent in the fifth and about 2.3 percent in the top decile. Hence, a 10 percent decrease in cooking expenditure cannot be expected to have any significant impact on any other expenditure category such as schooling or health. However, these savings still imply that within less than a year the investment costs for an ICS are earned back through lower incurred cooking expenditure.

What are the changes in health related outcomes (respiratory disease symptoms, eye infections)?

The impact analysis does not provide conclusive evidence on ICS-related health impacts; neither on respiratory disease nor on eye problems. This is not a surprising finding. The Roumdé is principally conceived to save woodfuel. It does not have a chimney and the induced smoke reductions are not strong enough to reach health relevant levels. At high levels of indoor pollution, marginal changes may also only have marginal health effects. Alternative transmission channels that have been observed in rural Senegal (Bensch and Peters 2012) could not be detected either, where the usage of the ICS partly lead to a change in cooking behaviour with effects on smoke exposure and, eventually, health: Outside cooking does not increase, cooking duration is not shortened substantially and the cooking process is not as much facilitated as in the Senegalese case, where virtually all households formerly cooked on a three-stone stove. In consequence, smoke exposure cannot be expected to decrease.

How are these impacts distributed across different household members (women vs. men, children vs. adults)?

Gender- and age-specific impacts may materialize in terms of health and time, whereas impacts on expenditures rather accrue to the whole household. As outlined above, for health no impacts could be determined. Instead, as indicated in the interviews, the cooking process with an ICS can be considered as more convenient and less time-consuming which could be at least partly corroborated by the time expenditure analysis in section 5.3.4. Virtually all persons responsible for cooking are women (96 percent), among whom only 1.5 percent were aged under 15. The time spent on fuel provision is only negligibly affected.

What (if any) are the un-intended or negative impacts?

Neither the structured questionnaire nor the qualitative and more open interviews have revealed any unintended impacts. However, it is worth to recall, that the adoption of an ICS does not necessarily lead to lower total cooking expenditures. Users seem to cook more hot meals to the extent that some households consume even more firewood than before they had an ICS. This then also implies that they spend more, not less, on cooking energy. In economic terms, this simply means that having an ICS lowers the cost of hot meals (which is per se a positive and intended effect). This allows to consume more hot meals and to spend more on any other good that is consumed. If the price elasticity of demand (for hot meals) is large enough total expenditure for hot meals may actually go up not down. This is a positive outcome from the consumer's perspective, but is of course in conflict with the environmental objectives that are associated with the intervention.

Moreover, potential unintended impacts may be related to the imitated ICS. The Roumdé stoves may in the first place have instigated the production of ICS imitations as a kind of counterfeit Roumdé. Second, Roumdé stoves may have served as good examples for existing producers of imitated ICS and inspired design and efficiency improvements, which would imply additional positive externalities of the FAFASO intervention.

In both surveyed cities many imitations of the Roumdé exist – in Bobo-Dioulasso as many as seven times more ICS imitations than Roumdé ICS could be found. The three metal stove types disseminated by FAFASO, the Ouaga métallique, Burkina mixte, and Multimarmite, have originally been developed in the 1980's in Burkina Faso. Apparently, the ICS imitations had existed already before FAFASO started in 2005. There is however no reliable data on whether their distribution has been affected by the FAFASO project. FAFASO itself is convinced that ICS differ substantially from imitated ICS in terms of quality, both with regards to woodfuel consumption and durability. According to FAFASO, the Roumdé ICS can only be produced with specific training in the production methods provided to producers. Actually, no producers of imitations could be identified who already received any training and only very few imitations could be found during the survey that were qualitatively highly manufactured. The origin of these stoves was in most cases difficult to determine. Generally, producers of ICS imitations try to offer stoves at a competitive price and hereby only consider the production costs, without taking into account the quality of the stove. They tend to be completely unaware of the fact that certain design features have an effect on the amount of fuel needed for cooking. With ICS imitations having the same model characteristics as original ICS at first glance, customers often do not recognize quality differences in terms of efficiency-enhancing characteristics while purchasing their stoves: lower-quality materials tend to be used, grills and doors are not properly customized, spacers are lacking between stove and cooking pot needed for an optimal match and further aerodynamic features are not respected.

The detailed analysis conducted in this study, though, shows that these technical deficiencies translate into efficiency losses only for imitated charcoal ICS. Here, no savings are found for imitated ICS users relative to a Malagasy stove. For firewood, on the other hand, the imitated ICS yields statistically significant compared to both the three-stones and the Malagasy stove. Although these savings tend to be lower than for Roumdé ICS, they are still substantial – in particular taking into account the lower price of the imitated ICS compared to the Roumdé. This would indicate that imitated ICS also generate benefits for their users and exhibit an intermediate alternative to the real ICS. However, the study results also suggest that imitated ICS have a lower durability. As this lower quality also comes at a lower price, it might well be that this lower durability and the lower fuel savings deter people from buying another ICS – including the true Roumdé ICS.

