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Reducing Pollution from Cooking Smoke: key lessons from the REDGAS randomized study in Burkina Faso

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ÉDITIONS AFD AGENCE FRANÇAISE DE DÉVELOPPEMENT

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Editorial

By the AFD Energies Division (EGI)

Access to energy is a core aspect of AFD's energy transition strategy. Although we are seeing a gradual improvement in access to electricity, estimated to affect 750 million people worldwide, the transition to clean and efficient cooking remains a major challenge. Every day, 2.3 billion people, mainly in sub-Saharan Africa and South Asia, still cook over open fires or with basic stoves that burn biomass (wood, charcoal, agricultural residues, etc.). This dependence leads to dramatic impact on health and mortality, particularly for women and children, who are exposed to harmful smoke, causing over 3 million premature deaths every year. The urgent need for action to achieve universal access to clean and efficient cooking is simultaneously an issue of health and gender. It is also linked to the fight against climate change and the preservation of natural resources. In fact, the use of traditional stoves for cooking is responsible for almost 2.5% of global greenhouse gas emissions, due to emissions from burning wood and to deforestation.

The international community is mobilizing to tackle these challenges. An international summit dedicated to clean cooking took place on May 14, 2024, in Paris. This came about following the publication by the International Energy Agency (IEA) of a report proposing a trajectory to achieve universal access to clean cooking by 2030, which would require an investment of $7 billion a year, including $4 billion for Africa. The event brought together high-level leaders from African countries and from industry and finance. It led to many commitments, including a pledge of $2.2 billion in investment in the clean and efficient cooking sector.

France has announced its contribution to this process: €100 million over five years, implemented by AFD Group, as well as the mobilization of the Finance in Common networks to accelerate the transition. To this end, and with our "100% SDG" and "by our partners' side" ambitions, AFD has developed an action plan that sets out the principles guiding the identification and implementation of projects in the coming years, including those on clean and efficient cooking.

This evaluation of the REDGAS project, aimed at reducing pollution from cooking smoke in Burkina Faso, comes at just the right time to inform our future operations by providing several lessons learned. First of all, the evaluation confirms that "stacking", which consists of combining various cooking methods, both traditional and clean, is a common practice. In addition, while the affordability of clean and efficient cooking solutions remains an obstacle, changes in habits are not immediate and take time, so biomass will remain a transitional solution for meal preparation. If AFD's commitment is to be fully effective, it must therefore be accompanied by sustainable natural resource management projects.

Thus, the evaluation results clearly indicate the **complexity of interventions in the field of clean and efficient cooking.** The use of financing alone to subsidize or facilitate the purchase of clean and efficient cooking solutions will never be enough to meet all the challenges of a subject that is intimately linked to the cultural codes of the countries and regions concerned. Achieving universal access will require **a holistic and user-centric approach, an understanding of users' practices and needs, and the inevitable patience needed to support the transition** to clean and efficient cooking.

Summary

This report presents the main results of the REDGAS study, a scientific evaluation of the impact of access to cooking gas on household behavior, on their exposure to domestic air pollution and on the associated health risks. The evaluation focused on the system implemented in Burkina Faso to facilitate access to gas cooking, by the social enterprise Nafa Naana and the NGO Entrepreneurs du Monde, with financial support from Agence Française de Développement. It is based on a randomized controlled trial in which 805 urban households were randomly assigned to a "credit" group, a "subsidy" group and a control group. Households in the first two groups received an offer to purchase a kit for cooking with gas from a retailer in their town. They could buy it either at a promotional price ("subsidy" group) or at the market price with the option of paying in three installments ("credit" group). We studied the effect these purchase subsidies and consumer loans had on the adoption of gas cooking and on the intensity of its use over the six-month period following the expiry date of the offers. Measurement took place via optical sensors installed on the cooking kits. We also estimated the effect of this intervention on i) household wood consumption; ii) average daily exposure to fine particles ($PM_{2.5}$), and iii) an objective health indicator: arterial hypertension among persons in charge of meal preparation.

The credit and subsidized offers increased the share of households equipped with a gas-cooking kit by 28 and 54 percentage points respectively. This result suggests that budget constraints as well as lack of access to credit had previously acted as an obstacle to strong household demand for gas cooking. On the other hand, even though the gas-cooking kits were used regularly by half the households that had purchased them, we did not find any effect from the increase in gas use on exposure to air pollution or on our main objective health indicator of high blood pressure among meal preparers. In fact, there was no drop in wood consumption among the groups that were assigned to the purchase offers, and total energy consumption among these households increased by around 15% compared to the control group. Gas therefore seemed to be used as a complementary energy source rather than as a substitute for wood, and the report points out an increase in the total number of hot meals consumed per day in the groups benefiting from the offers. We interpret the lack of reduction in wood consumption as the main explanation for the zero effect of the interventions on household exposure to fine particles. Our heterogeneity analyses nevertheless suggest that the interventions led to a slight decrease in fine-particle exposure among households that, prior to the intervention, used purchased wood (rather than collected wood) to cook their meals.

From this we conclude that purchase and use of gas-cooking kits do not guarantee that gas will replace wood use, and therefore do not automatically lead to health effects. The method of collection and hence the cost of wood prior to the intervention were therefore probably significant determinants of the success of the interventions. This suggests that financial incentives to adopt gas-cooking equipment could have a greater impact in urban areas, where wood is harder to collect. In particular, this finding could motivate similar evaluations to be carried out in situations where the proportion of households collecting their own fuel is low, in order to supplement the knowledge generated by the REDGAS study.

Box 1 – Impact evaluation at AFD

An impact evaluation focuses on questions relating to the effects of an intervention, namely, to what extent has the intervention really made a difference? How has the project contributed to the changes observed in the people and ecosystems under study? What mechanisms explain the effects? AFD Group finances and carries out impact evaluations of its projects, not only to provide accountability, but also to learn how to improve AFD's activities in terms of project management, dialog, and partner capacity building. AFD is therefore fully committed to diversifying impact evaluation approaches (e.g., counterfactual evaluations, contribution analysis, case studies, etc.) and methods (e.g., quantitative, qualitative, mixed).

This study was funded through the AFD-IRD partnership mobilizing research to conduct impact evaluations in the global south (PAIRES) which seeks to identify and implement a series of impact evaluations with counterfactuals on interventions supported by Agence Française de Développement (AFD), along with the expertise, networks and action capacities of the French National Research Institute for Sustainable Development (IRD).

Introduction

In 2021, one third of the world's population (approximately 2.3 billion people), relied on solid fuels such as wood or charcoal to cook their food (International Energy Agency, International Renewable Energy Agency, United Nations Statistics Division, World Bank, World Health Organization. 2022). The use of this type of fuel is linked to a range of sustainable development issues, including deforestation, climate change, women's time use, child labor, and public health (Putti *et al.*, 2015). The most recent edition of the "Global Burden of Disease" study (2021) shows the extent to which indoor air pollution from wood and charcoal combustion is a major public health issue. It was reportedly responsible for about 2.3 million deaths worldwide in 2019 (Bennitt *et al.*, 2021). This is one of the main reasons why the transition to less polluting cooking solutions is high on the agenda of development assistance policies. Up to now, the international effort in this area has largely consisted of promoting the use of energy-efficient biomass stoves that, although more economical, still use solid fuels. Unfortunately, the impacts of this type of intervention have proved disappointing in terms of air pollution exposure and health (Hanna, Duflo and Greenstone, 2016; Mortimer *et al.*, 2017; Berkouwer and Dean, 2022).

This partly explains why the efforts of governments and multilateral agencies have gradually turned to strategies to encourage households to switch from solid fuels to more modern technologies, in particular gas and electricity, whose use in principle releases fewer pollutants harmful to health. Large-scale subsidy programs based on social criteria have thus emerged in India, Indonesia, and Peru over the past two decades, to encourage people to adopt gas cooking (Imelda, 2020; Afridi, Debnath and Somanathan, 2021; Thivillon, 2022). Despite questions related to the fossil origin of gas, support by governments is backed up at the worldwide level by the international organization Sustainable Energy for All, founded by Ban Ki-moon when he was Secretary-General of the United Nations. Sustainable Energy for All is committed to converting 1 billion people to gas cooking by 2030 (*Sustainable Energy for All*, 2013).

Despite this growing interest by public decision-makers, there is still limited scientific knowledge about the impact that the transition from wood or charcoal to cooking gas will have on people's health and well-being. REDGAS was a randomized experiment to evaluate a gas-access facilitation scheme inspired by that implemented in Burkina Faso by the non-governmental organization (NGO) Entrepreneurs du Monde and its local partner Nafa Naana. The experiment involved two types of interventions: a credit component and a subsidy component, both aimed at removing two barriers to use: the purchase price of gas stoves and the liquidity constraints faced by Burkinabe households. First, we examine the impact of these interventions on the adoption of cooking with gas as a replacement for cooking with wood. Then, we document the effects of the interventions on household exposure to air pollution and on an objective health indicator (the arterial hypertension of those in charge of meal preparation).

The report is structured as follows: Section 1 presents the background and context of the study and the interventions evaluated, Section 2 describes our evaluation method, and Section 3 details the main results. Analyses of the mechanisms and heterogeneity of the results are presented in Section 4. The study concludes with Section 5, which discusses the results.

1. Background to the study and presentation of the technology evaluated

1.1 Meal cooking and exposure to air pollution in Burkina Faso

In Burkina Faso, 82.8% of the population use wood as their main fuel for meal preparation. Only 13.4% have access to a relatively low-polluting cooking solution such as LPG (liquid petroleum gas in a bottle) or electricity. Air pollution is a significant issue for the country and its people. Modeling by the World Health Organization (WHO) based on satellite data puts the annual median concentration of fine particles in ambient air at 37 μg/m³ (micrograms per cubic meter) for the country. This figure is nearly seven times greater than the maximum recommended annual average exposure threshold (WHO, 2021). Recent in-situ domestic air-quality measurements in Ouagadougou show that the average 24-hour concentration in spaces used for cooking can exceed 100 μg/m³, particularly in households that rely on wood and use traditional "three-stone" stoves (Kafando *et al.*, 2019). This suggests that women and young children who spend a lot of time in or near kitchens are exposed to particularly high levels of fine particles. Finally, air pollution ranks second among the leading risk factors for death in Burkina Faso, and respiratory infections are the fourth leading direct cause of death in the Global Burden of Disease Survey estimates for the country (Institute for Health Metrics and Evaluation, 2024).

Box 2 – Knowledge production: a core aspect of the partnership between CSOs and AFD

Civil society organizations (CSOs) and AFD are working together to achieve the Sustainable Development Goals (SDGs). This partnership includes strategic and sectoral dialog, the funding of field projects, and knowledge production to assess the relevance of CSO interventions and the added value of the innovations they develop.

For example, Entrepreneurs du Monde was able to count on AFD's support when, in 2010, it founded the social enterprise Nafa Nanaa in Burkina Faso. The purpose of this initiative was to make energy-efficient products accessible to vulnerable people, to improve their living conditions and to preserve the environment. The CSO Partnership Division (MPN-OSC) co-financed Nafa Nanaa's development over the next 10 years or so through its mechanism for CSO initiatives until it became technically and financially autonomous.

The REDGAS study can be considered the culmination of this partnership, as it sheds much-needed light on the benefits and limitations of the gas-cooking solutions distributed by Nafa Nanaa and provides lessons for future joint intervention in the clean and efficient cooking sector. Initiatives such as the PAIRES program help support the rigorous measurement of the impact of certain interventions that are strategic or innovative for AFD.

It is likely that a significant proportion of the pollution to which Burkinabe households are exposed comes from the use of wood and charcoal as energy sources within their own homes. Shupler *et al.* (2018) propose a modeling of individual exposure levels to fine particles in the West African sub-region and show very significant differences in exposure depending on the main fuel used in the household. Using data collected prior to the conducting of the interventions, De Vreyer, Djemaï and Thivillon (2023) show a strong correlation between biomass consumption and exposure to fine particles in Burkina Faso.

