REPORT

# BUILDING EVIDENCE TO UNLOCK IMPACT FINANCE

## A Field Assessment of Clean Cooking Co-Benefits for Climate, Health, and Gender

ESMAP
Energy Sector Management Assistance Program
THE WORLD BANK
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Ci-Dev
CARBON INITIATIVE FOR DEVELOPMENT

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1818 H Street NW, Washington, DC 20433
Telephone: 202-473-1000; Internet: www.worldbank.org

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# Acknowledgments

This report documents the findings from a field study that sought to build experience and evidence for quantifying the climate, health, and gender co-benefits from clean cooking interventions. The study was managed by a cross-sectoral World Bank team led by Yabei Zhang (Senior Energy Specialist) and Zijun Li (Energy Specialist) and consisted of Caroline Adongo Ochieng (Energy Consultant), Kathleen G. Beegle (Lead Economist), Jennifer Solotaroff (Senior Social Development Specialist), Yevgen Yesyrkenov (Senior Carbon Finance Specialist), Tamer Samah Rabie (Lead Health Specialist), Stephen Geoffrey Dorey (Senior Health Specialist), Inka Ivette Schomer (Energy/Gender Consultant), Jingyi Wu (Energy Consultant), and Alisha Noella Pinto (Energy Consultant). The study design also benefited from inputs provided by Matthew David King (Senior Climate Finance Specialist), Chandra Shekhar Sinha (Lead Climate Specialist), and Besnik Hyseni (Energy Specialist).

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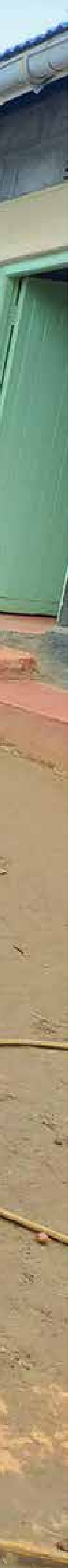
# Acronyms and Abbreviations

| | |
|---|---|
| ABODE | Air Pollution Burden of Disease Explorer |
| aDALY | averted disability-adjusted life year |
| ALRI | acute lower respiratory infections |
| BC | black carbon |
| BCe | black carbon equivalents |
| $CO_2e$ | carbon dioxide equivalents |
| FGD | focus group discussion |
| HAP | household air pollution |
| HAPIT | Household Air Pollution Intervention Tool |
| ISO | International Organization for Standardization |
| LMIC | low-and-middle-income countries |
| LoD | limit of detection |
| LPG | liquefied petroleum gas |
| LSM | Living Standards Measure |
| MTF | Multi-Tier Framework |
| OC | organic carbon |
| PE | personal exposure |
| PM | particulate matter |
| $PM_{2.5}$ | particulate matter with median diameter of 2.5 μm or smaller |
| RBF | Results-Based Financing |
| SDG | Sustainable Development Goal |
| SLCP | short-lived climate pollutant |
| SUM | stove use monitor |



# Key Findings

**Results-Based Finding (RBF) is viewed as an innovative mechanism to support results-based payment streams from impact buyers.** Successful application of impact-level RBF instruments in the clean cooking sector has been observed for the climate co-benefit, where the carbon finance market for averted greenhouse gas (GHG) emissions has enjoyed strong performance. Supplementing existing GHG emission-reduction credits with tradeable assets from clean cooking's additional co-benefits requires building field experience and evidence using rigorous methods and tools that can be confidently applied on a wide scale.

**This study reviewed existing methodologies for measuring and quantifying the climate, health, and gender co-benefits from clean cooking interventions (Phase 1), followed by a field-test case (Phase 2),** covered in this report. The Phase 2 objectives were to validate the various methodologies in a real-world setting, agree on methodological assumptions, understand field procedures and cost implications, and make recommendations for further field application and improvement. A biogas technology already applied in rural Kenya was competitively selected for methodology testing. Significant development impacts from the household adoption and use of the biodigester system—in addition to the traditional $CO_2$ emission reductions, which are well-demonstrated under the Gold Standard and Clean Development Mechanism (CDM) frameworks—were measured and quantified for the three co-benefits.

**The study coincided with and complemented an International Finance Corporation (IFC)–supported study on the same clean cooking intervention in another location of rural Kenya.** Based on positive co-benefit outcomes from that study, which were consistent with those of this Phase 2 study, the first Clean Impact Bond transaction was signed, offering a practical example of stakeholder demand for innovations in co-benefits monitoring that this study aimed to advance. To our knowledge, these two independent studies are the first to have attempted to quantify multiple co-benefits from clean cooking interventions with the goal of monetizing them for impact investment.

**Using field-based emission factors as defaults, this study estimated the net reduction in black carbon equivalents (BCe) across the biogas program's five-year, carbon-offset cycle at 963 tonnes for an estimated 84,000 biogas digesters.** The performance results revealed a large difference in estimated BCe reductions using the current Gold Standard methodology (100 t BCe) compared to applying field-based emission factors from the literature (963 t BCe). The factor driving this difference is the much larger BC emission factor for wood stoves in the field (1.43 g per kg) compared to the laboratory (0.22 g per kg).

**Measured personal exposure (PE) to particulate matter ($PM_{2.5}$) decreased linearly according to the fuel-use behavior of the primary cooks.** The highest average exposure (126.5 µg per $m^3$) was observed in households that only used biomass fuels. The subset of households that used biogas exclusively and/or stacked only with other clean fuels, such as liquefied petroleum gas (LPG) and ethanol, had the lowest exposure, at 53.5 μg per $m^3$ on average. Results of a hypothetical high-contrast scenario comparing exclusively clean-fuel-using biogas households with exclusively biomass-using households in the control group showed a 58 percent exposure reduction. The PE difference observed between households in the biogas and control groups overall would result in 323 averted disability-adjusted life years (aDALYs) per year for each 10,000 homes with a functioning biodigester.

**Female primary cooks in biogas-using households reported spending less time on cooking and drudgery, as well as greater satisfaction with time available for rest and leisure.** Time-use surveys indicated time savings of 35 minutes per day on cooking activities in association with biogas adoption, and a reduction of 7.7 hours per week on activities perceived as drudgery. While these time savings did not consistently translate into a quantitative finding of increased time spent on productive activities or rest and leisure, most primary cooks in biogas-using households were positive about the technology's impact on their lives and satisfied with the amount of time available for leisure—a measure more closely related to time-use agency. These findings suggest the biogas system was yielding important improvements for time-use agency and thus empowerment among its users.

**Existing methodologies to assess short-lived climate pollutants (SLCPs) and health benefits are feasible approaches that warrant promotion.** This study confirmed that the existing Gold Standard methodologies to mitigate SLCPs and reduce adverse health benefits are largely well poised to efficiently assess program impact for RBF. The study also identified opportunities for their improvement. For example, SLCP benefit estimation can be simplified by making use of recently published emission factors from field-based activities.

**The methodology for assessing the gender impact of clean cookstove adoption requires further development, including new instruments for measuring time-use agency.** A large proportion of the primary cooks (most of them women) reported a substantial positive impact of biogas on their lives that was not linked to health or climate benefits, suggesting empowerment pathways not captured by time use. Future programs should consider making use of new field-tested instruments for measuring time-use agency that were not available at the time of this study. In addition, a rating system could be considered for the gender co-benefit using letters and/or symbols (AA, B+) to effectively reflect the range of confidence levels in the co-benefit measurements and the qualitative and temporal aspects.