These findings underscore the additionality of the FAFASO intervention, even though imitated ICS already represent a low-priced, efficiency-enhanced alternative to traditional stoves and, hence, reduce the net impact attributable to the intervention. The widespread usage of imitated ICS even in the presence of Roumdé ICS further indicates that the existence of the Roumdé ICS do not seem to produce a positive push towards quality improvements in imitated products. Hence, there is a risk of a "the not-so-improved driving out the improved" in the market after the project end of FAFASO that might compromise the sustainability of the intervention. If support, monitoring, training and awareness raising are fading out, Roumdé producers might either be tempted or forced to reduce their quality standards in order to compete with the lower-priced imitations. This, however, is similarly speculative and can only be influenced by the project through preventive measures in the form of putting much effort in institutionalizing the established structures, particularly in terms of quality standardisation.

7. Conclusion

This report assesses the impact of a programme that provides training as well as support in the procurement of raw materials to whitesmiths to allow them producing improved cooking stoves with a label “Roumdé”. The programme, called Foyers Améliorés au Burkina Faso (FAFASO), also trains sales personnel and invests in marketing to distribute these stoves in the two major cities of Burkina Faso, Ouagadougou and Bobo-Dioulasso. The project is implemented by the GIZ, co-funded by the Promoting Renewable Energies Program (PREP). Since its start in 2005 the GIZ project has helped to distribute about 172,000 stoves, 103,000 alone since January 2010.

A representative survey among households in Ouagadougou and Bobo-Dioulasso especially conducted for this evaluation in early 2011 shows that about nine to ten percent of all households in both cities owned an improved cooking stove with the label "Roumdé".

As a first result, we found a penetration rate of below 10 percent in the surveyed areas – which is around half the rate that one would expect if all ICS reported as having been sold in Ouagadougou and Bobo-Dioulasso in the FAFASO monitoring were actually used in these cities. FAFASO suspects this difference being driven by ICS that are "exported" to the countryside, where, so far, ICS are not produced locally. It is definitely worth being investigated by a follow-up study – not only to verify the accuracy of FAFASO figures, but also to obtain an idea if ICS are really transported to rural areas at large scale, and if yes, how. This could have implications for future ICS dissemination programs as well, also for those who target rural areas. Building up production capacities in such rural areas is often much more difficult than in large cities. If the export of large numbers of ICS can be confirmed, this could be a scaling-up option for reaching rural centres and villages as well.[24]

The observed firewood savings rate of 27 percent relative to a three-stone is less than the up to 40 percent (depending on stove model used) achieved in controlled cooking experiments. Furthermore, the robustness across different methods is striking. This confirms what has already been found in other contexts, namely that new technologies have to be tested under real-world conditions to account for the behavioural response of users before one can conclude on their effectiveness. Households may not use their stove appropriately and also neglect maintenance, which obviously reduces the actual effectiveness of such a stove. The results of this study are comparable to those of Bensch and Peters (2013) who apply a similar approach to evaluate a comparable programme in urban Senegal. The authors find that ICS-using households save on average 25 percent of charcoal per stove utilization if the comparison is made with traditional stoves.

Notwithstanding, from an economic and from a development policy point of view the savings rates (per dish prepared) found in this study are quite considerable. Given the subtle character of the "treatment" – the disseminated ICS are not a sophisticated technology – systematic savings of scarce fuels can be considered a success. In particular, if one takes into account the manageable additional costs related to the traditional stoves and the high firewood and charcoal prices in urban Burkina Faso. The weekly firewood savings attained on average in a firewood using household that owns a Roumdé amount to about 3.5 kg relative to a comparable household equipped with traditional stoves. This implies that the investment in a Roumdé is on average earned back after two and a half to four months. The life-span of the Roumdé is around two years – even though the survey revealed that many Roumdé stoves are still in regular use after that. Therefore a rational and well informed consumer should definitely buy a Roumdé. However, in reality consumers are not always well informed or they are simply liquidity constrained. Poor households that are unable to save or to take a formal or informal credit – because they lack collateral – may not be able to buy such a stove (although FAFASO reports that some traders would in principle allow that buyers pay their stove in several instalments). Here, it is also important to recall that the investment in an ICS may compete

[24] Not least, confirming the export of ICS to the countryside would have implications for the EnDev programme and the outcomes FAFASO can claim towards EnDev. While ICS used in urban areas, where virtually all users are connected to the electricity grid and/or simultaneously using LPG are not countable for EnDev, ICS used in rural areas would meet the EnDev reporting conditions and, hence, would be countable.

with many other needs that may have higher priority, including health and education expenditures. The aggregate annual saving estimates of about 2,700 tons of firewood and 1,500 tons of charcoal only represent less than 0.5 percent of total woodfuel consumption in the country, but are in absolute terms of course far from negligible. This is definitely also only a lower bound estimate that can be attributed to FAFASO, as many may have left the two major cities for rural areas and other cities.

There is no major evidence for impacts on health outcomes and time use. This is in line with a priori expectations, since the Roumdé is first of all designed to save woodfuels and not to reduce smoke exposure. The Roumdé does, for instance, not have a chimney. Moreover, people cook mostly outside the house (64 percent), be it with an ICS or not. It bears noting, though, that this study was not designed to find health effects potentially triggered by the FAFASO intervention. Given the rather limited reduction in smoke emissions and exposure, health effects – if they exist – can be expected to be quite small. In order to detect such small effects, a much larger sample size or more accurate (and not self-reported) health indicators would be required. While in general, self-reported health information is widely used and an acceptable early indicator, it might be noisier than objective indicators. Furthermore, there is reason to believe that poorer households answer differently to subjective questions.