Given the endogeneity of fuel choices, current literature on the subject does not make it possible to give a causal interpretation of these differences in pollution exposure. However, the differences do justify making the search for alternatives to woodfuel and charcoal a key aspect of air-quality improvement policies (see Box 2). The Burkinabe government was aware of this situation and in 2015 set itself the target of achieving an LPG use rate of 40% in urban areas and 10% in rural areas by 2025 (Ministry of Mines, Quarries and Energy, 2015). Until now, the emphasis has been on a universal subsidy for gas bottle refills, but there is no specific government scheme to help households finance the investment involved in acquiring gas-cooking equipment.

Box 3 – The expected health and social benefits from adoption of gas for cooking

From a health angle, the main advantage of gas cooking is its low emissions of aerosol pollutants, particularly fine particles less than 2.5 micrometers in size ($PM_{2.5}$), one of the most harmful categories of pollutants for health. A study commissioned by the United States Environmental Protection Agency concluded that LPG achieved WHO-recommended $PM_{2.5}$ emission levels in 90% of 89 laboratory tests conducted on five models of commercially available gas stoves (Shen *et al.*, 2018). On the other hand, gas combustion emits gaseous pollutants. In particular, it has a high emission rate of nitrogen dioxide, a powerful respiratory irritant (Lin, Brunekreef and Gehring, 2013; Kashtan *et al.*, 2024). The effects that the adoption of gas cooking has on exposure to this pollutant are poorly documented, as impact studies usually focus on aerosol pollutants. In addition to the health aspect, gas cooking is also very fast and convenient, especially because it is easy to light the flame. This suggests that gas cooking can provide time-saving benefits that cannot be achieved with biomass stoves, which are energy-efficient but have cooking times comparable to those of traditional methods.

1.2 Technology evaluated

The evaluation focuses on a single-burner gas cooker model widely used in West Africa. In Burkina Faso, this model is known as the “Télia” stove or kit. It can be described as a large gas stove, consisting of a 6-kg LPG cylinder, a burner screwed directly onto the cylinder without hose or regulator, and a locally-made pot stand installed on the burner (see Photo 1). It is designed to be used on the ground, in the courtyard or on the kitchen floor; in this it provides the same flexibility of use as most traditional charcoal stoves used by urban households. At the time when this evaluation was conducted, the retail price proposed by Nafa Naana (the study’s project partner) was 25,000 CFA francs (FCFA), or approximately €38. This price represented around 90% of the minimum monthly wage in Burkina Faso at the time. Gas refills for the 6-kg cylinders supplied with the Télia kit are subsidized by the Burkina Faso government to keep their price down to FCFA 2,000 (or €3, the current price in Ouagadougou). This price is subsidized at a rate of around 50%. The Télia kit is promoted by Nafa Naana because of its relatively affordable price compared to other LPG cooker models, but also because it is popular among Burkinabe households and well adapted to local cooking practices.

Photo 1 – The Télia kit

(a) Télia kit with a use monitor

(b) Downloading of data from the use monitor, via its remote control

Box 4 – Payback period and Return on Investment (ROI)

To understand the choices households make when it comes to purchasing Télia kits, it is useful to calculate the ROI they can expect from their eventual purchase. To determine the ROI, we used wood price estimates based on households' valuation of their wood stock during the baseline surveys. The average price of the wood obtained this way was FCFA 45 per kg. The regulated price of gas in the study area was, in principle, FCFA 375 per kg for 6-kg cylinders. We used a useful-energy equivalence of 89 g of gas per kg of wood based on default thermal efficiency values from Champion *et al.* (2021) and the net calorific values of wood and LPG reported in the 2006 Intergovernmental Panel on Climate Report (GIEC, 2006). These values are detailed in Section 4. For a daily consumption of 5.15 kg of wood, we estimate that households saved FCFA 1,800 per month if they had initially purchased 100% of their wood consumption and substituted it entirely with gas (5.15 x 30 x 45 – 5.15 x 0.089 x 30 x 375 = 1,796).

Theoretical payback periods and ROI rates are shown in Table 1. The payback period is 16 months for the credit offer. This means that, for a household that bought its wood before switching to gas, the savings generated by the gas-cooking kit cover the initial investment in the kit from the 16th month of exclusive use. Assuming that the burner (the main wearing part of the Télia kit) does not have to be replaced during the first two years of use, this gives an ROI of 51% at 24 months. In other words, after 24 months, the difference between the savings made thanks to the gas-cooking kit and the amount initially invested represents 51% of that amount. These calculations highlight the strong appeal of the subsidized offer, which reduces the kit's payback period by half and triples its ROI. However, these payback period and ROI figures must be viewed with caution, as in reality few of the households in the sample had purchased their wood prior to the intervention, and few of them adopted gas as their exclusive fuel after it. The ROI calculation presented here must therefore be understood foremost as an exercise to understand the implications of the different offers for a household having to decide between its theoretical ROI and its liquidity and credit constraints.

Table 1 – Payback and ROI of Télia kit offers

Offer	Purchase price (FCFA)	Payback (months)	Return on investment at 24 months
Credit	**28,500**	**15.9**	**51%**
Subsidy	**15,500**	**8.6**	**178%**

1.3 Activities evaluated

The REDGAS study evaluated Nafa Naana's system for facilitating access to gas. Nafa Naana is one of Burkina Faso's leading distributors of gas-cooking equipment. While most of its competitors are conventional businesses, Nafa Naana is a social enterprise. It was created by the NGO Entrepreneurs du Monde in 2012. As a social enterprise, it specifically targets low-income households that have more difficulty accessing gas cooking because of lack of last-mile distribution points, as well as because liquidity constraints make the Télia kit less affordable for them. Nafa Naana partners with retailers from local communities and village associations to establish new points of sale for its products. It has also developed a credit payment service that enables members of its partner village associations to purchase a Télia kit in three installments. An administrative fee of FCFA 3,500 (€5.30) is charged for this service. The purchaser generally pays 35% of the total due upon delivery of the product, 35% one month later and the final 30% after two months.

When the study was designed, Nafa Naana's management team estimated that its installment plan represented over 50% of its gas stove sales. However, this credit system only partially solves the problems of liquidity and credit constraints that can prevent households from purchasing equipment. Indeed, data on fuel prices collected during our surveys suggests that a household replacing all its wood consumption by gas can save at best FCFA 1,800 (€2.70) per month if it was initially buying all its wood rather than collecting it (see Box 4). This means that the savings generated by the Télia kit in the two months following purchase cover little more than the administrative costs invoiced for the sale by credit, and that the amount still to be amortized at the end of the credit period is equivalent to what the household would have had to pay for the equipment in cash. As a result, households choosing to use this payment facility have substantial savings or additional sources of credit at their disposal, and they take advantage of the extended payment period to mobilize them.

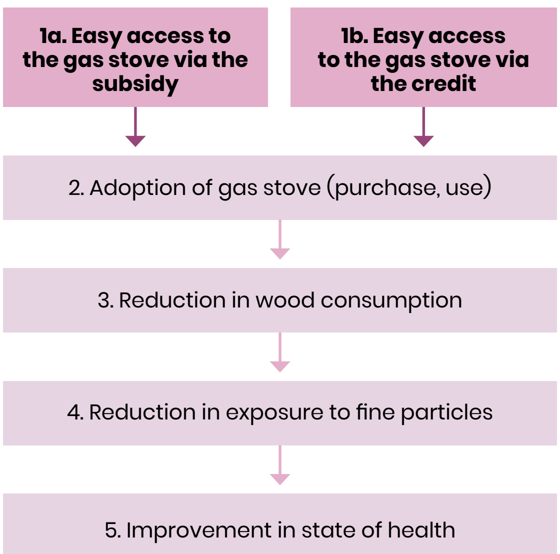
To reach a wider target (that includes households not having these types of financial resources) and to assess the effect of access to gas on these more vulnerable households, we chose to include a second offer in the study that is not part of Nafa Naana's commercial strategy. This offer, designed by the research team, consisted of offering the Télia kit through a cash purchase, but with a 38% subsidy, making for a price of FCFA 15,500 (€23.70). The subsidy covers the cost of the kit's wearing parts, i.e., the burner and the pot stand. The amount paid by the purchaser covers the deposit for the returnable gas bottle and the first gas refill contained in the bottle. The subsidy rate selected was chosen to avoid any risk of destabilizing the gas cylinder deposit system existing at the time in Burkina Faso, as a subsidy higher than 38% would effectively lower the amount of the security deposit. This type of partially subsidized offer is similar to those implemented on a large scale in other countries, notably India (Afridi, Debnath, and Somanathan, 2021).

2. Evaluation methodology

2.1 Theory of change

How can financial incentives for the purchase of a gas cooker help improve household health in Burkina Faso? Diagram 1 presents the theory of change, in which we put forth the hypothesis that facilitating the purchase of gas stoves through a subsidy or easier access to credit should enable households to reduce their wood consumption and thereby their exposure to the air pollution generated by its use as fuel.[5] It is based on several underlying assumptions: i) the price of the stove is a disincentive to its purchase, ii) the use of gas rather than wood or charcoal reduces exposure to fine particles, and iii) the ambient pollution to which the household is exposed and which is generated by households and businesses in its vicinity represents a relatively small proportion of its total exposure to atmospheric pollutants, including the pollution generated by the household itself.

Diagram 1 – Theory of change



[5] The experiment's protocol is described in more detail in the analysis plan: de Vreyer *et al.*, (2022).

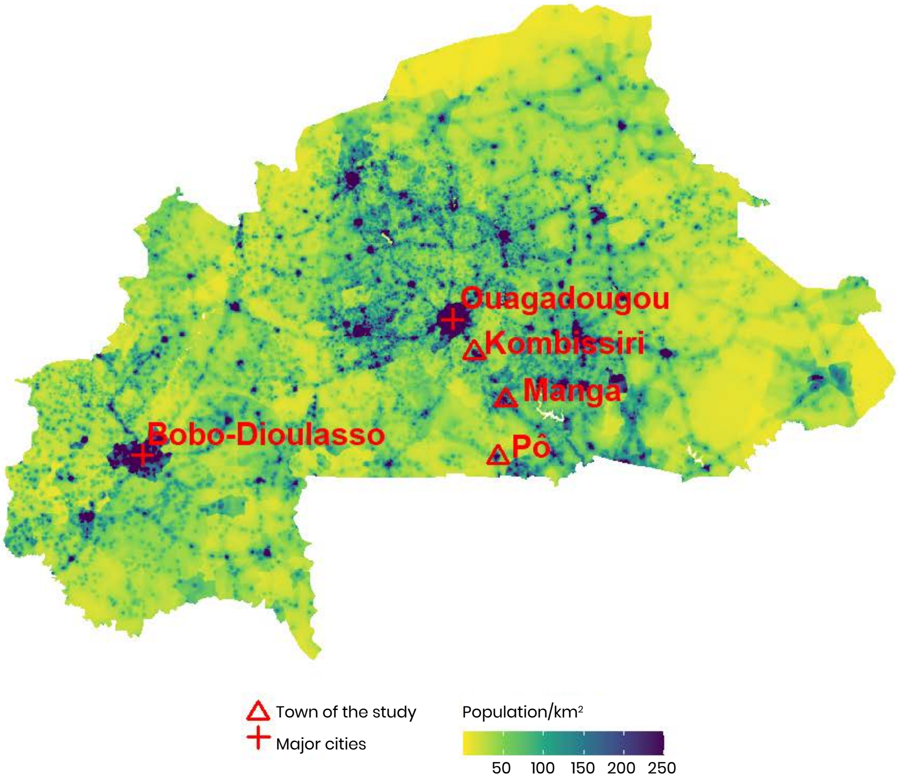
2.2 Sample selection and random assignment to offers

We evaluated the two offers presented above in a sample of 805 households living in Kombissiri, Manga, and Pô. These are three medium-sized towns located in the Centre-Sud region, south of Ouagadougou (see Map 1 below). The choice of medium-sized towns made it possible to carry out the study in places where ambient air pollution is relatively low, notably due to the lower levels of automobile traffic compared with large cities. The idea was to facilitate identification of the effects of access to gas on household air pollution. Of the sample households, 731 were included in the study in November 2019, and a supplementary sample of 74 households was selected in June 2021 after interruption of the study due to the COVID-19 crisis. The sample was selected using a spatial sampling strategy. A list of urban enumeration areas for the target towns was drawn up in conjunction with the National Institute of Statistics and Demography (INSD). The most densely populated areas of the three target towns were selected and divided into blocks of equivalent size using QGIS software. GPS points spaced at least 60 meters apart[6] were plotted within the blocks. Data collection team supervisors visited each GPS point and used a random walk established by an algorithm built into the data collection software[7] to identify a household for surveying, based on the GPS point. Household eligibility requirements for inclusion in the study were that they had no gas or electricity for cooking and did not produce *dolo* for commercial purposes. Between June 2021 and December 2022, all households in the sample took part in another field experiment focusing on COVID-19 prevention (see Figure A.1 in the annex).