**The study recommended key actions to improve the feasibility and cost-effectiveness of co-benefits monitoring.** Prior to starting co-benefits monitoring, diagnostic research should be conducted to characterize the customer group, develop the screening criteria for a matched control group, and pre-qualify potential participants for the research. Also, donors should build monitoring capacity, relationships with institutional review boards, and filter-weighing facilities for household air pollution (HAP) in the regions where cookstove programs are under way or anticipated. In the interim, larger-scale, results-based carbon finance projects should consider concurrent, rather than independent, measurements of the SLCP, health, and gender co-benefits, given the strong synergies found among these measurements; however, for many small- and medium-sized carbon projects, the resource and capacity demand of these assessments may prove prohibitive. Stove use monitors (SUMs) should only be required for larger-scale projects. For smaller-scale projects, modern cooking devices with self-embedded meters for measuring cooking fuels used to enable the pay-as-you-go business model offer opportunities for better and more cost-effective measurements.

# Executive Summary

**Clean cooking access for all—Sustainable Development Goal (SDG) indicator SDG 7.1.2—is key to achieving SDG 7 and related SDG targets for, health, gender, and climate.** Along with electrification, clean cooking is an essential component to achieving SDG target 7.1—ensuring universal access to affordable, reliable, and modern energy services. Beyond energy access, the adoption and use of clean cooking solutions are expected to provide co-benefits that contribute to meeting the SDG targets of multiple sectors, particularly closely related ones.[1]

**The World Bank estimates that lack of progress on clean cooking is costing the world more than US$2.4 trillion each year,** driven by the adverse impacts for health (US$1.4 trillion), gender (US$0.8 trillion), and climate/environment (US$0.2 trillion) (ESMAP 2020a). The stark reality is that some 2.4 billion people currently live in cooking poverty, meaning that they rely on polluting traditional fuels and technologies to cook their meals. Without accelerated action, one can expect that 2.1 billion will remain in cooking poverty in 2030. Between 2015 and 2019, the annually tracked clean-cooking investment commitments in 20 high-impact countries languished at around US$130 million (SEforALL 2021), far less than the estimated US$25 billion per year needed to reach universal access by 2030 (United Nations 2021). This means that substantial public and private investments are needed to close the large access-deficit gap.

**Results-Based Financing (RBF) is viewed as an innovative financing instrument that can allow for capital mobilization from both the public and private sectors.** At the output and outcome levels, RBF allows public-sector entities to specify results and subsidies and pay private-sector suppliers against third-party verified delivery of stoves and their performance. Recently, RBF has been gaining popularity as an innovative mechanism to support results-based payment streams from impact buyers. At present, private-sector players have a significant potential to level up their returns on investment in the clean cooking sector (e.g., from carbon finance) (ESMAP 2023). There is a growing appetite for applying RBF to the clean cooking sector by the World Bank and other development organizations.

**Rigorous methods and tools that can be confidently applied on a wide scale are required to quantify and monetize the impacts of clean cooking interventions.** To date, the generation of tradeable impact assets from clean cooking interventions has been limited to averted greenhouse gas (GHG) emissions. This situation can be explained, in part, by the lack of advanced methods to measure and monetize the additional co-benefits of interventions

1 Access to clean cooking is strongly aligned with SDG 3, "Ensure healthy lives and promote well-being for all at all ages;" SDG 5, "Achieve gender equality and empower women and girls;" and SDG 13, "Take urgent action to combat climate change and its impacts."

(e.g., for health and gender). Supplementing existing GHG emission-reduction credits with tradeable assets from clean cooking's additional co-benefits requires building field experience and evidence using methodologies that can be confidently applied.

## Study Purpose and Target Audiences

**This study was conducted with the purpose of validating, in a real-world setting, the measurement of co-benefits that accrue from the adoption of clean cooking interventions.** The existing methodologies for measuring the add-on benefits of clean cooking interventions have remained untested and underutilized. This situation can be attributed to various factors, among which are lack of awareness of the methods, lack of field evidence on their performance, whether the methods can be applied in an integrated fashion, and their demonstrated strengths and limitations. This study attempted the accurate and concurrent measurement and quantification of three co-benefits that would generate additional tradeable assets to supplement the existing GHG emission-reduction credits for clean cooking interventions.

**The report targets a wide range of stakeholders across the clean cooking industry. For impact buyers,** the commitment to pay for benefits can only come if the achievement of pre-agreed results is verifiable in a robust, cost-effective, and scalable manner. This includes measures that avoid "gaming" the system (e.g., through double-counting results). This report contributes to bridging this gap by bringing to the fore novel methodologies that have been developed, demonstrating their feasibility and potential, as well as their strengths, limitations, and areas for further development. For **project developers and implementers,** the lack of impact buyers is a barrier to adopting the verification methodologies, given the high cost of monitoring the wide range of co-benefits that accrue from clean cooking operations. A commitment to purchase verified results would provide much needed certainty for project developers to invest in and expand the scope of their monitoring beyond GHG emission reductions. Beyond these primary stakeholders, the report offers practical lessons and guidance for many others along the RBF value chain—**researchers and verification agents, technology suppliers, multilateral and bilateral donors and governments,** and **other cadres of investors**—helping to incentivize them to monetize additional streams of co-benefits beyond GHG emission reductions by demonstrating the wide scale of impacts from clean cooking interventions.

## Study Approach and Methods

The following three co-benefits from clean cooking interventions were investigated:

*Climate*—Measured as a reduction in the warming impacts from black carbon (BC) and other short-lived climate pollutants (SLCPs), in addition to the traditional carbon dioxide-equivalent ($CO_2e$) emission reductions measured by well-established methodologies.

*Health*—Measured as averted disability adjusted life years (aDALYs) and improvement in perceived well-being.

*Gender*—Measured as an increase in women's time used for productive tasks and/or rest and leisure and a decrease in their time engaged in tasks related to procurement of cooking fuels and/or tasks perceived as drudgery.

**The study comprised a review of existing methodologies for measuring these co-benefits (Phase 1) (ESMAP 2020b), followed by the field test case (Phase 2),[2] covered in this report.** Objectives of the Phase 2 test case were to validate the methodologies in the field, agree on methodological assumptions, understand field procedures and cost implications, and make recommendations for further field application and improvement. To fulfill the study purpose, a biogas project in rural Kenya implemented by Sistema.bio was competitively selected for testing the assessment methods for each of the three co-benefits (box ES.1).

The study sample comprised 300 households in two counties of rural Kenya,[3] drawn from a random sample of program beneficiaries and a matching control group that had not adopted

**BOX ES.1**

### COMPLEMENTARITIES WITH CLEAN IMPACT BOND PILOT TRANSACTION

This study has strong complementarities with the first Results-Based Financing (RBF) transaction on measured health and gender co-benefits from the Sistema.bio project. The first pilot transaction of the Clean Impact Bond (CIB)—an RBF model that monetizes health and gender co-benefits from clean cooking interventions for low-income households—was signed at the time of this report's completion for the measured health and gender co-benefits; these were based on positive findings from an International Finance Corporation (IFC)–funded study conducted for the same clean cooking intervention (biogas) in another rural location of Kenya. The CIB transaction offers a practical example of stakeholder demand for innovations in co-benefits monitoring that this report aimed to advance.

*Source:* World Bank.