Another interesting point found in this study is the role of the imitated ICS, which also seems to allow for some savings while being considerably cheaper than the Roumdé. Here, future research could probe into the role the FAFASO intervention plays for the development and diffusion of this imitated ICS. This might in fact be a non-negligible spillover effect of the programme.

Overall, this report shows that the impacts of using the Roumdé are limited to fuel savings. These savings, though, are significant, substantial and robust. Hence, the major objective of reducing woodfuel consumption for cooking is clearly achieved, although the savings are lower than what has been expected by FAFASO. This, in turn, is due to the nature of the evidence this expectation was based on. It is straightforward that savings rates in controlled cooking tests are higher than what is effectively observed in the field. The reason for this is the day-to-day cooking behaviour of households with, for example, different dishes cooked than in cooking tests where the cook is furthermore being observed while cooking. In real life situations cooks, again mostly women, do a number of activities simultaneously and hence cannot dedicate the same attention to their stove as a cook in a cooking test. Finally, cooking tests of course calculate savings per dish, however we consider also total savings, which are also influenced by the number of dishes cooked. If these increase, total savings are lower than they potentially could be. It must also be recalled that many ICS users still use simultaneously other stoves.

We abstain from doing a cost-benefit analysis, simply since the information to determine the benefits somewhat comprehensively is not available. We could of course easily calculate the monetary savings of Roumdé (and imitated Roumdé) using households. This, however, would only be a first-round effect. The straightforward second round effect occurs at charcoal and firewood traders and producers who lose the same amount of money. Net effects are therefore virtually limited to the non-renewable part of the wood extraction, which, in turn, is not known at all. Calculating only the first round effect would be a misleading exercise.

A strong feature of FAFASO is definitely that it relies on market forces. Selling the stoves makes people value and use them properly. Indeed most users use the stove regularly. To give a contrasting example, a stove programme in Orissa (India), which has been evaluated by Hanna et al. (2012), distributed stoves almost for free which at the end might be responsible for the observed low usage rates among owners there. In fact, it has already been suggested in other contexts that the provision of ICS for free might be ineffective (Barnes et al. 1994, Martin et al. 2011, World Bank 2011). Another strong feature of FAFASO is that the stove is well adapted to the local context and based on model types known for decades. In Burkina Faso many households cook outside and hence it is important that the Roumdé does not force households to break with this tradition. The improved stoves provided in Orissa are fixed in-house constructions, although people predominantly cook outside – according to the authors of that study on average only 1 in 13 meals is cooked inside.

In spite of the successes of the FAFASO intervention, there are still several challenges ahead. The first challenge is to further increase the uptake of the technology not only in Ouagadougou and Bobo-Dioulasso but also in rural areas. The dissemination in rural areas will be more difficult, as firewood is typically collected and not bought; hence the households can pay the ICS from monetary firewood savings. In urban areas, further uptake will of course also depend on the price of LPG. Many households already use LPG as cooking fuel. If Burkina Faso follows a butanisation strategy as pursued by Senegal in the past, LPG use will probably increase in the near future and hence the market for woodfuel stoves will shrink. From a clean fuels perspective, though, this would of course be a desired development. The second challenge is maintaining quality. Past stove programmes mainly failed because they could not maintain the higher quality compared to traditional metal stoves. So far, the quality assurance strongly depends on the FAFASO activities. Yet, FAFASO envisages institutionalizing this quality assurance task at the local research institute IRSAT.

8. References

Bago D'Uva T., E. v. Doorslaer, M. Lindeboom and O. O'Donnell (2008), Does Reporting Heterogeneity Bias the Measurement of Health Disparities? *Health Economics*, 17 (3): 351–375.

Barnes D.F., K. Openshaw, K. Smith, and R. van der Plas (1994), What Makes People Cook with Improved Biomass Stoves? A Comparative International Review of Stove Programs. *World Bank Technical Paper* No. 242.

Bensch G. and J. Peters (2012), A Recipe for Success? Impact Evidence from a Field Experiment on Improved Stoves in Senegal. *Ruhr Economic Papers* #325. RWI, Essen.

Bensch G. and J. Peters (2013), Alleviating Deforestation Pressures? Impacts of Improved Stove Dissemination on Charcoal Consumption in Urban Senegal, *Land Economics,* forthcoming.

Blackden M. and Q. Wodon (2006), Gender, Time Use, and Poverty in Sub-Saharan Africa. World Bank Working Paper No. 73, World Bank, Washington D.C.

Bonfrer I., E. van der Poel., M. Grimm and E. van Doorslaers (2012), Does health care utilisation match needs in Africa. *iBMG Working Paper* #2012.02, iBMG, Erasmus University of Rotterdam.

Briceno-Garmendia C. and C. Dominguez-Torres (2011), Burkina Faso's Infrastructure. A Continental Perspective. World Bank Policy Research Working Paper #5818, World Bank, Washington D.C.

Brunell T.L. and J. DiNardo (2004), A Propensity Score Reweighting Approach to Estimating the Partisan Effects of Full Turnout in American Presidential Elections. *Political Analysis*, 12 (1): 28-45.

Burwen J. and D. I. Levine (2012), A rapid assessment randomized controlled trial of improved cookstoves in rural Ghana. *Energy for Sustainable Development*, 16 (3): 328-338.