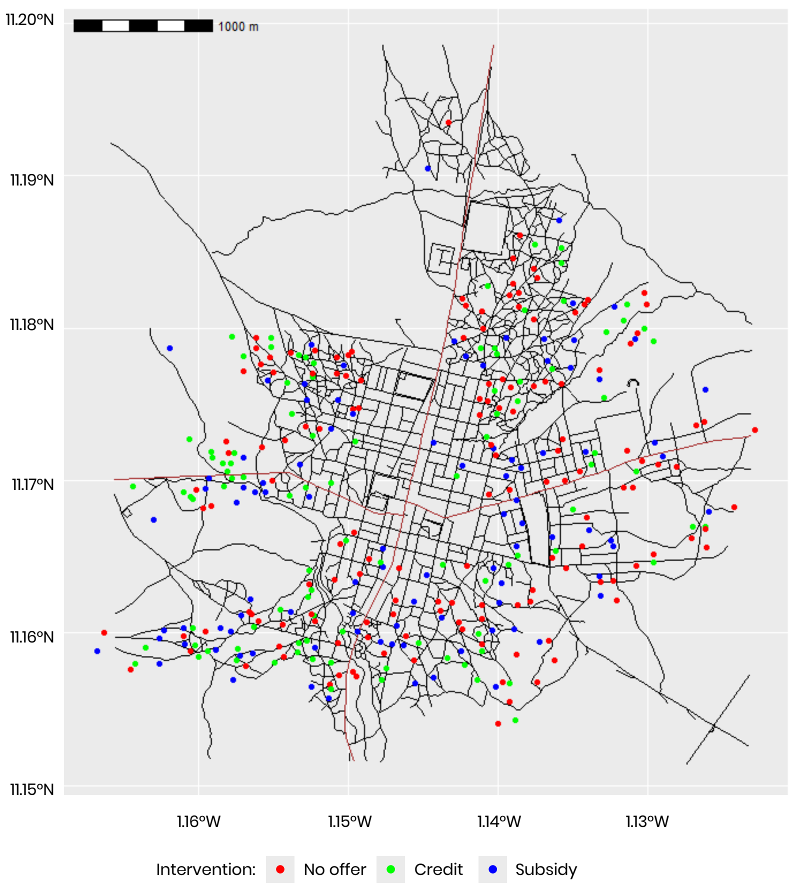
[6] To limit the risk of selecting neighboring households.

[7] The algorithm randomly selected a walking direction for the interviewer, then redirected them if they failed to identify an eligible household after walking a predetermined distance in the initial direction.

Map 1 – Study areas



(a) Location of study's target towns



(b) Location of sampled households in Pô

In spring 2022, the 805 urban households in our sample were randomly assigned to one of the three treatment groups[8] according to the distribution shown in Diagram 1.[9] Group 1 (credit) was presented with an offer to purchase a Télia kit at the market price of FCFA 25,000, with the option of paying in three installments according to the terms usually offered by Nafa Naana (see above). Households assigned to Group 2 (subsidy) received an offer for a cash purchase for a Télia kit at a reduced price, according to the terms of the complementary intervention designed by the research team, as described above. The price of this offer was FCFA 15,500. In Group 3 (control group), there was no special offer. All offers were distributed at the end of April 2022, at the homes of study participants, to minimize potential interference between groups. Interested individuals could then purchase the Télia kit under the proposed conditions within one and a half months after the offer was made, at a gas retailer that was partner to the study and located near their home.

2.3 Data

Four quantitative surveys were carried out among the sample households: baseline survey (December 2019–March 2020), update of the baseline survey[10] (June–July 2021), follow-up survey (December 2021), post-intervention survey (December 2022). The detailed progress of the study is described in the timeline in the annex (Figure A.1). The quantitative surveys listed all the members of the households surveyed and all the stoves used (including their characteristics, locations, and frequency of use). Household heads and the persons in charge of cooking activities were surveyed first. We had self-reported information available on the fuel use and health status of each household member, as well as objective measurements for the study's main variables of interest: frequency and duration of use of the Télia kits purchased as part of the interventions; wood, charcoal, and gas consumption of the sample households; and average exposure to fine particles over 24 hours for a person in charge of meal preparation per household.

The frequency and duration of use of the Télia kits were measured over a six-month period from the purchase date, using optical sensors[11] installed on the kits before they were

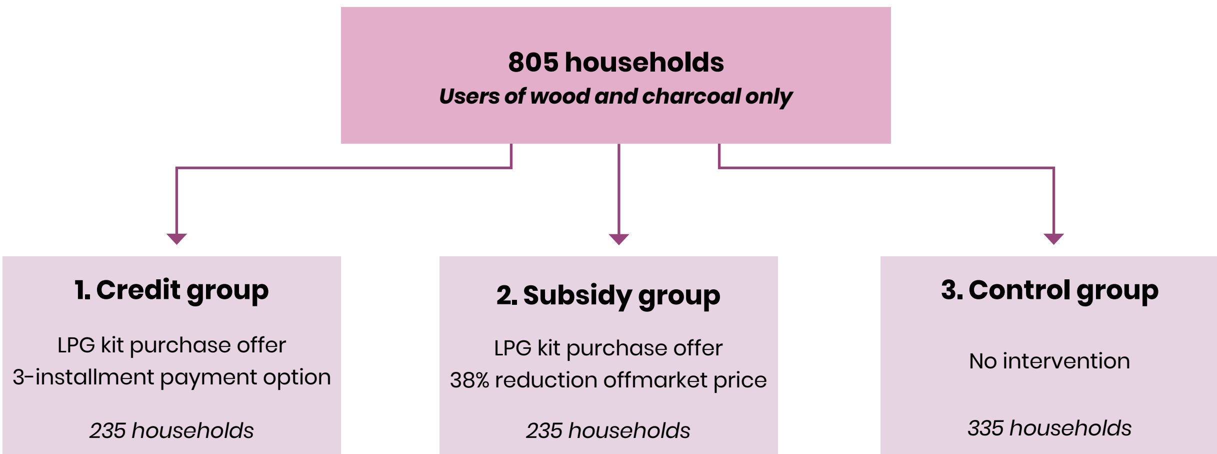
[8] The study used the randomized controlled trial methodology. See explanations in the "Statistical and econometric analyses" subsection.

[9] Randomization at the household level.

[10] Restrictions linked to the COVID-19 epidemic altered the study schedule.

[11] See attached photos in the annex.

Diagram 2 – Randomization strategy



delivered to the households. These sensors detect the status of the cooker (in use or turned off) based on the burner temperature and record a value every minute. For each kit, we were thus able to continuously observe periods of use over the entire six-month recording period.

To measure household fuel consumption in the baseline survey, baseline update survey and post-intervention survey, we used a modified version of the Kitchen Performance Tests protocol (Bailis *et al.*, 2018). In concrete terms, we asked the households participating in the study to assemble the stock of fuel needed to prepare their meals for several days, and we then weighed this stock once a day, at 24-hour intervals. We then obtained the consumption of a given fuel over a 24-hour period by deducting the mass of the stock at the end of the period from that of the stock at the beginning of the period. These measurements were taken over 72 hours during the baseline survey (3 periods of 24 hours), 24 hours during the baseline update survey, and 48 hours during the post-intervention survey (2 periods of 24 hours).

Exposure to fine particles was measured using the gravimetric method, which is the reference method for this indicator (see Box 5). A 24-hour exposure measurement was carried out during i) the baseline survey, ii) the baseline update survey, and iii) the post-intervention survey.

Finally, during the baseline update survey and the post-intervention survey, we also collected a blood pressure measurement from the person who had worn the fine-particle exposure measurement device. The reason for this is that medical literature associates exposure to air pollutants such as fine particles and nitrogen dioxide with a short-term rise in blood pressure (Chang *et al.*, 2015; Kubesch *et al.*, 2015; Yang *et al.*, 2018; Choi *et al.*, 2019; Bista *et al.*, 2023). We therefore chose this variable as an objective indicator of the effect of interventions on the health of people using cooking fuels.

Box 5 – Personal exposure to fine particles

Analysis of the intervention's effects was based on a precise measurement of individual exposure to fine particles, on a sample size larger than those in previous studies carried out in sub-Saharan Africa. In each sample household, one person in charge of cooking activities wore gravimetric air-quality measurement equipment for 24 consecutive hours. The day of the week chosen to carry out this measurement in a given household was determined according to a predefined schedule for data collection and the deployment of teams of field investigators, who had to adapt the schedule if the person in charge of the kitchen was absent on the predefined day. We then took into account in our econometric analyses the days on which the measurement actually took place. The measurement device consisted of a constant-flow pump, a selector for particles smaller than 2.5 micrometers, and a filter.[12] By comparing the mass in the filter before and after sampling to the volume of air sampled over the 24-hour period, we were able to estimate the average exposure to fine particles for the person who wore the pump. The weighing of the filters was carried out in France by the French National Institute for Industrial Environment and Risks (Ineris).

Pre-intervention data reveals particularly high $PM_{2.5}$ exposure levels in the sample of households studied. Exposure to fine particles measured on the persons in charge of meal preparation was 180 µg/m^3, more than 10 times greater than the threshold of an average 15 µg/m^3 over 24 hours recommended by WHO. Using the linear risk ratio of 1.0065 per 10 µg/m^3 adopted by WHO to model the impact of fine-particle exposure on overall mortality, we can estimate that this level of exposure corresponds to a 12.4% heightened mortality risk compared to a situation without pollution (WHO, 2021).

[12] See attached photos in the annex.

2.4 Sample characteristics

In the post-intervention survey, 775 of the 805 households included in the trial were located and provided us with full data. There was thus attrition rate of 3.7% over a one-year period (i.e. the time elapsed between the follow-up survey and the post-intervention survey; see timeline in Figure A.1 of the annex). Table 2 shows the main socio-demographic characteristics of the households found at the pre-intervention stage. These were vulnerable households whose probability of living below the $1.90 per day poverty line[13] was 31% and in which only a third of household heads had attended school. These households had a wood consumption rate of 5.2 kg per day, and for two thirds of them the wood they consumed was all collected. Despite the fact that households equipped with a gas stove at the time of the sampling were excluded from the study, 8% of households had an LPG kit when fuel consumption was measured in June–July 2021. This can be explained by the 18 months that had elapsed since sampling, during which time some households may have purchased a kit outside the scope of the study. Finally, average exposure to fine particles measured on the persons in charge of meal preparation was 180 µg/m³ (see Box 5).

[13] Probability calculated according to the Poverty Probability Index methodology for Burkina Faso (Kshirsagar *et al.*, 2017).

2.5 Statistical and econometric analysis

This impact study is based on a randomized controlled trial. This method involves randomly assigning interventions (randomization) and then making comparisons among the final results of households belonging to the different intervention groups and the control group. An "intervention" is an action implemented by an actor that may be public (e.g., government ministry) or private (e.g. association). Interventions may involve, for example, communicating informational messages or providing financial assistance. In the case of the present study, the interventions are the Télia kit purchase offers as described above.