2 One should note that the field test case is not an impact evaluation of the selected clean cooking technology.

3 For the BC and health impact assessments, sample sizes are consistent with Gold Standard methodology recommendations.

the biogas system. As this was not an impact evaluation, the sample size and other design considerations were informed by a range of criteria assessed during Phase 1, including cost-effectiveness, scalability, and operational feasibility, among others. The field study entailed two rounds of data collection using multiple data-collection methods and instruments, including household surveys, focus group discussions (FGDs), personal exposure (PE) measurements, instrumental monitoring of stove use, and emissions modeling.

## Performance of the Biogas Intervention

**Significant outcomes from the household adoption and use of the biodigester systems were measured and quantified for the climate, health, and gender co-benefits.** These outcomes are in addition to the traditional $CO_2$e emission reductions, which are well-demonstrated under the Gold Standard and Clean Development Mechanism (CDM) frameworks. The performance results are presented in table ES.1.

**Biogas was found to emit considerably less black carbon (BC) compared to wood, resulting in substantial mitigation potential for short-lived climate pollutants (SLCPs).** Applying recently published field-based emission factors across Sistema.bio's five-year, carbon-offset project cycle for an estimated 84,000 biogas digesters, the study estimated a net reduction of approximately 963.4 tonnes in BC equivalents (BCe).[4,5] In addition, Sistema.bio's carbon offset project, through the Gold Standard certification framework, generates annual GHG emission reductions amounting to 57,500 t$CO_2$e per 10,000 homes.

**In biogas-using households, measured personal exposure (PE) to $PM_{2.5}$ decreased to a range that can be associated with important health improvements for the population.** The reduction of PE to $PM_{2.5}$, at approximately 32 μg per $m^3$ over the 48-hour monitoring

**TABLE ES.1**

**Key study outcomes from the adoption and use of biogas cooking technology**

| CO-BENEFIT | KEY IMPACTS | UNIT | VALUE |
|---|---|---|---|
| Climate | Reduction in black carbon (BC) equivalents | Tonnes per 10,000 homes per year | 22.9 |
| | Reduction in carbon dioxide ($CO_2$) equivalents[a] | t$CO_2$e per 10,000 homes per year | 57,500 |
| Health | Reduction in particulate matter ($PM_{2.5}$) exposure | μg per $m^3$ over the 48-hour monitoring period | 32 |
| | Averted disability-adjusted life years (aDALYs) | per 10,000 homes per year | 323 |
| Gender | Time savings on cooking activities | Minutes per day | 35 |
| | Reduction in activities considered drudgery | Hours per week | 7.7 |

*Source:* World Bank.

a. Based on 2018–19 issuance of the carbon credits to the developer (the biogas intervention was already registered for carbon credits).

4 One kilogram of BC is about 460 times more potent than an equivalent amount of $CO_2$ over a 100-year time horizon and 1,600 times more potent over a 20-year horizon based on unofficial estimates of the Intergovernmental Panel on Climate Change (IPCC). The IPCC estimates of global warming potential are conservative compared to others in the published literature.

5 BCe is analogous to $CO_2$e, both of which normalize the warming impact of an emission species to the equivalent quantity of BC or $CO_2$, respectively.

period, was estimated to avert 323 disability-adjusted life years (aDALYs) per year for every 10,000 homes with a functioning biodigester system. However, the reduced exposure level still exceeds the latest guidelines for global $PM_{2.5}$ air quality established by the World Health Organization (WHO 2021), suggesting the need to address other sources of air pollution in order to maximize health benefits.

**Biogas use was also associated with significant time savings and drudgery reductions for female primary cooks, although the impact on gender empowerment is to be further defined.** Time-use surveys indicated time savings of 35 minutes per day on cooking activities in association with biogas adoption, and a reduction of 7.7 hours per week on activities considered drudgery. However, these time savings did not consistently translate into a quantitative finding of increased time spent on productive activities or rest and leisure. That said, 78 percent of the primary cooks in households that adopted biogas were overwhelmingly positive about the substantial impacts the technology had had on their lives.

**Considerable stacking of biogas with lower-grade fuels limited the co-benefits associated with the technology adoption.** More than 85 percent of the biogas-using households in this study considered biogas as their primary fuel. However, simultaneous or intermittent use of wood and/or charcoal alongside cleaner fuels for cooking was observed in 76 percent of biogas-using homes. Stacking with other clean fuels, such as liquefied petroleum gas (LPG) and ethanol, was observed in a smaller number of biogas-using households.

## Methodological Findings

**The study found that field-based emission factors from the literature provide a more accurate means of quantifying SLCP impacts than does the Gold Standard methodology.** A comparison of the two methodologies for estimating SLCP impacts yielded quite divergent results. The approach using field-based emission factors indicated a tenfold increase in BC savings, suggesting the need to update the Gold Standard's SLCP methodology with the newer field emissions data to improve its accuracy.

**The Gold Standard methodologies for estimating aDALYs (using measured PE to $PM_{2.5}$) were efficient and feasible for conducting in a field setting.** However, the up-front cost of this measurement on a per-sample basis is fairly high. Thus, it could be cost-effective for larger programs but would likely present a barrier for smaller ones.

**One should carefully consider the distinguishing features of this study when generalizing its findings to other populations and interventions.** This includes the prevalent use of LPG as the primary or secondary fuel in both the intervention and matched control groups; sporadic procurement of wood fuel with portions of the procurement process delegated to hired help; and the surprisingly lack of seasonal effect on fuel availability and usage patterns. Future studies and RBF programs should carefully consider these aspects, as they would determine the methodology used to measure benefits and the results.

## Recommendations Moving Forward

**Existing co-benefit methodologies to assess SLCPs and health benefits are largely well poised to efficiently assess program impact for RBF and warrant promotion.** Their use should not be deterred because of limited field-based data to provide default emission-factor estimates for BC and organic carbon (OC). Instead, such limitations should incentivize further development of the methodologies. This study identified several opportunities for methodology improvement, including simplifying SLCP benefit estimation by making use of recently published emission factors from field-based studies.

**The methodology for assessing the gender impact of clean cookstove adoption requires further development, including new instruments for measuring time-use agency.** Despite the reported time savings, time-use surveys did not yield significant differences between primary cooks in the biogas-using and control groups related to time spent on activities more closely linked to women's empowerment. That said, a large proportion of the primary cooks (nearly all of them women) reported a substantial positive impact of biogas on their lives that was not linked to health or climate benefits, suggesting empowerment pathways not captured by time use. Future programs should consider making use of recently developed and field-tested instruments for measuring time-use agency in low-and-middle-income countries (LMIC) that were not available at the time of this study (Sinharoy et al. 2021). In addition, a rating system using letters and/or symbols (e.g., AA, B+) could be considered to reflect the range of confidence levels in the gender co-benefit measurements and effectively reflect the qualitative and temporal aspects.

**Baseline fuel-use patterns should be carefully considered at project design since they heavily determine the co-benefits.** The adoption of clean cooking technologies is often associated with increasing socioeconomic status. As a result, those households most likely to transition to a clean-fuel technology may already be using other clean alternatives (at least sporadically) alongside traditional fuels. In theory, greater benefits could be expected via a full transition from exclusive use of biomass fuels to the use of clean ones; however, such a scenario rarely occurs in reality.

**Shifts in clean cooking interventions' rates and patterns of adoption should be monitored and accounted for in impact estimates.** Impact is associated not only with the rate of adoption of the new technology; it is also related to the degree to which clean cooking adopters abandon polluting technologies. In this study setting, more than 76 percent of biogas adopters also continued cooking with biomass fuels on traditional cookstoves, which attenuated the effect of adopting the clean cooking intervention. Such factors as renewability, production processes, and combustion techniques associated with continued biomass use should also be considered. Overall, reducing the continued use of polluting technologies among biogas adopters would be expected to enhance climate, health, and gender co-benefits.