Cameron A.C. and P.K. Trivedi (2005), *Microeconoetrics: Methods and Applications*. Cambridge University Press, New York May 2005.

Clancy J., T. Winther, M. Matinga and S. Oparaocha (2013), Gender Equity in Access to and Benefits from Modern Energy and Improved Energy Technologies. World Development Report Background Paper. World Bank, Washington D.C.

Diaz E., T. Smith-Sivertsen, D. Pope, R.T. Lie, A. Diaz, J. McCracken, B. Arana, K.R. Smith and N. Bruce (2007), Eye discomfort, headache and back pain among Mayan Guatemalan women taking part in a randomized stove intervention trial, *Journal of Epidemiology and Community Health*, 61 (1): 74-79.

Duflo E., M. Greenstone and R. Hanna (2008), Indoor air pollution, health and economic well-being, *S.A.P.I.EN.S*. [http://sapiens.revues.org/130]

European Commission (2009), Evaluating Socio Economic Development, Sourcebook 2: Methods & Techniques. Propensity score matching. http://ec.europa.eu/regional_policy/sources/docgener/evaluation/evalsed/sourcebooks/method_techniques/counterfactual_impact_evaluation/propensity/propensity_details_en.htm

FAFASO (2007), Energising Development. Final Technical Report. July. GIZ Burkina Faso.

Filmer D. and L. Pritchett (2001), Estimating Wealth Effects Without Expenditure Data –Or Tears: An Application to Educational Enrollments in States of India, *Demography*, 38 (1): 115-132.

Filmer D. and L. Pritchett (1999), The Effect of Household Wealth on Educational Attainment: Evidence from 35 countries, Population and Development Review, 25 (1): 85-120.

Freedman D.A. and R.A. Berk (2008), Weighting Regressions by Propensity Scores. *Evaluation Review*, 32 (4): 392-409.

Grenier L. (1998), Working with indigenous knowledge: a guide for researchers. Canada: International Development Research Centre.

Grimm M., G. Bensch, K. Peter, J. Peters and L. Tasciotti (2011), The Provision of Solar Energy to Rural Households through a Fee-for-service System. Baseline Report. Report for the Operations Evaluation Department (IOB) of the Netherlands Ministry of Foreign Affairs.

Hanna R., E. Duflo and M. Greenstone (2012), Up in Smoke: the Influence of Household Behavior on the Long-run Impact of Improved Cooking Stoves. *Massachusetts Institute of Technology Department of Economics Working Paper* 12-10. Boston, MA.

Herring H., S. Sorrell and D. Elliott (2009), *Energy Efficiency and Sustainable Consumption – The Rebound Effect*. Palgrave Macmillan, New York, USA.

Hirano K. and G.W. Imbens (2001), Estimation of Causal Effects using Propensity Score Weighting: An Application to Data on right Heart Catheterization. *Health Services and Outcomes Research Methodology*, 2: 259-278.

Hirano K., G.W. Imbens and G. Ridder (2003), Efficient Estimation of Average Treatment Effects Using the Estimated Propensity Score. *Econometrica*, 71(4): 1161-1189.

Hosgood H.D., P. Boffetta, S. Greenland, Y.A. Lee, J. McLaughlin, A. Seow, E.J. Duell, A.S. Andrew, D. Zaridze, N. Szeszenia-Dabrowska, P. Rudnai, J. Lissowska, E. Fabiánová, D. Mates, V. Bencko, L. Foretova, V. Janout, H. Morgenstern, N. Rothman, R.J. Hung, P. Brennan and Q. Lan (2010), In-Home Coal and Wood Use and Lung Cancer Risk: A Pooled Analysis of the International Lung Cancer Consortium. *Environmental Health Perspectives,* 118: 1743–1747.

International Energy Agency, IEA (2011), World Energy Outlook, 2011. International Energy Agency, Paris.

Lindeboom M. and E. Van Doorslaer (2004), Cut-point shift and index shift in self-reported health. *Journal of Health Economics*, 23, 1083-1099.

Martin II W.J., R.I. Glass, J.M. Balbus and F.S. Collins (2011), A major environmental cause of death, *Science*, 334, 180-181.

Masera O., R. Edwards, C.A. Arnez, V. Berrueta, M. Johnson, L.R. Bracho, H. Riojas-Rodriguez and K.R. Smith (2007), Impact of "Patsari" improved cookstoves on Indoor Air Quality in Michoacán, Mexico, GIRA's *Energy for Sustainable Development*, 6 (2): 45-56.

Ministère de l’Economie et des Finances (2009a), Recensement général de la Population et de l’Habitation (RGPH) de 2006 – Thèmes 10 : Ménages et Habitations, *Institut National de la Statistique et de la Démographie*, Burkina Faso.

Ministère de l’Economie et des Finances (2009b), Recensement général de la Population et de l’Habitation (RGPH) de 2006 – Monographie de la Commune Urbaine de Ouagadougou, *Institut National de la Statistique et de la Démographie*, Burkina Faso.

Ministère de l'Environnement et du Cadre de Vie (2004), Note d'Information sur la Filière Bois – Énergie au Burkina Faso - Direction des Aménagement Forestiers.

Ministère de Mines des Carrières et de L’Energie (2007), Vision 2020. De l’accès aux services énergétiques modernes.