The randomized controlled trial method is based on the assumption of independence between intervention assignment status (i.e., whether the segment

Table 2 – Descriptive statistics prior to intervention

	Average	Standard deviation	25th percentile	Median	75th percentile
Size of household	5.51	2.81	4	5	7
Gender of household head [Female=1]	0.26	0.44	0	0	1
Household head attended school [Yes=1]	0.30	0.46	0	0	1
Probability of poverty [<USD 1.90/day=1]	0.31	20.80	14	27	44
Collect their wood [Yes=1]	0.66	0.48	0	1	1
Wood consumption (g/day)	5157.24	3038.95	3258	4816	6447
Possess an LPG kit [Yes=1]	0.08	0.27	0	0	0
Useful energy consumption/day [kj]	13877.54	7384.38	9102	12227	17228
Exposure to $PM_{2.5}$ (µg/m³/24hrs.)	178.49	241.15	60	98	168
Observations	775				

How to read the table: The values shown in the first column of the table for the variables "gender of head of household", "head of household has attended school", "probability of poverty", "wood collection" and "owns an LPG kit", are probabilities. For example, for the "gender of head of household" variable, the mean value of 0.26 indicates that 26% of heads of households in the sample are women.

belongs to an intervention group or a control group) and the observable and unobservable characteristics of the treated units (in this case, households). In other words, the purpose of dividing the households using random selection is to obtain the most comparable groups possible, so that any differences between groups observed at the end of the study can be attributed to the effects of the interventions. To test this hypothesis, it is possible to check, using data from the baseline survey, whether the groups have similar characteristics before the interventions are carried out. This is shown in Table A.1 in the annex. This test is quite well justified in this study, because in the post-intervention survey it was not possible to find all of the 805 households that had been assigned to the treatment groups. This situation may have negatively affected the comparability of the groups. But analysis suggests that this is not the case, as none of the differences between the groups, as presented in Table A.1, are statistically significant.[14] This indicates that any differences between groups provide relevant information about the causal effect of the offers on the indicators of interest in our sample.

In the following section, we present our analysis of the differences between treatment groups in the REDGAS study at the time of the post-intervention survey in December 2022, six months after offers to purchase Télia kits were made available. The analyses presented below are based mainly on comparisons of mean values between treatment groups. Where results have required the use of more sophisticated methods, these latter are described in the notes accompanying the graphs or tables of results.

[14] The results presented in the p-value columns are those of the test of the hypothesis that there is no statistical difference between groups for the variable of interest. The p-value can be interpreted as the probability of observing as large a difference between groups as if the groups had been samples from target populations that were distinct but with identical mean values for the variable of interest. Differences are generally considered statistically significant when the p-value is less than 0.1.

3. Results

Infographic 1 – Summary of results

MAIN FINDINGS OF THE EVALUATION

FINANCIAL INCENTIVE

More people adopt the subsidized kit than the credit kit

Six months after the intervention, 49% of households that received a credit offer had the kit at home, compared to 75% of households that received a subsidized kit.

USE OF EQUIPMENT

40% of the kits were in use on a given day after 6 months (with 20 minutes of average use per day per household)

The use of gas equipment decreased over time, but without giving it up massively.

WOOD CONSUMPTION

Fuel stacking: no substitution effect with wood

Total energy consumption increased in the intervention groups due to access to a new cooking fuel.

HEALTH

No effect on exposure to air pollution or on arterial hypertension

The average exposure levels to fine particles ($PM_{2.5}$) over 24 hours and the probability of being in a state of hypertension were comparable in the control group and in the intervention groups at the end of the study, on average.

HETEROGENEOUS RESULTS DEPENDING ON THE METHOD USED TO SECURE WOOD

For households that collect their own wood

- ↑ **+ 87%** gas stove acquisition
- ↑ **+ 73 grams** of gas consumed per day
- ✗ No effect on wood consumption
- ✗ No effect on exposure to fine particles

For households that purchase their wood

- ↑ **+ 105%** gas stove acquisition
- ↑ **+ 136 grams** of gas consumed per day
- ↓ **- 670 grams** of wood consumed per day
- ↓ **- 17%** fine particles in the air inhaled by the person in charge of meals

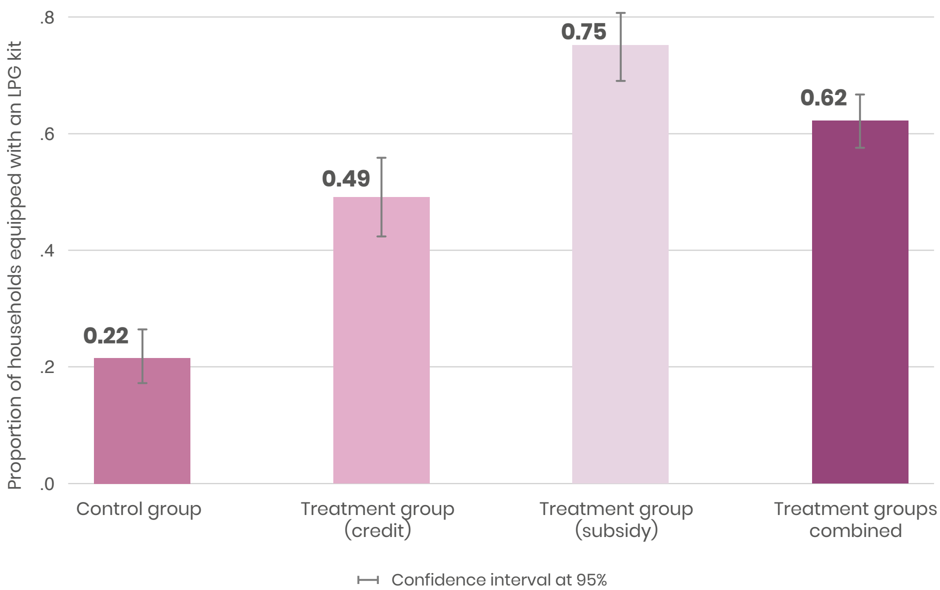
3.1 Effect of subsidy and effect of credit on gas cooker purchase

The first research question we address is that of the effect of financial incentives, - offers for payment with credit, and subsidized offers - on the probability of owning gas-cooking equipment. To answer this question, Chart 1 shows the share of households in which one or more gas cylinders in working order were found during fuel consumption measurements at the time of the survey six months after the intervention, in December 2022. This proportion was 22% in the control group, which received no offer, compared to 49% in the group of households that received a credit offer, and 75% in the group that benefited from the subsidized offer. The effect of the offer is therefore an increase of 27 percentage points in the probability of having a gas cylinder in the credit case and 53 percentage points in the subsidy case. The lack of overlap between the confidence intervals of the first three bars of the graph indicates that our sample size is sufficiently large for estimating these effects accurately and for rejecting the hypothesis of no difference between the groups. The last bar of the graph shows the average effect of offers on the equipment rate across the two intervention groups. This effect is 40 percentage points (62-22=40).

The reported effects are very large and correspond to a twofold increase in household equipment rate compared to the control group mean in the case of credit and a 3.5-fold increase in the case of the subsidized offer. This suggests that the households in our sample had a strong demand for gas-cooking equipment at the time the offers became available, but that their ability to purchase equipment at the market price was hindered by a low-income level (budget constraint), lack of access to credit, a propensity to pay below the market price, or a combination of these factors. It is unlikely that the increases in equipment rates are linked to an “information” effect, considering that gas cooking was already well known in Burkina Faso prior to our study and that, during the baseline survey in November 2019, 96% of households surveyed reported that they wanted to use it.[15] We also deem it unlikely that the improved retail availability of the Télia kits made possible by the offers had an effect on the adoption of gas. This is because only 3.5% of households surveyed in 2019 reported the absence of a point of sale near their home as a barrier preventing them from equipping themselves. Furthermore, the unavailability of kits at points of sale was never mentioned as a problem.

[15] Awareness of gas cooking and high demand for gas cooking equipment were also confirmed by qualitative data collected prior to the study.

Chart 1 – Proportion of households equipped with an LPG kit at the time of the post-intervention survey



How to read the graph: Each bar represents the proportion of households in which at least one gas cylinder was found during the post-intervention survey. The value of 0.22 for the control group indicates, for example, that 22% of households in that group had at least one gas cylinder in their homes at the end of the study.

This figure of 22% represents an increase of 14 percentage points compared with the pre-intervention period. This represents a significant increase in the equipment rate in the absence of any intervention and once again illustrates the strong appeal of gas for the sample households. In fact, the equipment rate had already risen by 8 percentage points between the November 2019 baseline survey and the update survey conducted in June–July 2021 (see "Sample characteristics" section above). It is also possible that some of this increase can be explained by spillover effects between treatment groups; in other words, access to gas in the intervention groups may have had an impact on a control group's disposition to equip itself in gas, via peer example and learning. In particular, this type of mechanism could have been at work if the test experience of households in the intervention groups had revealed an actual cost of gas use lower than that anticipated, and if this information had then reached the control group. A detailed exploration of this hypothesis is beyond the scope of this report, but the hypothesis is credible if we consider that 50% of households interviewed in the baseline survey cited the price of refills among the barriers to gas adoption. In any case, the possibility that spillover may have occurred should lead us to view the results presented in Chart 1 as conservative estimates of the effect of the interventions on gas adoption. The effect probably would have been even greater had we been able to implement a research method that prevented any spillover effects.

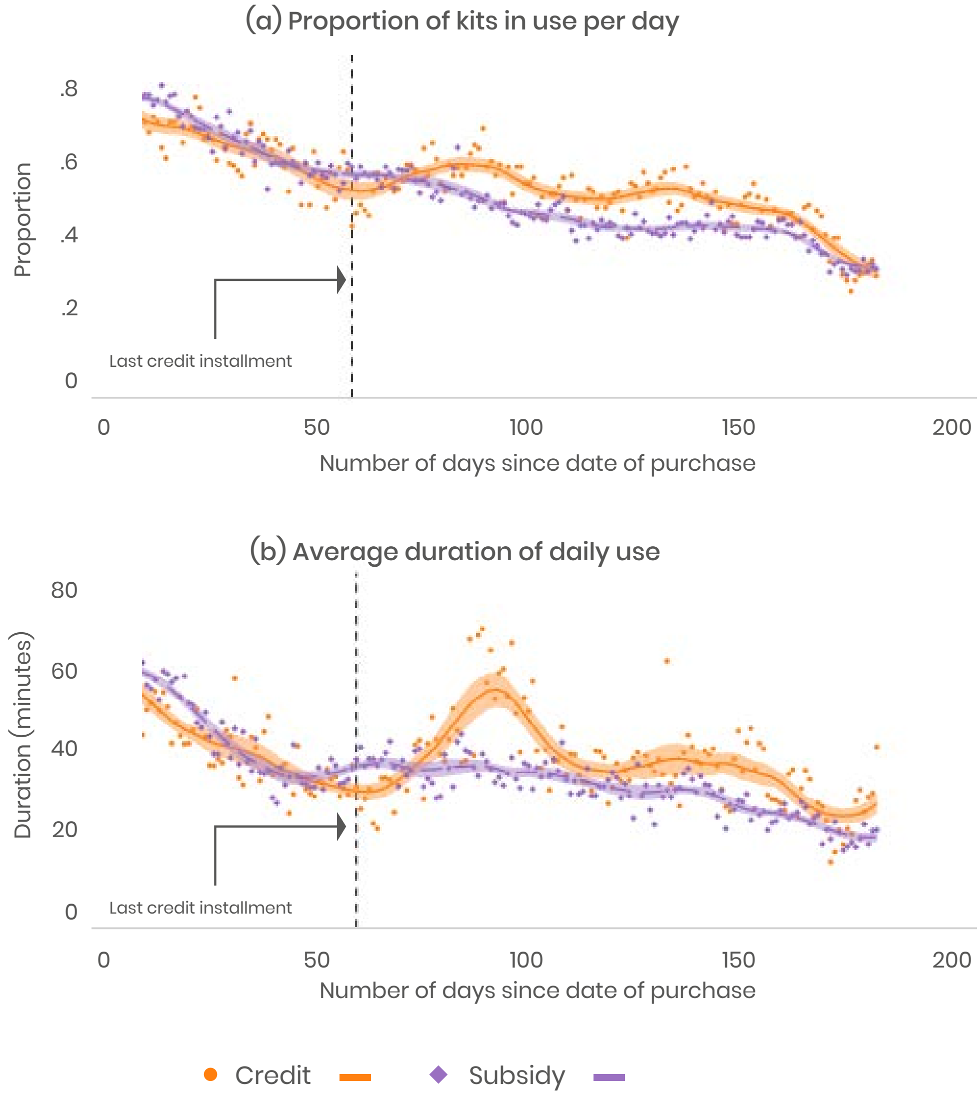
3.2 Use of gas-cooking equipment purchased as part of the interventions