**Results-based carbon finance projects should consider concurrent measurements of SLCP, health, and gender co-benefits.** This study found strong synergies among these measurements, suggesting that concurrent measurements could be more cost-effective than measuring each outcome independently. However, this recommendation would most likely apply to large-scale projects in the interim. For many small- and medium-sized carbon projects, the resource and capacity demand of these assessments may prove prohibitive.


# ONE INTRODUCTION

## Impacts of Traditional Stove-and-Fuel Dependence

Worldwide, some 2.4 billion people live in cooking poverty, meaning they rely on polluting, traditional fuels and technologies (e.g., wood and coal) to cook their meals,[6] with severe consequences for public health, the environment/climate, and advancement toward gender equality. According to recent estimates, household air pollution (HAP) from cooking contributed to 2.3 million deaths or about 4 percent of all global deaths in 2019 (HEI 2020). Women and children are disproportionately affected as they spend the most time in proximity to stoves and bear much of the burden of cooking, as well as collecting firewood and other traditional fuels.

Incomplete combustion of fossil fuels and biomass emits a variety of climate-heating particles. The most important is black carbon (BC), a component of particulate matter (PM) air pollution and a significant human-caused contributor to global warming. In low-and-middle-income countries (LMIC), residential heating and cooking practices using such solid fuels as coal and biomass (e.g., wood, crop residues, and dung) are important sources of BC emissions. An estimated 44 percent of anthropogenic BC emissions has been attributed to household fuel combustion (Klimont et al. 2017). Short-lived climate pollutants (SLCPs) like BC have a larger impact than $CO_2$ on global temperatures and the climate system over short periods. BC may be responsible for close to 20 percent of the planet's warming (World Bank and CCAC 2015), making it the second largest contributor to climate change. Estimates show that household energy is the single largest controllable source of BC globally, accounting for up to 58 percent of emissions caused by human activities (IIASA 2017). Clean cooking, heating, and lighting technologies can reduce BC and other SLCP emissions.

The gender implications of biomass reliance extend beyond the adverse health impacts associated with disproportionate HAP exposure. Time poverty—arising from time spent gathering and preparing fuel, preparing and cooking food, and cleaning utensils and the cooking and eating areas—is another well-documented consequence of dependence on traditional fuels and stoves. World Bank data from more than 70 time-use surveys across various geographies shows that fuel collection is a significant time-opportunity cost for rural households, consuming an average of 1.3 hours per day (ranging from 30 minutes to more than 6 hours) (ESMAP 2022). The gender cost of inaction, in the form of women's lost productivity associated with time use, is estimated at US$0.8 trillion per year (ESMAP 2020a). Other documented gender impacts include safety hazards and risks to well-being during fuel collection and cooking, as well as drudgery.

6 Universal access to clean cooking is the goal of Sustainable Development Goal (SDG) indicator 7.1.2. Between 2010 and 2020, the number of people gaining access to clean cooking on a global scale rose steadily; however, those gains were uneven by region. In Sub-Saharan Africa, where population growth outpaced access gains, the access deficit in 2020 totaled 923 million people, the highest among all world regions (IEA et al. 2022).

## Results-Based Financing in the Clean Cooking Sector

Lack of financing has greatly impeded development of the clean cooking sector. Estimates by Sustainable Energy for All (SEforALL 2021) show that clean cooking investments have fallen critically short of the US$25 billion needed annually to achieve the universal access ambition (United Nations 2021), with only a small number of capital providers and a few large projects operating in a handful of countries. The latest SDG 7 tracking report highlights that international public financial flows to developing countries in support of clean energy decreased for the second year in a row, falling to US$10.9 billion in 2019 (IEA et al. 2022). Closing the large access-deficit gap requires substantial public and private investments, including redirecting the significant household funds currently being spent on unclean energy, particularly in Sub-Saharan Africa.

Results-Based Financing (RBF) is viewed as an innovative financing instrument that can allow for capital mobilization from both the public and private sectors. Its basic features are (1) payments made to a recipient contingent on achievement of previously agreed results; (2) discretion given to the recipient as to how results are achieved; and (3) verification of the achievement of results undertaken before disbursement occurs. Aligned with these features are key actors in the value chain, including the funder (results purchaser), implementing agency, service provider, and independent verifier. By linking investments to results, RBF allows for the alignment of clean cooking targets with national policies and priorities, and offers a means of tracking investments and progress. In the lead-up to the 2021 UN Climate Change Summit, for example, some 67 countries had included household energy or clean cooking–related goals in their Nationally Determined Contributions (NDCs) (CCA 2021). Because discretion on how results are achieved are left up to the service provider, RBF can also catalyze technology and business innovations and cost-effectiveness in the delivery of results. In addition, by linking incentives to verified results, RBF enhances accountability for invested funds, thereby increasing investors' confidence.

Over the years, the World Bank has supported innovative financing approaches linking funding to the results delivered in order to enhance low-income households' access to basic infrastructure services (e.g., water and sanitation, health, education, and energy). Examples include investments in electricity access under the Global Partnership for Results-Based Approaches (GPRBA), as well as other project portfolios. In the clean cooking sector, successful application of RBF instruments has been observed for the climate co-benefit,[7] with the market for averted greenhouse gas (GHG) emissions having enjoyed strong performance.[8] The booming voluntary carbon market following new rules on Article 6 of the Paris Agreement,[9] was led, in no small part, by clean cooking projects garnering relatively high

7 Since 2015, the World Bank's investments in clean cooking and heating through the Efficient, Clean Cooking and Heating (ECCH) Program and the Clean Cooking Fund, operationalized in 2020, have totaled more than US$396 million and are steadily growing, with RBF instruments deployed in 67 countries to date.

8 The Clean Development Mechanism (CDM), Gold Standard, and Verified Carbon Standard (VCS) methodologies are widely accepted and used. According to Ecosystem Marketplace (August 2022), between 2005 and 2021, a total of US$8 billion from the sale of carbon offsets was mobilized for the efficient cooking sector in the voluntary carbon markets (Gold Standard and VCS).

9 Agreed to at the 2021 UN Climate Change Conference (COP26) held in Glasgow, Scotland.

prices (US$10 per $MTCO_2e$). However, RBF payments for the impacts generated from clean-cooking project interventions are not yet widely applied. This can be explained, in part, by the lack of advanced methods to measure and monetize the impacts of clean cooking interventions. Success of the market for averted GHG emissions has been underpinned by the following features that are yet to advance for other clean cooking co-benefits (Putti et al. 2015): (1) the development of widely agreed on methodologies for determining the quantity of avoided $CO_2e$ emissions resulting from an intervention; (2) credible, independent third-party verification of results; and (3) clear demand and a price signal for verified results (through a strong market price).

Borrowing from this experience, the World Bank works to support approaches whereby impact-driven funds could be deployed to pay for the verified co-benefits (i.e., climate, health, and gender impacts) from clean cooking interventions. A growing appetite for applying RBF to the clean cooking sector by the World Bank and other development organizations also necessitates the development of rigorous methods and tools that can be confidently applied on a wide scale to quantify and monetize these impacts to generate tradeable assets to supplement existing GHG emission-reduction credits.