Ministry of Foreign Affairs (2009), Terms of reference impact evaluation of Energy and Development Cooperation by the Netherlands. Ministry of Foreign Affairs, The Netherlands.

Owsianowski J.V. and P. Barry (2008), Improved cooking stoves for developing countries, unpublished paper. [http://mepred.eu/_docs/Improved_stoves-V2.5.I.26.pdf]

Pattanayak S., and A. Pfaff (2009), Behavior, Environment, and Health in Developing Countries: Evaluation and Valuation. *Annual Review of Resource Economics*, 1: 183–217.

Pitt M.M., M.R. Rosenzweig and N. Hassan (2006), Sharing the Burden of Disease: Gender, the Household Division of Labor and the Health Effects of Indoor Air Pollution. Mimeo. Brown University, Harvard University, Dhaka University.

Posner M.A. and A.S. Ash (2012), Comparing Weighting Methods in Propensity Score Analysis. Mimeo, Villanova University.

Rehfuess E. (2006), Fuel for Life: Household Energy and Health. World Health Organisation (WHO), Geneva.

Sagnon L.C. and S.P. Sawodogo (2009), Recensement General de la Population et de l’Habitation 2006. Analyse des Résultats Definitifs. Theme 10 : Ménages et Habitation. INSD, Burkina Faso.

Sahn D.E. and D.C. Stifel (2003), Exploring Alternative Measures of Welfare in the Absence of Expenditure Data, *Review of Income and Wealth*, 49 (4): 463-489.

Sahn D.E. and D.C. Stifel (2000), Poverty Comparisons over Time and Across Countries in Africa, *World Development*, 28 (12): 2123-2155.

Salomon J., C. Mathers, S. Chatterji, R. Sadana, T. Üstün, and C. Murray (2003), Quantifying individual levels of health: Definitions, concepts, and measurement issues. In C. Murray, & D. Evans (Eds.), *Health systems performance assessment: Debates, methods and empiricism*. Geneva: World Health Organization.

Schmidt C.M. and B. Augurzky (2001), The Propensity Score: A Means to An End. *IZA Discussion Paper Series*, 271.

Smith K.R., J.P. McCracken, M.W. Weber, A. Hubbard, A. Jenny, L. M. Thompson, J. Balmes, A. Diaz, B. Arana, N. Bruce (2011), Effect of reduction in household air pollution on childhood pneumonia in Guatemala (RESPIRE): a randomized controlled trial. *Lancet*, 378: 1717–26.

Smith K.R., J.M. Samet, I. Romieu and Nigel Bruce (2000), Indoor air pollution in developing countries and acute lower respiratory infections in children. *Thorax,* 55: 518–532.

Smith K.R. and J.L. Peel (2010), Mind the Gap, *Environmental Health Perspectives,* 118: 1643–1645.

Smith-Sivertsen T., E. Díaz, N. Bruce, A. Díaz, A. Khalakdina, M.A. Schei, J. McCracken, B. Arana, R. Klein, L. Thompson and K.R. Smith (2004), Reducing indoor air pollution with a randomised intervention design: A presentation of the Stove Intervention Study in the Guatemalan Highlands. *Norsk Epidemiologi,* 14 (2): 137-143.

Smith-Sivertsen T., E. Díaz, D. Pope, R.T. Lie, A. Diaz, J. McCracken, P. Bakke, B. Arana, K.R. Smith and N. Bruce (2009), Effect of Reducing Indoor Air Pollution on Women's Respiratory Symptoms and Lung Function: The RESPIRE Randomized Trial, Guatemala. *American Journal of Epidemiology*, 170: 211-220.

United Nations Development Program, UNDP (2011), Human Development Report 2011. Sustainability and Equity: A better future for all. UNDP, New York.

Wethe J. (2009), Energy Systems: Vulnerability – Adaptation – Resilience (VAR). Burkina Faso. Helio International, Paris.

World Bank (2011), Household Cookstoves, Environment, Health, and Climate Change. A New Look on an Old Problem. Washington, USA.

World Health Organization, WHO (2002), Addressing the Links between Indoor Air Pollution, Household Energy and Human Health. Based on the WHO-USAID Global Consultation on the Health Impact of Indoor Air Pollution and Household Energy in Developing Countries (Meeting report), Washington, DC, 3-4 May 2000.

World Health Organization, WHO (2006), Fuel for Life: household energy and health, World Health Organization. Geneva.

World Health Organization, WHO (2009a), Global health risks – Mortality and burden of disease attributable to selected major risks. Geneva, Switzerland.

World Health Organization, WHO (2009b), Country profile of Environmental Burden of Disease – Burkina Faso. Geneva, Switzerland.

Yameogo G. (2005), Etablissement de la Situation de Référence pour la Production et la Diffusion à grande Échelle des Foyers Améliorés au Burkina Faso.

Yu F. (2011), Indoor Air Pollution and Children's Health: Net Benefits from Stove and Behavioral Interventions in Rural China. *Environmental and Resource Economics*, 50 (4): 495-514.