For access to gas to bring about a reduction in exposure to air pollution, households need to do more than just acquire the equipment. They also need to use their new equipment on a daily basis, instead of their pre-existing wood-burning stove. To ensure this, we used the data from the optical usage monitoring sensors installed on the Télia kits prior to their delivery to the households. Chart 2(a) shows the proportion of kits acquired through purchase offers that were in use between the date they were picked up at the point of sale (Day 0) and the last day of the follow-up period (Day 180). The two curves follow the same trend over the entire follow-up period: while the use rates were around 70% to 80% in the first month, they declined steadily and continuously to just under 40% after six months. The other notable feature is that the use rate remained around 10 percentage points higher in the "credit" group than in the "subsidy" group from the theoretical date of payment of the last credit installment, and this until a few days before the end of the monitoring period. Chart 2(b) confirms this difference in usage profile, since households in the "credit" group also used their kit a few minutes more per day than those in the "subsidy" group over the same period. Six months after purchase, the daily use time was around 30 minutes in the credit group and 20 minutes in the subsidy group.

How can we interpret these use curves? At first glance, the continued decline in use may seem worrying, as it could suggest that households gradually gave up gas cooking in the months following the end of the study. However, a background element must be taken into account here: the kit purchases were made in May and June 2022, at the start of the rainy season, which is the most favorable for gas use due to the difficulty of collecting dry wood. With this season ending in September, households had less incentive to use gas during the second part of our use monitoring period. It is therefore likely that the slope of the curve partly reflects a seasonal effect, and that use increased again during the 2023 rainy season.

Moreover, presenting a daily use rate is conservative and hides the fact that many kits were used regularly but not on a daily basis. For example, 45% of the cookers obtained through purchase offers were used on at least 10 different days during the last month of follow-up, and 70% were used at least once. The observed reality is therefore that of a transition from extremely intensive use just after purchase to regular but less intensive use at the end of the follow-up period, rather than a situation of gas use having been given up massively. Nevertheless, 30% of households did not use their kit once during the last month of monitoring, either because they did not need it or because they could not afford a new gas refill.

Chart 2 – Proportion and average daily use of Télia kits



NB: Curves obtained by kernel regression. The colored surfaces represent the 95%-confidence intervals.

How to read the graphs: Chart 2(a) shows the proportion of kits acquired through purchase offers that were in use between the date they were picked up at the point of sale (Day 0) and the last day of the follow-up period (Day 180). For each day, the orange dot represents the proportion of kits in the "credit" group that were used, and the purple dot corresponds to the proportion in the "subsidy" group. The curves show the time trend for each group, and the colored areas around them delimit the 95% confidence interval. Chart 2(b) shows the average duration of daily use of kits acquired through purchase offers between the date they were picked up at the point of sale (Day 0) and the last day of the follow-up period (Day 180). For each day, the orange dot represents the average duration of use of the kits in the "credit" group, taking into account those that are not used (duration of use equal to 0). The purple dot corresponds to the average duration of use in the "subsidy" group. The curves show the time trend for each group, and the colored areas around them delimit the 95% confidence interval.

With regard to differences in use profiles, the relative increase in use intensity in the "credit" group from the theoretical date of repayment of the last installment can be interpreted in two ways. On the one hand, this increase suggests that the credit offer, which was more expensive, was chosen by households different from those taking advantage of the subsidized offer, and that they had a higher propensity to use gas and therefore a higher ROI. While use of the LPG kit was initially limited by the financial burden of loan repayment, the difference in propensity to use it compared to the subsidy group appeared from the 60th day after purchase, when the loan was repaid. On the other hand, it is possible that the increase in intensity of use after the end of the credit period is the result of a psychological effect linked to so-called sunk costs. In this hypothesis, the large sums invested by households in the "credit" group to purchase the Télia kit would encourage them to use their equipment more regularly than households having benefited from a reduced price. Either one of these two theories, which are not incompatible, might apply. It is nevertheless interesting to note that the peak in usage observed around the 100th day in Chart 2(b) for the "credit" group is easier to explain by a psychological effect than by a selection effect. Finally, whatever the contribution of these two mechanisms to the difference in use profile between treatment groups, the direct implication of this difference is that the lower take-up rate of credit offers in the "credit" group should be partly offset by their higher use rate when we compare the effect of offers on fuel use. This is examined in the next section.

3.3 Adoption of gas and consumption of solid fuels

Chart 3 shows the differences in daily gas, wood, and charcoal consumption between experimental groups at the time of the post-intervention survey in December 2022. For each fuel and for each group, the bars show the group's average consumption regardless of gas-access status (estimating the "intention-to-treat" effect). Averages are expressed in grams per 24 hours. Chart 3(a) shows that regular use of the kits by households results in significantly higher gas consumption than in the control group, despite the fact that the post-intervention survey was carried out during the dry season, which is less favorable to gas use. The difference in consumption for each of the intervention groups was around 100 g compared with the control group. This difference represents the useful-energy equivalent of around 1 kg of wood, or 20% of wood consumption in the sample prior to the intervention. Average gas consumption is not statistically different between the two intervention groups, confirming that the more intensive use in the "credit" group compensates for its lower adoption rate compared to the "subsidy" group.[16]

Chart 3(b) indicates that households in the intervention groups that used energy obtained from burning gas did not reduce their wood consumption. The differences in wood consumption compared to the control group are minimal, between 200 and 340 g, representing between 4 and 7% of the control group's consumption. These differences are not statistically significant. Consumption rates of charcoal, a secondary fuel in our sample, are also equivalent between the groups (Chart 3(c)).

Chart 3(d) shows the average total useful-energy consumption per 24 hours for each group.[17] These averages are obtained by multiplying the measured consumption for each fuel by a default value for the thermal efficiency of combustion[18] and for

[16] In fact, each bar in Chart 3 shows an average calculated for a group of households according to its treatment assignment, i.e. whether the households in this group were offered to buy a stove on credit, or at a subsidized price, or whether they received no purchase offer. Since proportionally fewer households in the "credit" group purchased the kit than did households in the "subsidy" group, the fact that the average consumption of these two groups is not statistically different indicates that households in the "credit" group who purchased the kit used their stove more intensively than those in the "subsidy" group.

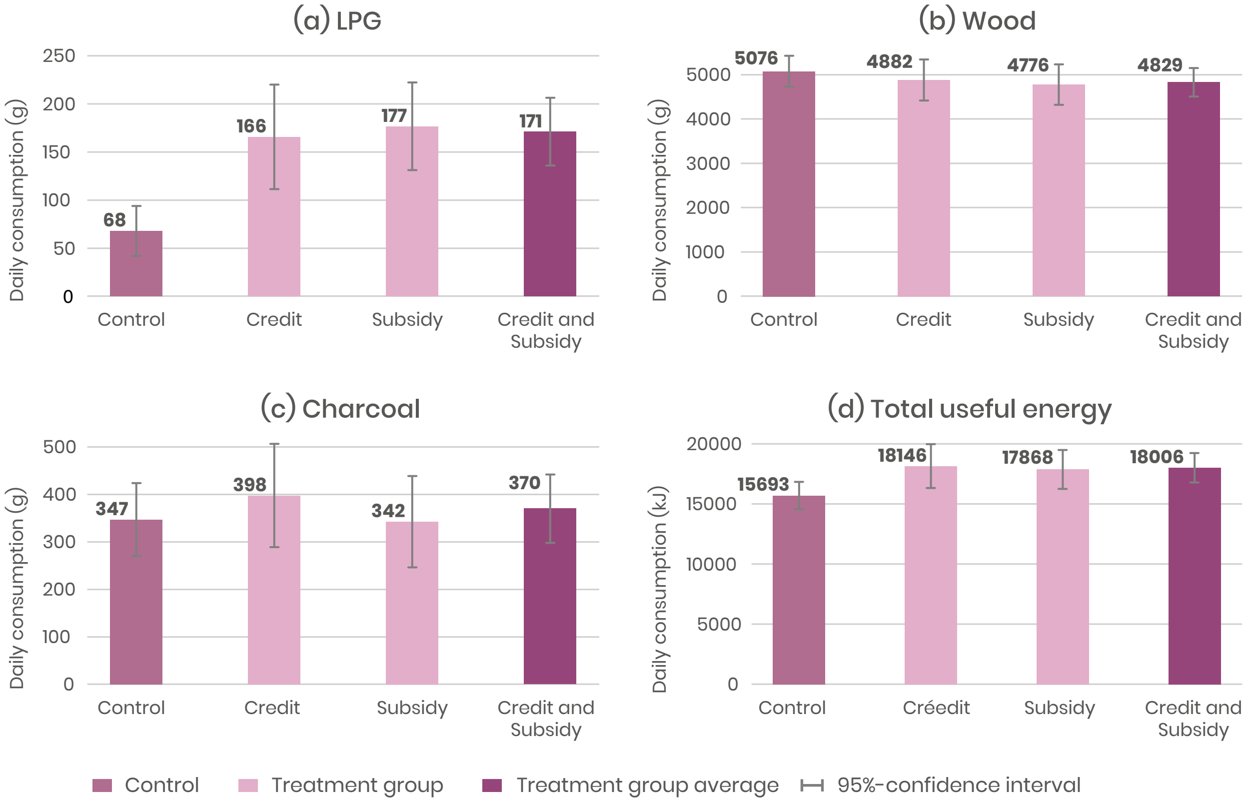
[17] Figure A.3 in the annex also shows the comparison of average fuel consumption expressed in kilojoules of useful energy by fuel type.

[18] Thermal efficiency rates from Champion *et al.*, (2021): 14% for wood (3-stone stove), 27% for charcoal, 56% for gas.

the net calorific value of the fuel,[19] and then by adding up the useful-energy amounts from each fuel. The comparison between the control and intervention groups confirms that the households which adopted the intervention technology did not substitute gas for wood. In fact, total useful-energy consumption was around 15% higher in both intervention groups. These differences are statistically significant. This result has important implications for public policies promoting clean cooking technologies, because while the issue of fuel accumulation ("fuel stacking") by households is well documented, it is generally understood to involve partial substitution of traditional fuel by the less polluting fuel. Here, we show that in the context of medium-sized towns in Burkina Faso, there is hardly any substitution in households that had mostly collected their woodfuel prior to having access to gas. Insofar as gas combustion is not free of pollutant emissions, this means that financial incentives for adopting gas could lead to an increase in total exposure to air pollution in this type of situation.

[19] Net calorific values: 15.6 MJ/kg (megajoules per kilogram) for wood, 29.5 MJ/kg for charcoal, 43.8 MJ/kg for LPG. (GIEC, 2006).