## Co-Benefit Measurement Context

This study comprised a review of existing methodologies for measuring the climate, health, and gender co-benefits from clean cooking interventions (Phase 1), followed by the field test case (Phase 2) covered in this report. Phase 1, conducted in 2019–20, provided a thorough literature review on the evolution of co-benefit measurement methodologies, their applicability, and relative strengths and weaknesses (ESMAP 2020b). That study generated important learning for future impact quantifications, including informing this Phase 2 test case. The co-benefit outcomes of a separate 2021–22 study conducted by the International Finance Corporation (IFC) using the same clean cooking technology and intervention context were consistent with those of the Phase 2 study (box ES.1).[10,11] To our knowledge, no other studies to date have attempted to quantify multiple co-benefits with the goal of monetizing them for impact investment.

10 Application of the rigorous technology-selection criteria consistent with Gold Standard recommendations for BC evaluation virtually eliminated all other technologies; thus, it is not surprising that the two independent studies selected the same technology and intervention context. The advantages and drawbacks of applying such stringent criteria are discussed in this study's Phase 1 report (ESMAP 2020b).

11 While the two studies share key similarities, their populations and objectives differ. Unlike the Phase 2 study's focus on methodology testing, the IFC study's aim is application of the methods to measure the technology's co-benefits and pay for the impacts. Also, the IFC study does not include BC estimation.

## Field Study Objectives and Method

The Phase 2 field study sought to validate the various existing methodologies in a real-world setting, agree on methodological assumptions, understand field procedures and cost implications, and make recommendations for further field application and improvement.[12] The clean cooking intervention was selected through a competitive process.[13] A request for proposals (RFP) was issued, inviting all entities that disseminate clean stoves and/or fuels to household consumers to apply. The eligibility criteria were as follows:

- Promotion of the stove-and-fuel technology had to have achieved at least Tier 3 of the ISO/TR 19867-3:2018 voluntary performance targets on thermal efficiency, carbon monoxide (CO) emissions, and fine particulate matter (PM) emissions of cookstoves (ISO 2018a, 198). The stove's performance had to have been demonstrated by laboratory and/or field data, and field evidence of a high standard of safety and durability was also required.
- The stove-and-fuel combination was required to meet most household cooking needs.
- The fuel supply had to be environmentally sustainable.

In all, 12 applications were received and evaluated. Solutions submitted for consideration included improved cookstoves utilizing wood or charcoal (4), biogas (3), ethanol (2), electricity (1), liquefied petroleum gas (LPG) (1), and wood pellets (1). Out of these submissions, a biogas technology implemented by Good Farmland Management Kenya Ltd, the Kenyan subsidiary of Sistema.bio,[14] was selected.

## Target Audiences and Structure of This Report

The field study's findings and recommendations offer practical lessons and guidance for a wide range of stakeholders along the RBF value chain, including donors and governments, cookstove program developers, researchers, verification agents, and investors. The report is organized into five chapters, with additional materials available upon request (Appendix A). Chapter 2 presents an overview of the biogas technology and study methods and metrics for estimating its climate, health, and gender co-benefits. Chapter 3 provides the intervention's performance results for the three co-benefits, while chapter 4 turns to the challenges and opportunities in measuring them. Finally, chapter 5 concludes and summarizes recommendations for moving forward.

12 Outcome-level results were reported for each of the three co-benefits; however, they should not be treated as conclusive since the study's focus was not impact estimates.

13 Although not part of the eligibility criteria, priority was given to interventions implemented in Sub-Saharan Africa.

14 Sistema.bio is a global social enterprise that manufactures, sells, installs, and provides financing for biodigester systems for small- and medium-scale farmers; it has been selling biodigester/stove systems to rural Kenyan households since 2017.

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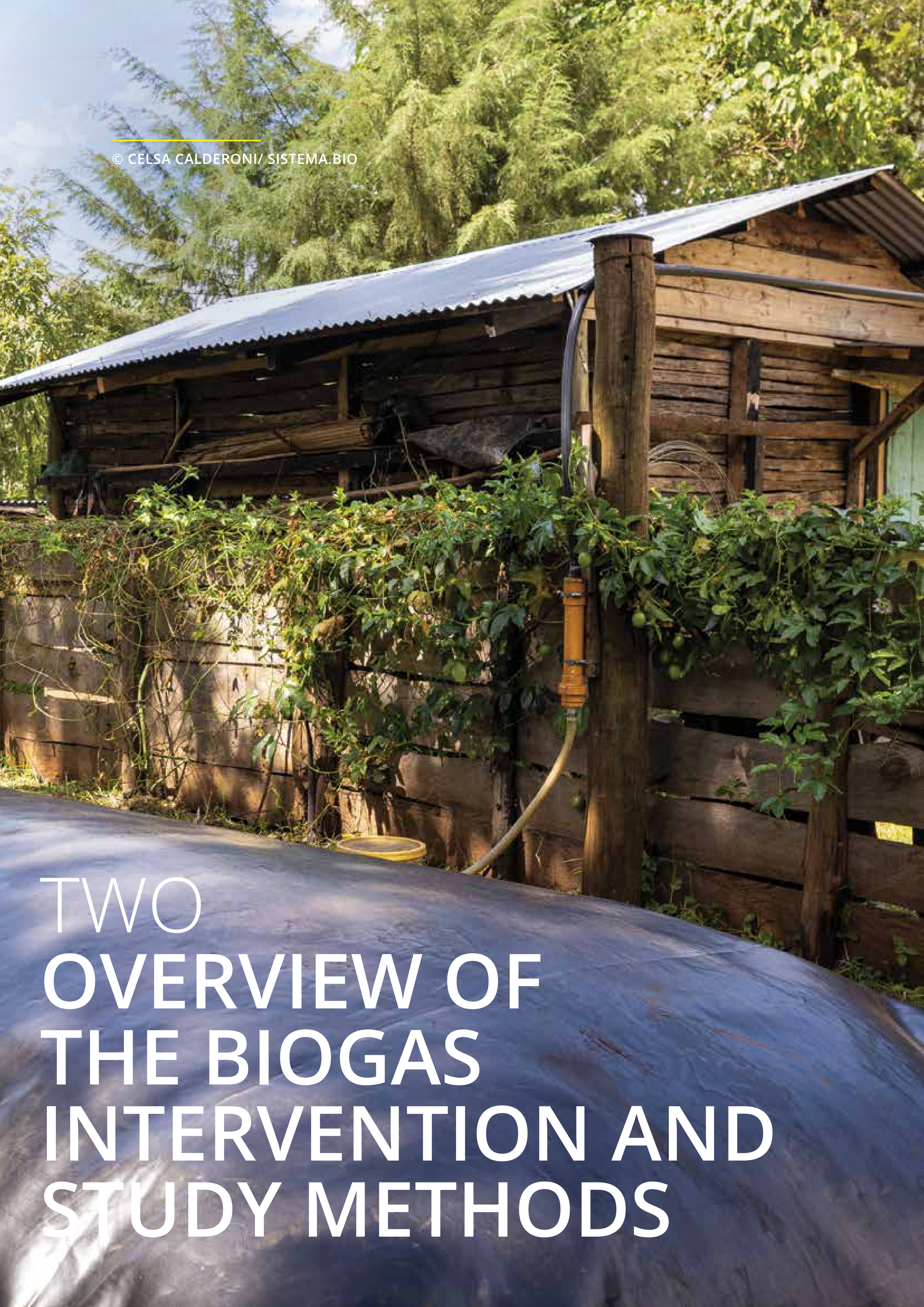
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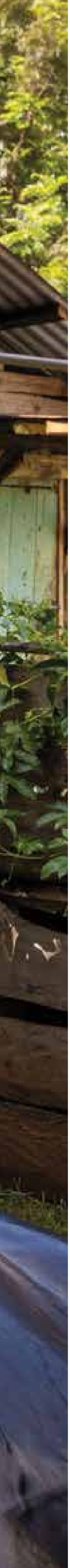
# TWO
# OVERVIEW OF THE BIOGAS INTERVENTION AND STUDY METHODS