Annexes

Annex 1: Stove types in Burkina Faso

Traditional cooking stoves		
1.a Three-stones 	1.b improved three-stones 	2. LPG stove 
3. Traditional metal stove/ "Malagasy" (charcoal) 	4. Traditional metal stove/ "Malagasy" (firewood) 	

FAFASO Improved cooking stoves („Roumdé")				
	Ouaga Métallique	Burkina Mixte	Multimarmite	Céramique
				
Material	Metal	Metal	Metal	Clay
Fuel	Firewood	Firewood or charcoal	Firewood or charcoal	Firewood
Price	1500 CFA (size 2) 2000 CFA (size 3) 2500 CFA (size 4)	1500 CFA (size 2) 2000 CFA (size 3) 2500 CFA (size 4)	2000 CFA 2500 CFA (Malian model)	750 CFA

Source: Own illustration. Photos FAFASO.

Annex 2: Roumdé logo

Annex 3: Weighting by Propensity Scores (matching)

As it has been discussed in Section 3.2, a major problem of the impact evaluation that needs to be overcome is non-random-selection into the treatment group, i.e. the users of ICS may systematically differ along a number of characteristics from non-ICS users and these characteristics might be correlated with the outcomes of interest. Hence, there is a risk to attribute effects to the use of an ICS which in reality are due to the differences in characteristics in both groups. The straightforward solution to redress at least the bias that stems from observable differences is to control for these differences in the regressions that relate outcomes and treatment. A superior method in terms of the precision of the impact estimates is to apply 'propensity score matching (PSM)'.[25] The matching estimator ensures that the comparison is limited to very homogenous groups, i.e. groups of observations that are equally likely – or have the same propensity – based on observable characteristics to own a stove. Put differently, it is assumed that the ICS owners that are observed would behave – in case they would not own an ICS – in the same way as the matched non-owners to which they are compared.

PSM is based on an econometric regression model where the decision to use a stove is regressed on the observables that potentially affect both the decision to use a stove and the outcome variables (see Schmidt and Augurzky, 2001). The thereby estimated probability of using a stove given the observable characteristics represents the propensity score. The treatment and control households are then solely matched on this propensity score. This reduces the matching from a multi-dimensional problem (where the number of dimensions depends on the number of available variables) to a one-dimensional problem.

The fundamental assumption for the validity of this matching approach is that, when observable characteristics are balanced between the two groups, the two groups are balanced with respect to all the characteristics relevant for the outcome. The larger the number of available pre-intervention characteristics, the higher the chance that this assumption holds true. For the project evaluated in this report, no pre-intervention data is

[25] Besides PSM, the literature proposes a number of other matching estimators (see e.g. Cameron and Trivedi 2009).

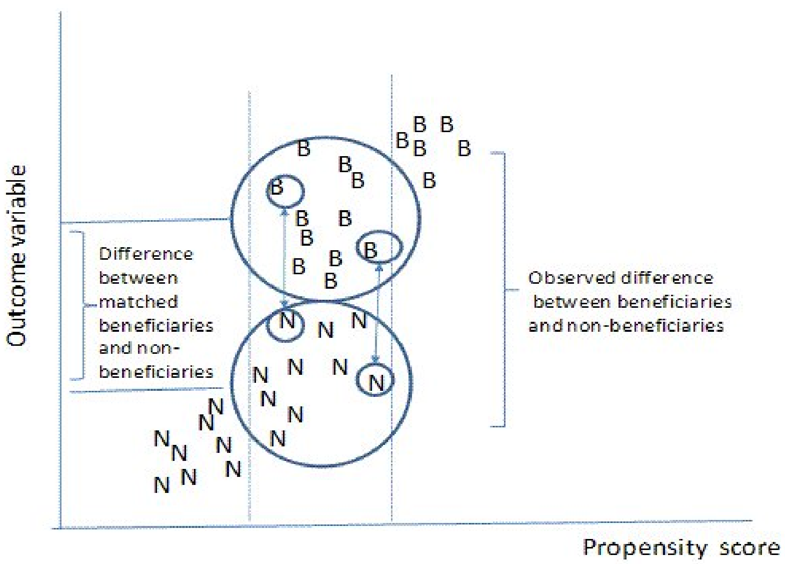
available. However, there are some characteristics that can be considered as non-responsive to the treatment and therefore serve for the purpose.

The figure below provides an intuitive graphical representation of the matching method. The “N” represents a sample of non-treated controls, while the “B” represents beneficiaries/ treated individuals. The two dimensions of the graph are the outcome and the propensity score. In this stylized example, two matches are indicated with two small circles connected by an arrow. They are matched due to similar propensity score values. The same holds for all individuals in the larger circles, while those “N” and “B” outside the circles do not find a suitable match and are therefore not considered. The figure also shows that the difference between the means of matched treated and control individuals can be substantially different from the difference between the means of all treated and control individuals.

Given that in the present case the impact assessment needs to be done separately for firewood and charcoal users and for different types of stoves (three-stone, Malagasy etc.) the standard matching approach is not feasible as the number of cases in the various treatment and control groups would be too small.

In this case it is better to rely on a special variant of the matching approach, proposed by Hirano, Imbens and Ridder (2003) and further discussed in Hirano and Imbens (2001) in which the inverse of the propensity score is used to weight each observation in the treated group, and the inverse of one minus the propensity score (i.e. the propensity of not being in the treated group) in the control (see Hirano and Imbens, 2001; Posner and Ash, 2012). This formula is used to determine the average treatment effect, whereas Brunell and DiNardo (2004) provide an extension thereof for the treatment effect on the treated (see below), which will be used in this study. Weighting has the nice property of including all the available data and does not depend on random sampling. The risk is, as shown by Freedman and Berk (2008) that weighting may increase random error in the estimates, and bias the estimated standard errors downward, even if the selection mechanism is well understood.