Chart 3 – Effect of interventions on fuel consumption



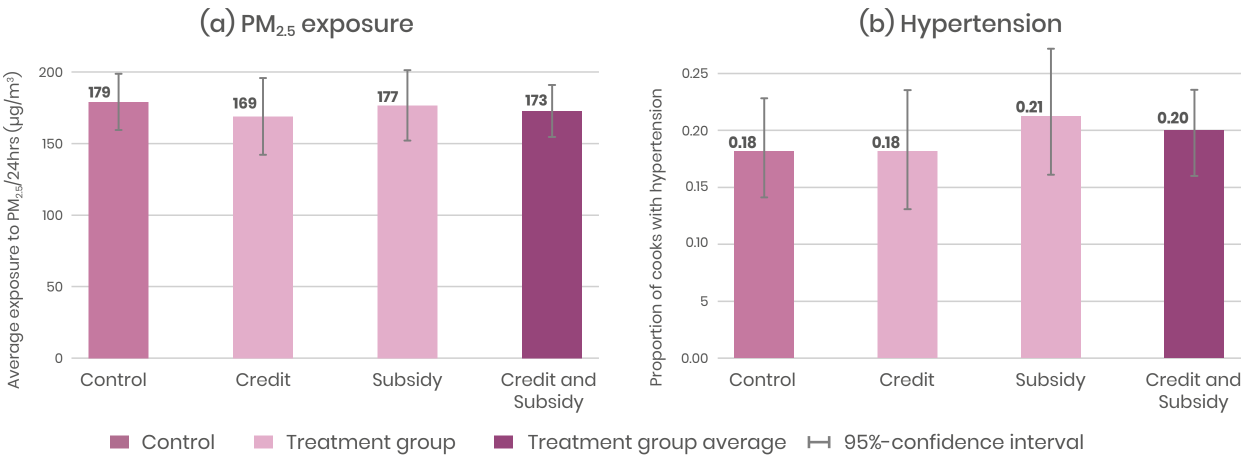
How to read the graphs: The bars in each graph show the average daily consumption of the fuel or energy type stated in the sub-heading for the treatment group indicated on the x-axis and in the unit indicated on the y-axis, at the time of the post-intervention survey. For example, the first bar in Chart 3(a) shows that average LPG consumption in the control group was 68 grams per day (taking into account households with zero consumption). The gray markers indicate 95% confidence intervals.

3.4 Impact on exposure to air pollution and hypertension

In the absence of a reduction in wood consumption in the groups exposed to the interventions, what effects can be expected in terms of exposure to fine particles and the probability of suffering from hypertension among the household members in charge of meal preparation? Chart 4(a) shows that average 24-hour $PM_{2.5}$ exposure levels were equivalent in the three groups six months after the intervention. Indeed, even though the averages are very slightly lower in the "credit" and "subsidy" groups, the confidence intervals almost totally overlap that of the control group. There is therefore no intention-to-treat effect on our air pollution exposure indicator. Nevertheless, it is possible that exposure to other pollutants, which were not measured in this study, may be increased by interventions that result in the consumption of a new fuel without reducing that of wood, as discussed above. This should be a future research topic, as the data collected in this study does not make it possible to answer this question.

In terms of health risk, exposure levels measured in the post-intervention stage are over 10 times higher than the threshold of an average 15 µg/m³ over 24 hours recommended by WHO, as was already the case prior to the intervention. These exposure levels therefore represent a major health risk (see Box 4). Lastly, Chart 4(b) shows that the interventions similarly had no effect on the likelihood of hypertension among the persons in charge of preparing meals.

Chart 4 – Effect of interventions on exposure to fine particles and hypertension



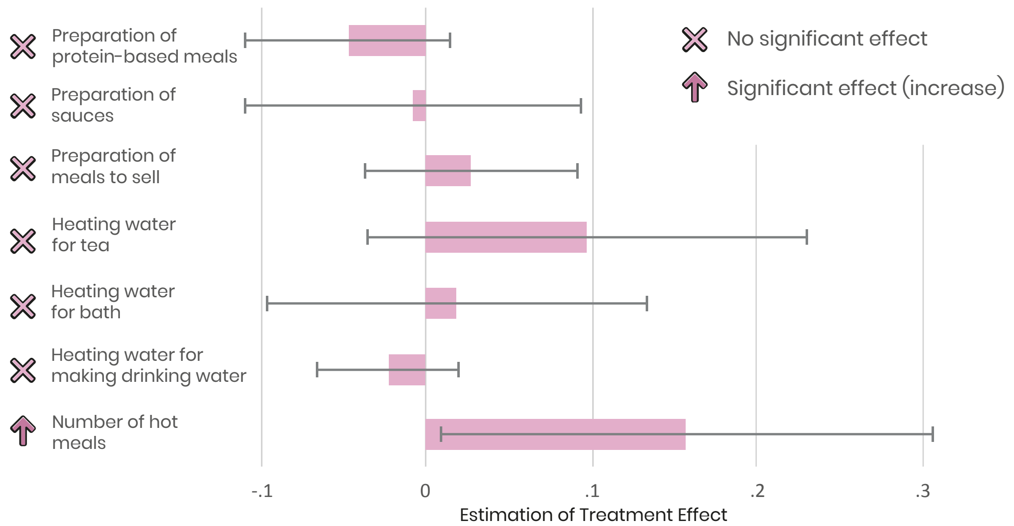
How to read the graphs: The bars in Chart 4(a) show, for each treatment group, the average 24-hour exposure to fine particulate matter ($PM_{2.5}$) measured among persons in charge of preparing meals, at the time of the post-intervention survey (in micrograms per cubic meter of inhaled air). The bars in Chart 4(b) show, for each treatment group, the probability that the persons in charge of preparing the meals who participated in the measurements of fine particle exposure were subject to hypertension at the time of the post-intervention survey. The gray markers indicate 95% confidence intervals.

4. Mechanisms and heterogeneity of results

4.1 Mechanisms explaining the rise in total energy consumption

The increase in total energy consumption observed in the intervention groups raises the question of whether there were changes in activities within households that took-up the LPG kit. To answer this question, in Chart 5 we present estimates of the effect of the offers on the probability of carrying out the most common fuel-consuming activities among households that took advantage of the offers (all offers combined). These activities were recorded over the 48-hour period during which fuel consumption was measured in December 2022. The estimated effects are not statistically different from zero for the probabilities of having cooked protein foods; of having prepared a sauce; of having cooked for an income-generating activity; or of having boiled water for tea, for bathing, or to obtain drinking water. On the other hand, the impact on the number of hot meals consumed is positive and statistically significant. The size of the estimated effect is around 0.16 additional meals per day, representing a 9% increase compared to the average of 1.75 hot meals per day in the control group. It therefore seems that equipped households used their Télia kit to reheat their food more frequently.

Chart 5 – Effect of interventions on energy-consuming activities



NB: Coefficients and 95%-confidence intervals for estimation of Local Average Treatment Effect (LATE) by instrumental variable regression with post double lasso (Chernozhukov *et al.* 2015). Each coefficient is derived from a separate regression. Confidence intervals calculated from hetroskedasticity-robust standard errors.

How to read the graph: The bars in Chart 5 show the estimated average effect that access to gas cooking has on the probability of having carried out one of the activities listed on the y-axis during the 48-hour fuel-consumption monitoring carried out as part of the post-intervention survey, and on the number of hot meals prepared in the course of a day (last variable listed on the y-axis). These effects are estimated for households that effectively purchased gas cooking equipment within the scope of the study (i.e., households that took up the offers). The different activities taken into account are: the preparation or reheating of proteins (meat, fish); sauces; food intended for sale as part of income-generating activities; as well as boiling water for tea, bathing or showering, or preparing drinking water. For these different activities, the length of the orange bar indicates the effect size on the probability of having performed the activity concerned. For example, an effect size of 0.1 indicates a probability increase of 10 percentage points, and an effect size of -0.1 a probability decrease of 10 percentage points. In the case of boiling water for tea, for example, the length of the orange bar indicates an effect size of around 9 percentage points. However, the gray marker in the 95% confidence interval shows that the estimated effect is not statistically significant, as it includes the x-axis corresponding to an effect size of 0. In the case of the number of hot meals, the orange bar indicates the average effect of the interventions on the number of hot meals prepared per day among households having used the intervention products. The value of 0.16 means that these households prepared on average 0.16 more hot meals per day than a similar household in the control group at the time of the post-intervention survey.

4.2 Heterogeneity of impacts on exposure to air pollution

It is possible that the lack of effect of the interventions on exposure to fine particles in reality conceals heterogeneous impacts within our sample. To test this hypothesis, we used the generic machine-learning inference method developed by Chernozhukov *et al.*, (2018). This method enabled us to identify household characteristics associated with variations in impact, without making any a priori assumptions about the nature of these characteristics. This analysis highlights three key variables: wood consumption prior to the intervention, the mode of wood acquisition (collection only or collection and purchase), and the probability of household poverty.

In Chart A.5, we compare the mean intention-to-treat effects of the two interventions on the study's main variables of interest, according to these three dimensions of heterogeneity. This analysis shows a reduction in wood consumption and a statistically significant reduction in exposure to fine particles in the sub-sample of households that, prior to the intervention, had obtained some of their wood through purchase. As summarized in Infographic 1, households in this sub-sample reacted more strongly to the interventions, and the effect of the offers on their probability of being equipped with a gas-cooking kit is 8 percentage points higher than that observed among households who prior to the intervention had collected their wood. Similarly, the magnitude of the effect on their gas consumption is almost twice as great (136 grams versus 73 grams). This greater effect on gas consumption reflects a drop in consumption of 670 grams per day in the sub-sample that buys its own wood, with wood consumption remaining stable in the rest of the sample. Similarly, our results suggest a reduction in exposure to fine particles of around 17% compared with wood-buying households in the control group, and that there was no effect on exposure among households that collect their own wood.

The consistency between the effects on the different variables of interest is notable for this sub-sample of wood-buying households. It suggests that these households have a stronger incentive to buy gas-cooking kits, use their equipment, and substitute wood for gas, thereby explaining the difference in effect observed on pollution exposure. It is therefore possible that the interventions evaluated could yield more encouraging results if they were replicated with a different targeting strategy that prioritized households that do not collect their wood. Nevertheless, in the event of a scale-up involving intervention in larger cities, where the proportion of households purchasing their fuel is likely to be higher, the health benefits of this type of intervention could be mitigated by higher levels of ambient air pollution than in our study area. Therefore, it is difficult to draw definitive conclusions from this heterogeneity analysis, which calls above all for replication of the evaluation of the same type of intervention among a population with more restricted access to collected fuel.

5. Discussion and conclusion

Access to gas is at the heart of governments' reflections and efforts to meet the challenge of universal access to "clean" energy in Africa. The fact that many oil companies and organizations linked to the gas sector were included among the signatories of the declaration on clean cooking methods[20] adopted at the Paris Summit on May 14, 2024, also reveals the financial and symbolic issues involved in promoting gas as an appropriate solution to the public health problem linked to African people's dependence on solid fuels. But the scientific knowledge of the impact of access to gas on exposure to air pollution and on people's health is still fragmented.

The REDGAS study has helped document these impacts by evaluating two types of financial incentives: a credit service to facilitate the financing of the purchase of a gas cooker by households, and a partially subsidized offer making the price of this equipment significantly more affordable. The evaluation targeted a sample of urban residents with no prior access to gas, living in small towns in southern Burkina Faso. We show that in this context the effects of the incentives on gas use are substantial: at the end of the study, the equipment rate among households that had access to the credit service was more than twice that of the control group, and the equivalent figure was 3.5 times higher among households that benefited from the subsidized offer. **This result suggests that, by making equipment more affordable, public decision-makers have extremely effective levers at their disposal for accelerating the development of gas cooking.** The validity of this result probably extends beyond the specific context of Burkinabe cities, as it is consistent with scientific literature that indicates similar effects of credit and price cuts on the adoption of other cooking technologies in other African contexts (Beltramo *et al.*, 2015; Levine *et al.*, 2018; Berkouwer and Dean, 2022).