## Key Features of Biogas

Biogas systems have been successfully implemented in numerous rural settings across South and Southeast Asia and Africa, although the reach of such programs remains fairly small in scale compared to the technology's potential (box 2.1). It has been estimated that 18.5–30 million households in Africa could be targeted for biodigester adoption, based on access to water and ownership of cattle (ESMAP 2019); to date, however, the rates of installation and adoption fall far short of these targets. Notably, biogas systems are best targeted to households that own upwards of two cows (and/or sixteen pigs) and have sufficient access to land and water to allow for the installation and maintenance of the biodigester. Household education and income levels have also been shown to correlate with adoption, with the effect of household income related to the ability to afford to install a digester and maintain it in good operation (ESMAP 2019).

A potential limitation of the biodigester system supplied by Sistema.bio is the higher socio-economic status of the biogas adopters and matching controls (i.e., middle-class and

**BOX 2.1**

### UNDERSTANDING BIOGAS SYSTEMS

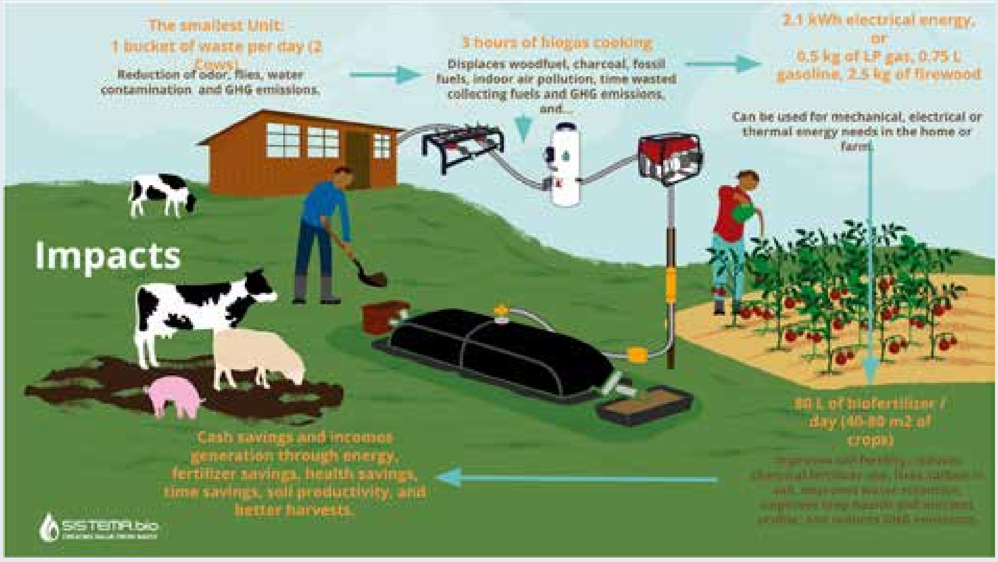
Biogas is a product of anaerobic digestion that occurs when organic waste (e.g., animal waste) is deposited in a biodigester: a closed, airtight vessel that allows for organic material to be degraded by bacteria in the absence of oxygen, converting it into a methane ($CH_4$) and carbon dioxide ($CO_2$) mixture. Biodigester technology ranges from simple plastic bags on beds of straw used to produce small amounts of gas for cooking to complex systems, such as Upflow Anaerobic Sludge Blanket (UASB) digesters used in farming installations, which are capable of producing several megawatts of electricity. In addition to cooking gas, the digester produces biofertilizer as a by-product of the conversion process (figure B2.1.1).

Biogas combustion is very clean and thermally efficient. With proper care and maintenance, biogas systems can have long durability. Various studies have shown that users appreciate the technology for financial and time savings (Clemens et al. 2018). It therefore has a high potential for displacing polluting household cooking technologies, as well as yielding substantial benefits for climate, health, and gender in some rural or peri-urban populations.

## BOX 2.1, *continued*

**FIGURE B2.1.1**

Life Cycle and Potential Benefits of the Biogas Stove System




*Source:* BAMG.

upper-middle-class households). These households are not likely representative of the majority of the population reliant on biomass for cooking; however, this choice was considered appropriate for the study since the primary aim was to gain experience implementing the co-benefits methodology with a commercially viable intervention, with the research results of secondary importance. It is worth noting that any climate, health, and gender co-benefits realized are valuable, even if they accrue to populations that are not at the bottom of the poverty pyramid.

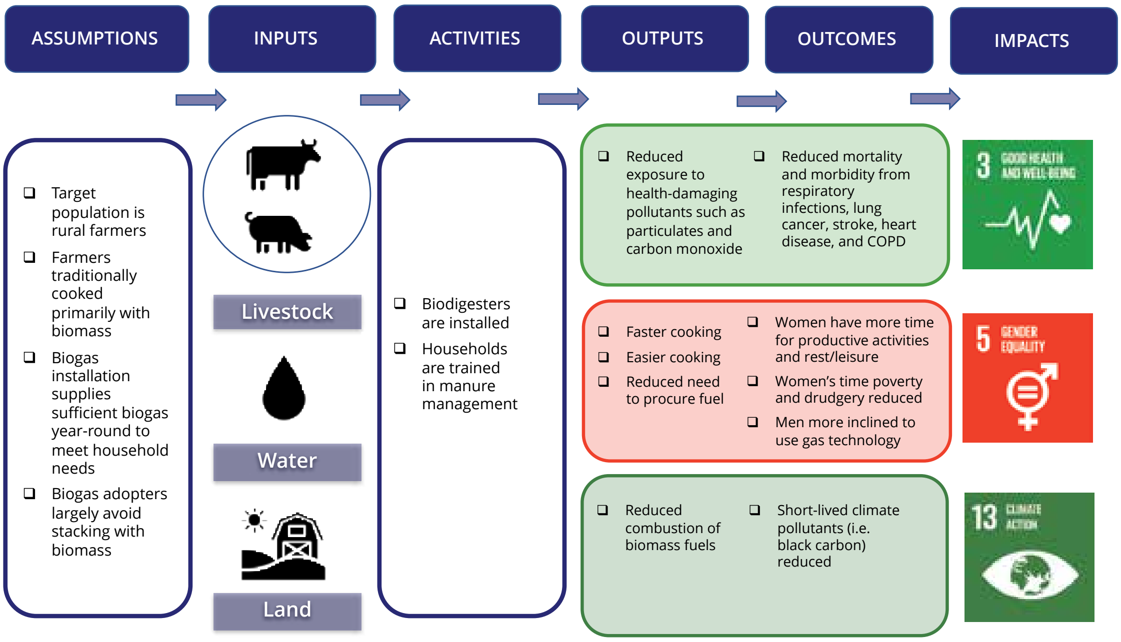
## Impact Pathways and Metrics for Co-Benefit Measurements

Figure 2.1 illustrates the pathways through which biogas interventions produce the co-benefits for climate, health, and gender. The diagram presents only a subset of the outputs, outcomes, and impacts of biogas systems that are relevant to the intervention evaluated (Sistema.bio) and within the scope of this study. Bio-slurry production was also considered as a secondary outcome.