Figure A8: Graphical representation of matching on propensity score



Source: European Commission (2009).

The implementation of the procedure involved the following steps. First a probit model of being an ICS user has been estimated:

$$\Pr_i(T_i = 1) = \theta(\beta_0 + X_{il}^{'}\beta_l + \omega_i), \quad \text{(A1)}$$

where the dependent variable is the binary outcome of an individual household *i* having an ICS. The underlying latent variable is the conditional probability of having an ICS. The matrix stands for a set of observable household characteristics *X* explaining stove ownership and the vector *ß* are the associated effects that are estimated. ω stands for the error term and *ϑ* stands for the cumulative standard normal distribution function, i.e. the underlying probability distribution in a probit model.

Formally, the propensity score is defined as

$$e_i(x_i) = \Pr_i(T_i = 1 | X_{il}) \quad \text{with} \quad 0 < e_i(x_i) < 1.$$

To attain the average treatment effect on the treated, weights can be computed from these propensity scores as outlined in Brunell and DiNardo (2004) for both treatment and control observations, denominated $\mu_i^{T=1}$ and μ^C respectively:

$$\mu_i^{T=1} = 1 \text{ and } \mu^C = \frac{Pr(T=1|X)}{1 - Pr(T=1|X)} \times \frac{p^C}{p^T},$$

where p^T to the fraction of treatment observations and p^C to the fraction of control observations. The Table below shows the differences in the household characteristics used to estimate the probit model above before and after reweighting. It can be seen that the reweighing procedure leads to an almost perfect balance; none of the differences between the group of owners and non-owners is statistically significant anymore.

Table A8: Test of balancing property of matching procedure

	ICS owners	ICS non-owners: Not weighted	ICS non-owners: Weighted by propensity score based weights	Difference before weighting
Adult Equivalents meal is cooked for	5.529	5.733	5.539	
Squared Adult Equivalents meal is cooked for	38.812	41.663	38.976	
Household head female	0.185	0.154	0.190	
Household has bank account	0.464	0.348	0.469	***
Floor is soil	0.151	0.218	0.152	***
HH has electricity	0.800	0.660	0.801	***
Ouagadougou	0.776	0.775	0.774	
Simultaneous LPG use (yes=2, no=1)	1.387	1.419	1.398	

Note: As indicated by the asterisks, there are three covariates that are significantly different before weighting (at 1 percent level) whereas these differences disappear after weighting. Values for ICS owners are identical before and after weighting as a weight of 1 is assigned to these observations.

Whenever it is referred to propensity score weighting in the assessment, observations have been weighted following this procedure. This approach is seen as a robustness check; the results without weighting are also always shown.

Annex 4: Selection of sectors

	Ouagadougou					Bobo-Dioulasso			
	#	Share	# to be drawn	Sectors drawn		#	Share	# to be drawn	Sectors drawn
Poor	0	0	-	-		6	0.26	2	**2, 20**
Average/middle-class	11	0.44	4	**7, 10, 17, 27**		8	0.30	3	**10, 8, 12**
Average/rich	3	0.12	1	**8**		3	0.13	1	**16**
Mixed	8	0.32	3	**21, 23, 24**		4	0.17	1	**15**
Mixed wealthy	3	0.12	1	**29**		1	0.04	-	*none*
Wealthy	0	0	-	-		2	0.09	1	**25**
Total	**25**					**24**			
Non-allotted	na	na	1	na		na	na	1	na
Not eligible	5	na	0	*none*		0	na	0	-
Total # to be drawn			10	9 + 1 non-allotted				9	8 + 1 non-allotted

Note: na = not applicable
Source: own illustration

Annex 5: Calculations for the number of oversampling households

Penetration rate	pre-oversampling sample size in Ouagadougou	pre-oversampling sample size in Bobo-Dioulasso	total pre-oversampling sample size	owners (replaced)	total sample size
5%	880 (88 in 10 sectors each)	270 (30 in 9 sectors each)	1150	361	1511
10%				346	1496
15%				331	1481
20%				316	1466

Source: Own calculations

Annex 6: Study timeline

Pre-Departure Preparation of the Studies	*until January, 2011*
Desk Study of relevant project documents and literature; adaptation of existing survey methodology; questionnaire design in French; Excel matrix for data entry; coordination with local partner BEGE	
In-Country Preparation of the Studies (RWI/ISS Mission – Solar Home Systems and Improved Stove Study)	*October 2010-March, 2011*
October 10th to 24th 2010 ▪ Coordination with local partner BEGE, project staff and national partners concerning both Solar Home Systems (Yeelen Ba) and Improved Stove (FAFASO) study; ▪ Field trips to stove producers and sellers; December 6th to 10th 2010 ▪ Pre-test with 4 respectively 2 interviewers in Bobo-Dioulasso and Ouagadougou; ▪ Revision of the questionnaire; January 16th to 23rd 2011 ▪ Design details of the study; ▪ Choice on survey sites and planning of survey organisation and logistics with the assistance of the supervisors and project staff; ▪ Training in Ouagadougou of a survey team (including two survey supervisors, enumerators and operators for the data) for the survey including a pre-test of the questionnaire; ▪ Final review of questionnaire and survey organisation and logistics; March 8th to 10th 2011 ▪ Training of the enumerators of the survey in Bobo-Dioulasso including a pre-test of the questionnaire.	
Realization of the FAFASO Survey	February to March, 2011
February 1st to March 3rd 2011 Survey implementation of the Improved Stove Study in Ouagadougou by RWI research assistant and enumerators March 11th to March 22nd 2011 Survey implementation of the Improved Stove Study in Bobo-Dioulasso by RWI research assistant and enumerators	
Data Compilation	*February to April, 2011*
Data entry by operators for the data	