Should we conclude from this that developing subsidy and payment-facility programs for gas-cooking equipment is a wise public policy choice? Our REDGAS results suggest that the answer to this question is negative. Despite the fact that gas-cooking kits were used regularly six months after date of purchase by half the households that had purchased them, we did not find any effect of the financial incentives on exposure to air pollution or on our main objective health indicator among the persons in charge of preparing meals. Cooking-fuel consumption data collected at the end of the study provides a simple explanation for this disappointing finding: **the use of gas did not lead to a reduction in wood consumption** in the treatment groups to whom credit or subsidies were available. Instead, **total post-intervention energy consumption turned out to be around 15% higher** than in the control group. In particular, we observe that households that purchased a gas cooker used it to consume hot meals more regularly rather than to reduce their wood consumption. However, analysis of the heterogeneity of impacts on exposure to air pollution provides a more optimistic nuance to this finding, as it suggests that **financial incentives for switching to gas could lead to reductions in exposure to fine particles among households that purchase their solid fuels** and who thereby have a stronger incentive to replace wood with gas. This result argues in favor of conducting similar evaluations in larger cities, where the proportion of households collecting their own fuel is lower.

[20] See: https://www.iea.org/news/the-clean-cooking-declaration-making-2024-the-pivotal-year-for-clean-cooking

Several significant limitations to the study are worth discussing here. The first concerns data on exposure to air pollution and the fact that **we have information available only on a single pollutant, fine particles.** This limitation can be explained by the complexity and high cost of measuring air pollutants. However, it would have been interesting to have had an estimate of our sample's exposure to nitrogen dioxide, one of the main pollutants emitted by gas-cooking equipment. This is because the impacts of the transition from cooking with wood or charcoal to cooking with gas on exposure to this pollutant are very poorly documented, and recent developments in knowledge about the toxicity of nitrogen dioxide has led WHO to recently revise downwards the maximum recommended exposure levels (WHO, 2021). Furthermore, insofar as the interventions resulted in a significant increase in gas consumption without a reduction in wood consumption, it seems plausible that they caused an increase in total exposure to nitrogen dioxide, which is found in both gas and wood emissions. It would have been useful to test this hypothesis, which we are keeping in mind for future research projects.

A second limitation concerns the **relatively short time horizon** on which the evaluation focuses, and the fact that post-intervention follow-up involved only a single survey, primarily for budgetary reasons. Conducting a multi-year follow-up or adding at least a second post-intervention survey in the wet season would have enabled us to reach more definitive conclusions on the benefits and limitations of financial incentives in our study context. Indeed, it is important to point out that the post-intervention data available to us correspond to the dry season, which predominates for most of the year in our study area, in principle from October to May. The data therefore reflects the dominant cooking practices over the course of a year and the associated levels of domestic pollution.

In addition, the medium- and long-term trend observed in many studies evaluating the adoption of cooking technologies is rather that of a gradual decline in the rate of use, due in particular to problems of aging technologies and the financial difficulties encountered by households in replacing or repairing damaged equipment.[21] Even if long-term learning effects may occur, and even if the economic consequences of the 2020–2021 health crisis perhaps continued to weigh on the budgets of some households at the end of 2022, it seems unlikely that a new survey conducted one or two years after the December 2022 post-intervention survey would have found much more encouraging results on the benefits of access to gas in terms of exposure to air pollution and substitution of wood for gas in real-life conditions.

In conclusion, REDGAS is to our knowledge the first field experiment to assess the impact of credit and subsidies on gas adoption, on its associated air pollution exposure and health impact. REDGAS complements recent insights provided by two large randomized trials, the GRAPHS and HAPIN studies, which showed that there were reductions in fine-particle exposure among rural households following free distribution of gas cookers, supplemented by unlimited access to free gas refills for one year and, in some cases, home visits and regular phone messages reminding households not to use wood (Chillrud *et al.* 2021; Clasen *et al.* 2022). The interventions evaluated as part of REDGAS were therefore much lighter and less costly to implement than these intensive programs to replace wood and charcoal with gas. They are also more similar to the public policies to facilitate access to gas actually implemented by States, with few governments having the resources to fully subsidize the gas consumption of entire segments of the population. The contrast between the results of the two types of

[21] See for example: Hanna, Duflo and Greenstone (2016) and Mortimer *et al.*, (2017).

studies nevertheless suggests that only a reduction to nearly zero in gas price levels can achieve the levels of substitution needed to bring about significant reductions in fine-particle emissions and the associated health benefits. If this finding were to be confirmed in the future by further research in other countries, it would call for a downward revision of expectations on the contribution of access to gas to improving people's respiratory health.

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List of acronyms and abbreviations

AFD	*Agence française de développement*
AGR	*Activité génératrice de revenus*
CFA	*Communauté financière en Afrique*
GPS	Global Positioning System (latitude, longitude)
IRD	*Institut de recherche pour le développement*
ITT	Intention-To-Treat
LPG	Liquefied Petroleum Gas
NGO	Non Governmental Organisation
PAIRES	*Partenariat AFD-IRD pour Réaliser des Évaluations d'impact en mobilisant la recherche du Sud*
$PM_{2.5}$	Particles less than 2.5 microns
ROI	Return on investment
WHO	World Health Organisation

Annexes

Figure A.1 – Study timeline

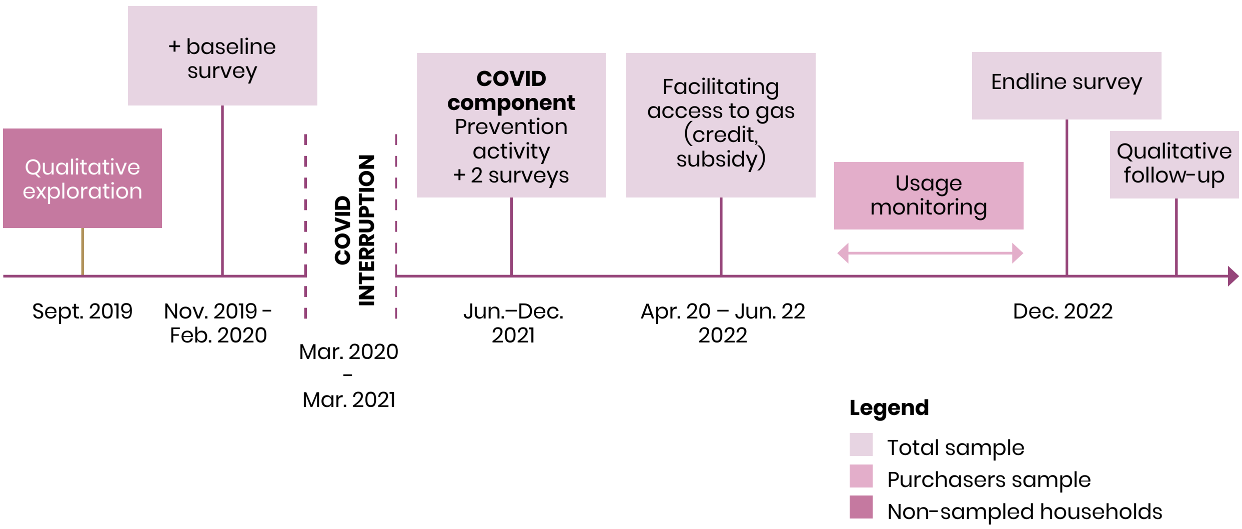
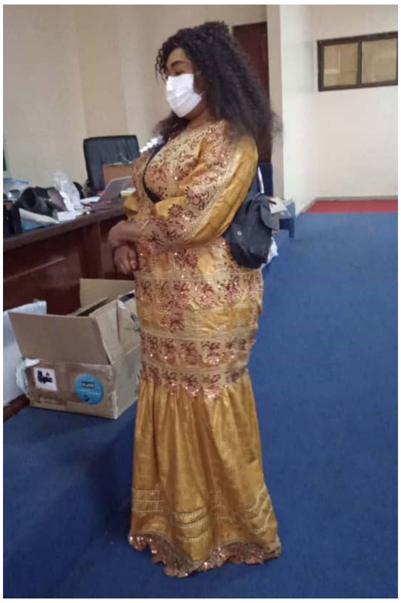


Figure A.2 – Photos of the device for measuring exposure to fine particles (right: worn by an interviewer).