Following the desk review's recommendations (ESMAP 2020b), the study followed the Gold Standard's methodology for black carbon (BC) (Gold Standard 2017a)—designed for application as an add-on to the GHG quantification methodology for cookstoves (Gold

**FIGURE 2.1**

Theory of Change




*Source:* World Bank.

*Note:* Output from analysis of the fieldwork conducted by Berkeley Air Monitoring Group (BAMG).

**TABLE 2.1**

Key study impacts and metrics

| CO-BENEFIT | HYPOTHESIZED OUTCOME | METRIC | |
|---|---|---|---|
| Climate | Reduction in warming impacts from black carbon (BC)/short-lived climate pollutants (SLCPs) | Fuel-use patterns and consumption for both the project and baseline stove<br>Kitchen BC-to-particulate matter (PM) ratios<br>Emissions factors | |
| Health | Averted disability adjusted life years (aDALYs) | Personal exposure (PE) to $PM_{2.5}$<br>Stove-use patterns (project stove and traditional stove displacement) | |
| | Improvement in perceived well-being | Symptoms associated with use of traditional cooking methods | |
| Gender | Increase in women's time used for productive tasks and/or rest/leisure, together termed "quality time" | Primary cook, other females, and males in household | Time spent actively cooking<br>Time spent cleaning utensils and kitchen area<br>Time spent procuring and preparing fuel for use with the stoves<br>Proportion of women's time engaged in income-generating tasks or rest and leisure<br>Use of any saved time (customer group only) |
| | Decrease in women's time engaged in tasks related to cooking/fuel procurement and perceived as drudgery[a] | Primary cook | Proportion of sample perceiving cooking-related tasks as drudgery[a]<br>Time spent on tasks perceived as drudgery[a] |
| | Increase in perceived sense of empowerment and agency | Primary cook | Self-reported perception of empowerment and agency in study communities and changes of status since using biogas stove |

*Source:* World Bank.

a. In this study, the term *drudgery* was presented to participants as "any regular household-related activities that are very hard work, either physically or mentally, and time consuming, repetitive, and unavoidable."

Standard 2021)—and the Gold Standard's adverted disability-adjusted life year (aDALY) methodology for health (Gold Standard 2017b). No similar methodology has been established for gender; thus, the approach used was experimental. Table 2.1 displays the key outcomes and metrics related to these co-benefits.

## Sample Selection

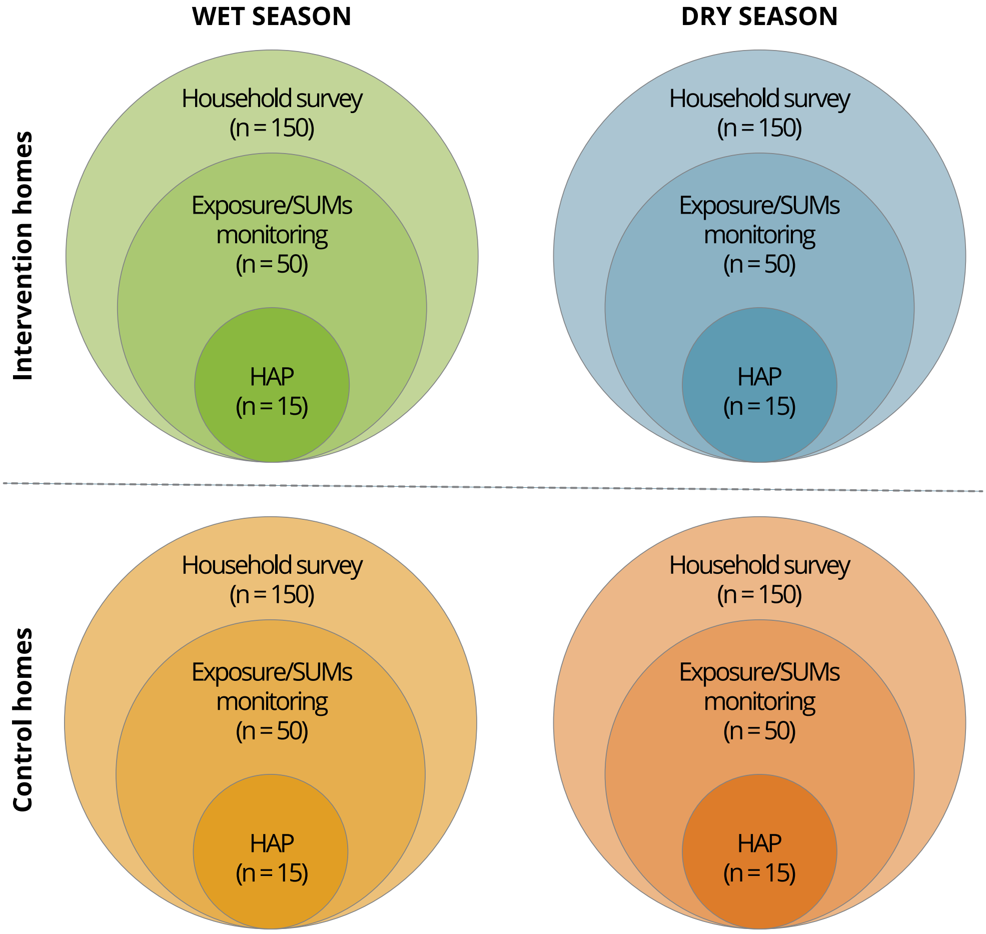
Data collection was conducted in two counties of Kenya (Kiambu and Nyandarua), which are located 38–80 km away from the capital city of Nairobi (figure 2.2). The study sample comprised 300 homes equally split between the intervention and control groups (figure 2.3) (Appendix B).

**FIGURE 2.2**

Commonly Used Stoves in Rural Kenya


*Source:* © Eco Research Ltd.
*Note:* Clockwise from top left: three-stone fire, LPG stove, Kenya Ceramic Jiko (charcoal) stove, and Sistema.bio biogas stove.

**FIGURE 2.3**
Sampling and Data Collection Schematic




*Source:* World Bank.
*Note:* Output from analysis of the fieldwork conducted by Berkeley Air Monitoring Group (BAMG).

## SAMPLE SIZE SELECTION

Selection of the sample size for each of the co-benefit assessments was informed by several major factors (details available upon request). The goal of the study was not an impact assessment of the intervention but an assessment of the field performance of methods for assessing the impacts, including sample size requirements; therefore, no power calculations were conducted beforehand to inform the number of households to include in the intervention and control groups. The Phase 1 methodological review provided a minimum sample size for measurement of black carbon (BC) (n = 20) and health impact estimation based on the Gold Standard methodology (30 households in each of the baseline and target groups). The number for BC gives the minimum precision level required for applying mean emission factor values. The evaluation criteria for an RBF-based application are similar to those of carbon offset schemes; they include cost-effectiveness, scalability, and operational feasibility, among others (ESMAP 2020b).