Source: own illustration

Annex 7: Differences between ICS and imitated ICS

ICS Roumdé	***Imitated ICS***
Matériel	
de bonne qualité  	de basse qualité  
Taille	
Plus grand 	Moins grand 
orifices d'échappement d'air	
grands; seulement situé en bas 	petits; aussi situé plus haut 
Troues dans la grille en tôle	
symétrique 	asymétrique 
Autres	
• La position de marmite • Pieds	• Porte manquant (type Multimarmite Burkina) • Souvent plus petit que le vrai Roumdé

Source: Own illustration.

Annex 8: Probit models estimating the impacts of ICS usage on health indicators for the person responsible for cooking

	Respiratory system disease			Eye infection		
	households using only firewood	households using only firewood and/or charcoal		households using only firewood	households using only firewood and/or charcoal	
		all households	lower three quintiles		all households	lower three quintiles
	(1)	(2)	(3)	(4)	(5)	(6)
	Basic OLS	Basic OLS	Basic OLS	Basic OLS	Basic OLS	Basic OLS
Most often used stove						
Non-ICS	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
ICS	0.680	0.731***	0.631*	0.119	0.305	0.320
	(0.446)	(0.271)	(0.343)	(0.383)	(0.226)	(0.277)
ICS and non-ICS	.	0.661	0.236	.	-0.176	0.208
		(0.476)	(0.476)		(0.520)	(0.550)
LPG	.	1.825**	.	.	1.250	.
		(0.841)			(0.773)	
Household only uses charcoal		-0.553	-0.157		-0.922***	-1.019***
		(0.404)	(0.395)		(0.226)	(0.297)
Ln number of usages of woodfuels per week	-0.023	-0.011	0.095	0.342	-0.130	-0.173
	(0.355)	(0.245)	(0.327)	(0.308)	(0.194)	(0.238)
Outdoor cooking	0.865*	0.904***	.	-0.269	-0.184	-0.182
	(0.452)	(0.333)		(0.358)	(0.240)	(0.282)
AE meal is cooked for	-0.044	-0.007	-0.187	-0.118	-0.062	-0.180
	(0.154)	(0.111)	(0.157)	(0.125)	(0.085)	(0.121)
AE meal is cooked for squared	0.003	0.003	0.010	0.003	0.003	0.005
	(0.007)	(0.005)	(0.007)	(0.006)	(0.005)	(0.006)
Cooking person's age	-0.014	0.005	0.008	0.008	0.016***	0.015*
	(0.012)	(0.009)	(0.011)	(0.009)	(0.006)	(0.008)
Cooking person has secondary education	0.622*	0.425*	0.556*	-0.121	-0.076	0.082
	(0.330)	(0.225)	(0.331)	(0.329)	(0.203)	(0.297)
Household head secondary education	0.301	0.405*	0.232	0.083	0.340	-0.203
	(0.509)	(0.238)	(0.349)	(0.335)	(0.252)	(0.341)
Household head female	0.665*	0.530**	0.405	-0.207	0.153	0.249
	(0.347)	(0.234)	(0.273)	(0.362)	(0.236)	(0.266)
Household has bank account	.	-0.557*	-1.388***	-0.254	-0.171	-0.133
		(0.301)	(0.486)	(0.306)	(0.275)	(0.327)
Floor is soil	-0.631**	-0.635**	-0.403	-1.561***	-1.305***	-1.487***
	(0.315)	(0.267)	(0.266)	(0.358)	(0.274)	(0.344)
HH has electricity	-0.538	-0.395	-0.735	-0.003	-0.209	-0.105
	(0.401)	(0.311)	(0.467)	(0.363)	(0.260)	(0.285)
Ouagadougou	0.243	0.462	0.351	1.099**	0.291	0.335
	(0.451)	(0.287)	(0.376)	(0.427)	(0.248)	(0.265)
Ln total monthly household expenditure	0.662***	0.247	0.799**	0.371*	0.441**	0.497*
	(0.191)	(0.159)	(0.355)	(0.225)	(0.179)	(0.291)
Constant	-9.596***	-6.105***	-10.752***	-6.715**	-6.496***	-6.274**
	(2.076)	(1.581)	(3.377)	(2.727)	(2.049)	(2.753)
Number of households	240	655	407	292	655	486
Pseudo R-squared	0.1921	0.1865	0.1992	0.1748	0.1551	0.1351

Note: Outputs of PSM weighted regressions are not displayed, since probit models cannot be implemented using this approach.