NB: 1.5L/min. constant-flow pump manufactured by Climate Solutions Consulting

Figure A.3 – Effect of interventions on useful energy consumption by fuel type

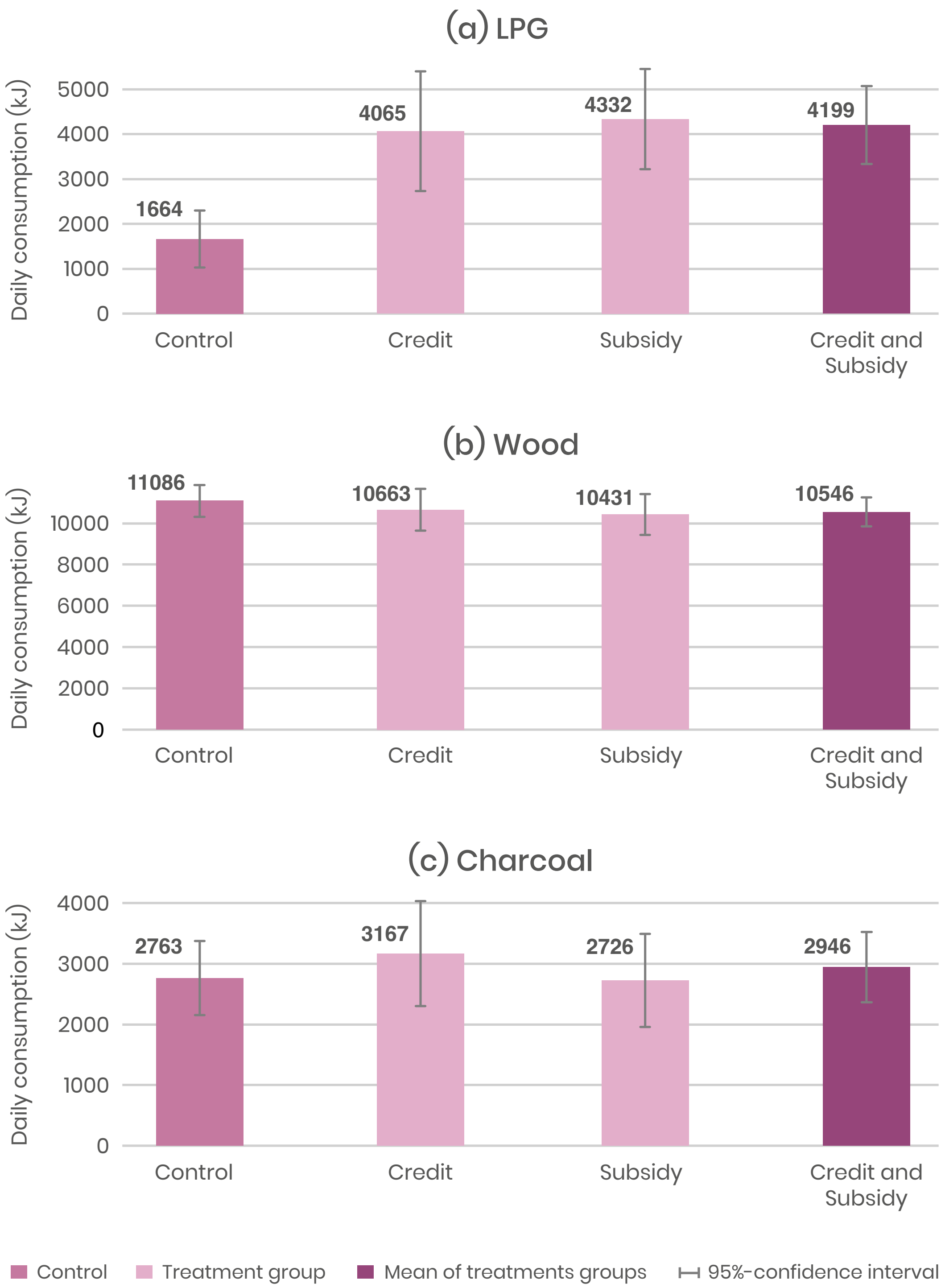
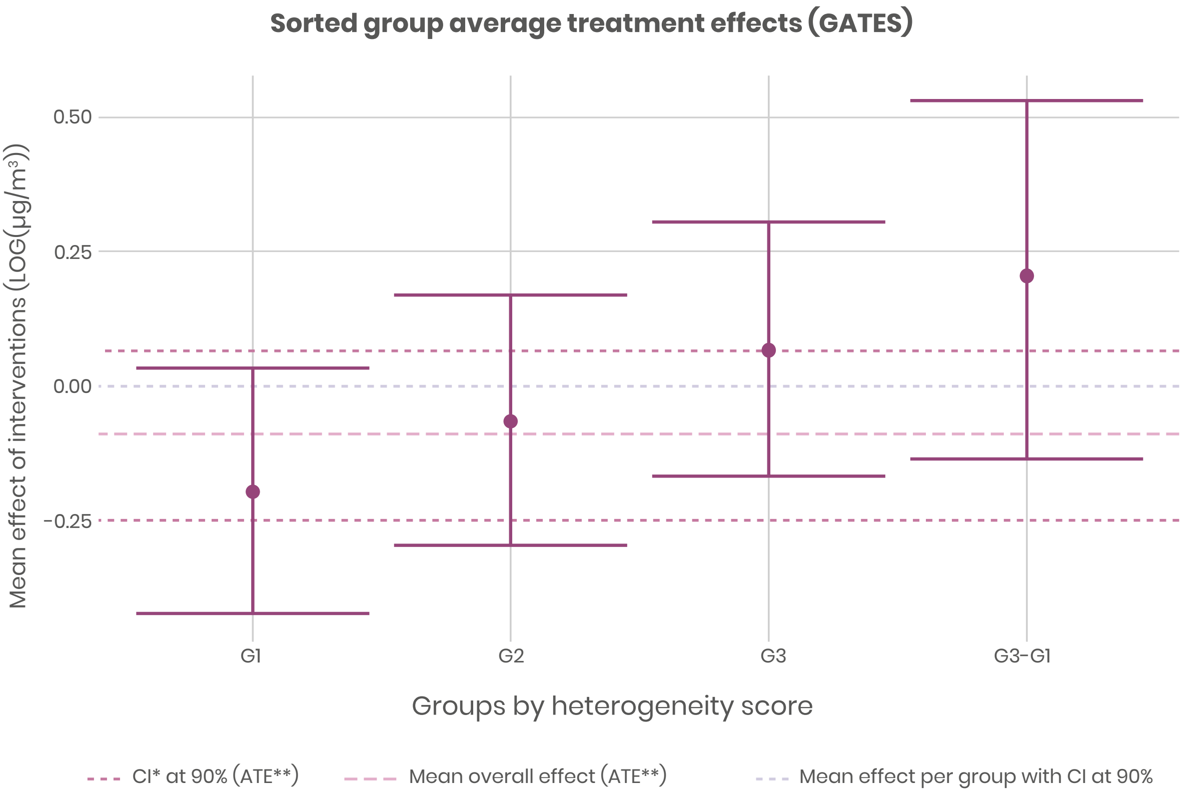
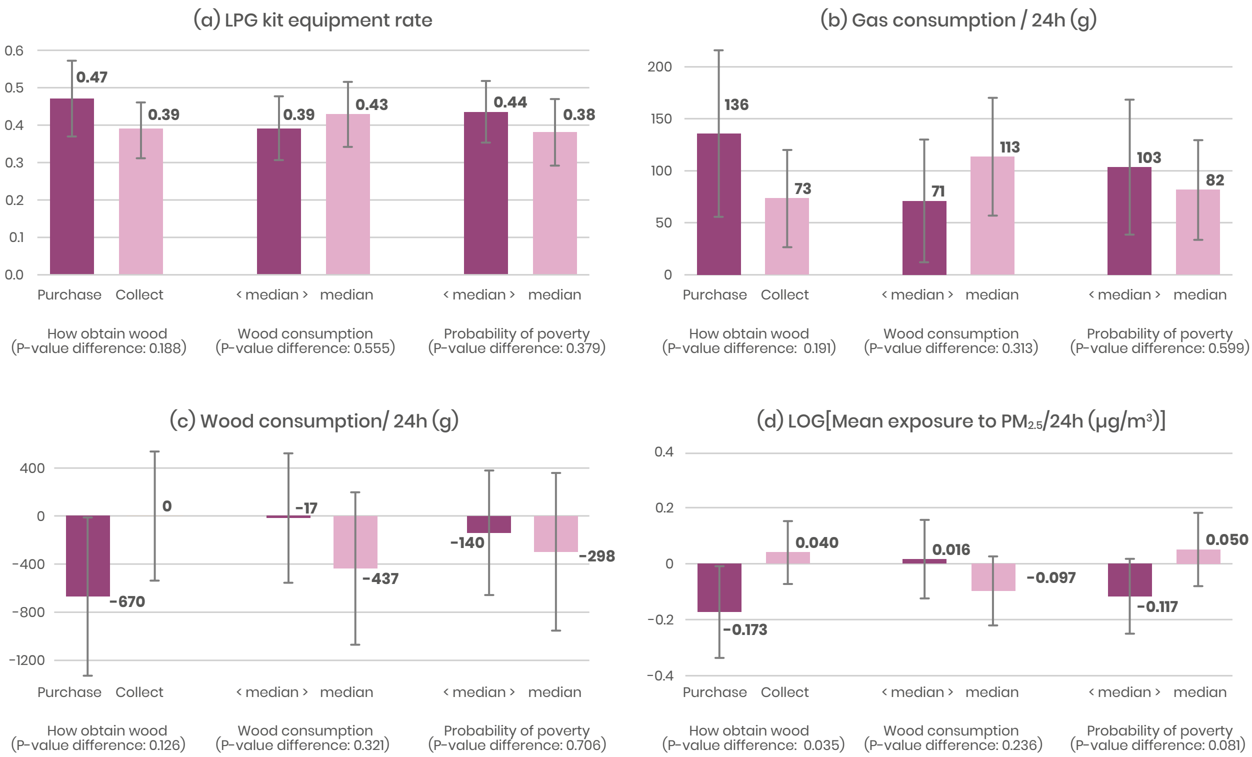


Figure A.4 – Analysis of the heterogeneous effects of interventions by heterogeneity group according to the method of Chernozhukov *et al.* (2018)



*C.I.: confidence interval; **ATE: average treatment effect

Figure A.5 – Mean effect of interventions by main dimensions of heterogeneity



NB: Coefficients and 95%-confidence intervals for estimating the average effects of interventions using post-double LASSO (Belloni, Chernozhukov and Hansen, 2014). Each coefficient is derived from a separate regression. Confidence intervals calculated from hetroskedasticity-robust standard errors.

Table A.1 – Analysis of pre-intervention differences between groups

	(1) Control		(2) Credit		(3) Subsidy		(4) Pairwise t-test		(3)-(2) Pairwise t-test		(4)-(2) Total	
Variable	**N**	**Average**	**N**	**Average**	**N**	**Average**	**N**	**Average**	**N**	**P-value**	**N**	**P-value**
Household size	775	5.515 (2.809)	325	5.662 (2.989)	224	5.362 (2.841)	226	5.456 (2.493)	549	0.255	551	0.421
Gender of household head [Female=1]	755	0.261 (0.439)	325	0.243 (0.430)	224	0.281 (0.451)	226	0.265 (0.443)	549	0.329	551	0.573
Household head attended school [yes=1]	775	0.298 (0.458)	325	0.320 (0.467)	224	0.268 (0.444)	226	0.296 (0.458)	549	0.179	551	0.566
Probability of poverty [<USD 1.90/day=1]	775	30.894 (20.796)	325	30.607 (21.033)	224	32.329 (20.911)	226	29.883 (20.351)	549	0.325	551	0.703
Collect their wood [yes=1]	775	0.657 (0.475)	325	0.665 (0.473)	224	0.643 (0.480)	226	0.659 (0.475)	549	0.547	551	0.826
Wood consumption (g/day)	775	5157.243 (3038.954)	325	5053.621 (2900.860)	224	5132.867 (3291.133)	226	5330.419 (2978.279)	549	0.766	551	0.279
Possess an LPG kit [yes=1]	775	0.081 (0.273)	325	0.089 (0.286)	224	0.076 (0.265)	226	0.075 (0.264)	549	0.601	551	0.569
Useful energy consumption/day [kj]	775	13877.537 (7384.376)	325	13681.310 (7037.851)	224	13710.878 (7935.040)	226	14324.907 (7318.824)	549	0.974	551	0.292
Exposure to $PM_{2.5}$ (µg/m³/24hrs.)	775	178.494 (241.151)	325	185.112 (235.616)	224	165.692 (229.366)	226	181.667 (260.249)	549	0.353	551	0.891

NB: Standard deviations in brackets.

Heterogeneous effects

Firstly, the indicator of interest is the heterogeneity coefficient presented in column 2 of Table A.2. This coefficient is statistically significant at 5%, indicating that the average effect of the interventions on exposure to fine particles is not homogeneous. Figure A.4 shows the diversity of sizes and the orientation of effects according to the heterogeneity score. Finally, Table A.3 provides a classification analysis that compares the observable characteristics of the tercile most affected by the interventions with those of the least affected tercile, in order to identify the most relevant variables to explain the heterogeneity of the effect of the interventions on exposure to air pollution.

Table A.2 – Analysis of the average conditional effect of treatments according to the best linear predictor (BLP).

ATE (ß1)*	HTE (ß2)ǂ
-0.09	21.98
(-0.25, 0.07)	(0.67, 83.53)
[0.253]	[0.045]

NB: Learning supervised by neural network. medians from 100 splits. 90%-confidence intervals in brackets. P-values for the test of the null-hypothesis of a coefficient size equal to zero in square brackets.
*ATE: Average Treatment Effect;
ǂ HET: Heterogeneity loading.

Table A.3 – Classification analysis

	33% more affected (G1)	33% less affected (G3)	Difference (G3-G1)
Exposure to $PM_{2.5}$ (μg/m³)	160.34 (125.98, 196.78) -	201.63 (152.66, 250.07) -	40.56 (-22.29, 101.48) [0.16]
Wood consumption (g)	5539.41 (4898.85, 6136.1) -	4723.83 (4303.15, 5144.51) -	-797.07 (-1532.77, -18.02) [0.045]
Closed kitchen [Yes=1]	0.54 (0.45, 0.62) -	0.76 (0.68, 0.83) -	0.23 (0.12, 0.34) [0.000]
Closed kitchen [Yes=1]	0.38 (0.29, 0.46) -	0.31 (0.23, 0.39) -	-0.07 (-0.18, 0.05) [0.275]
Probability of poverty	25.56 (22.13, 28.64) -	39.02 (35.59, 42.53) -	13.70 (8.9, 18.45) [0.000]
Household size	5.08 (4.62, 5.57) -	5.87 (5.3, 6.37) -	0.67 (-0.03, 1.43) [0.059]
Age of household head	47.53 (44.87, 50.16) -	50.63 (48.28, 53) -	3.24 (-0.33, 6.77) [0.073]
Household head able to read [Yes=1]	0.08 (0.03, 0.13) -	0.05 (0.01, 0.08) -	-0.03 (-0.1, 0.03) [0.249]
Household head able to to write [Yes=1]	0.07 (0.02, 0.11) -	0.03 (0, 0.06) -	-0.03 (-0.09, 0.03) [0.275]

NB: Classification analysis of the effect of the interventions on exposure to fine particles according to the method developed in Chernozhukov *et al.* (2020). Medians derived from 100 splits. 90%-confidence intervals in brackets. P-values for the test of the null-hypothesis of a coefficient size equal to zero in brackets.

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