### HOUSEHOLD SELECTION AND PROTOCOLS

The intervention group consisted of Sistema.bio customers who had purchased and installed domestic biodigesters at least six months prior to enrollment in the study. Households in the control group were selected based on a profile similar to that of the intervention group in terms of location, age of the primary cook, and socioeconomic class. Participating households in both groups ranged from middle class to skilled working class, according to the Living Standards Measure, which segments populations based on ownership of a wide range of products and services.[15] All study procedures and protocols were approved by the Institutional Review Board at Advarra (Columbia, Maryland), and informed consent was obtained from all study participants prior to data collection.

## Data Collection Instruments

Two rounds of data collection were done in order to capture any seasonal differences in cooking patterns and outcome variables.[16] The subsections below describe the tools deployed in each round.[17]

### HOUSEHOLD SURVEY

A survey was administered to the primary cooks in all participating households. Survey questions were informed by established survey tools, including the Multi-Tier Framework (MTF), which captures both primary and secondary cooking devices and fuels and questions for assessing the gender dynamics associated with household energy (World Bank and WHO 2021).

The surveys were administered by trained enumerators using participants' preferred language (English or Swahili); using tablets, the data was directly entered into the Open Data Kit (ODK) collection platform. Time information relevant to gender outcomes was gathered using questions about time used for (1) procuring and preparing fuels, (2) cooking, (3) maintaining appliances and cooking spaces, and (4) applying bio-slurry. The study also sought information on time spent on non-cooking productive activities (either generating income or producing goods they may otherwise have purchased) and engaging in rest and leisure. Effort questions were asked on a one-to-five scale using a visual aid (available upon request).

### FOCUS GROUP DISCUSSIONS

Two focus group discussions (FGDs) were conducted prior to the first round of data collection to inform development of the household survey tool. During the second round, six additional FGDs were conducted to provide contextual richness to the survey findings.

15 For details on the Living Standards Measure, see http://www.saarf.co.za/lsm/lsms.asp; on the definition of classes, see https://en.wikipedia.org/wiki/NRS_social_grade.

16 In the end, the findings showed no marked seasonal differences, and both sets of data were combined for analysis.

17 To ensure robustness of the field data collected, the study developed and adhered to strict quality control measures (Appendix C).

## AIR POLLUTION MONITORING

Personal exposure (PE) and household air pollution (HAP) monitoring data was collected for a subset of respondents, whose stove usage was also tracked quantitatively using stove use monitors (SUMs) (figure 2.4); 48-hour samples were collected using gravimetric $PM_{2.5}$ samplers,[18] which have been field-evaluated for exposure monitoring in the household sector (Pillarisetti et al. 2019). The samplers are small, quiet, and portable, allowing study participants to carry them over the sampling duration with minimal burden.

PE samplers were worn by primary cooks in custom-designed, culturally appropriate aprons, with the air inlets situated in the participants' breathing zone. A subsample of kitchen concentrations was also measured to determine the BC-to-$PM_{2.5}$ ratios as required for the BC methodology. Filters were weighed before and after sample collection on a 1-*μg* resolution microbalance following standard procedures of the United States Environmental Protection Agency (U.S. EPA). The BC weight on the filters was estimated using a Magee Transmissometer (Sootscan Model OT21, Magee Scientific, Berkeley, California), and the response was converted to BC mass according to the methods outlined in Garland et al. (2017).

Ambient (outdoor) samples in a sample of participant neighborhoods were also collected using UPAS sensors (i.e., wearable air pollution monitors) to contextualize the other samples collected throughout the study.

**FIGURE 2.4**

Installing Stove Use Monitors

*Source:* © Eco Research Ltd.
*Note:* Three-stone fire (left) and biogas stove (right).

18 Ultrasonic Personal Air Sampler (UPAS), Access Sensor Technologies, Ft. Collins, Colorado.

### STOVE USE MONITORING

For a subset of households in both the intervention and control groups, stove use monitors (SUMs) were deployed to better capture the use of each stove during the study period. In each household, all stoves used during the month prior to the start of the survey were fitted with a monitor. Two models of SUMs were used: (1) temperature loggers outfitted with K-type thermocouples (Model SN-61, Wellzion) and (2) iButtons (model DS1922T, Maxim, USA). The choice of SUM was determined according to its availability and the kitchen arrangement. SUMs were installed on any stove used at least once per week. Seven stove types were monitored: (1) three-stone fire, (2) modified three-stone fire, (3) metal charcoal stove, (4) Kenya Ceramic Jiko, (5) ethanol stove, (6) LPG stove, and (7) biogas stove. Sensors were set to log temperature at five-minute intervals for the full duration of both data collection periods.

Geocene Studies, a web-based data management and processing platform, was used to convert the SUMs temperature data into time and usage event metrics. The initial performance of the Firefinder detection algorithms was evaluated manually and the algorithm parameters were adjusted for the full data set to achieve a high-quality output.

One method that was tested but not applied in the study due to several challenges was Time Tracker, a novel means for collecting time-use data using a smartphone-based application (TimeTracker).

## Estimating the Co-Benefits

### SHORT-LIVED CLIMATE POLLUTANTS

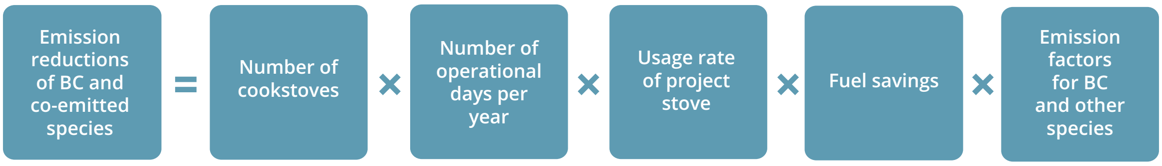
The potential mitigation of short-lived climate pollutants (SLCPs) provides an opportunity to slow climate change in the short-term while longer-term strategies to lower $CO_2$ and other emissions are developed and implemented. Household energy is especially critical to this effort as approximately 50 percent of anthropogenic BC emissions is estimated to result from the combustion of solid biomass fuels for cooking and heating (Klimont et al. 2017).

The Gold Standard organization provides a methodology for estimating the impact of SLCPs that can be layered on top of more traditional carbon offset projects (Gold Standard 2017a). The methodology provides approaches to quantify the emissions of SLCPs, including BC, organic carbon (OC), and other associated short-lived forcing pollutants. The emission reductions of BC and co-emitted species are quantified by comparing the project and baseline scenarios; BC is quantified by combining the fuel savings, emission factors for pollutants, and other input parameters (figure 2.5).

At the time of publication of the Gold Standard's SLCP methodology, limited field-based data were available to provide default emission factor estimates for BC and organic carbon (OC), which are the most impactful SLCPs for household energy programs. Thus, the methodology

**FIGURE 2.5**

Quantification Approach for Black Carbon (BC) and Co-emitted Species




*Source:* Gold Standard (https://globalgoals.goldstandard.org).

requires that direct measurements of fuel savings from adoption of new technology be made in the laboratory and/or field. This effort requires substantial costs and technical capacity.[19] In recent years, however, numerous field studies of various stove-and-fuel combinations and relevant emissions factors (primarily BC and OC) have been conducted (Champion et al. 2021; Coffey et al. 2017; Du et al. 2018; Fleming et al. 2018; Garland et al. 2017; Johnson et al. 2019; Wathore, Mortimer, and Grieshop 2017; Weyant, Thompson, et al. 2019). These published estimates allow for a much less burdensome method for estimating SLCP impacts than direct field testing. Furthermore, they greatly improve on the estimates from laboratory testing, which consistently demonstrate poor correspondence with field performance (Johnson et al. 2008, 2019; Naved et al. 2022; Roden et al. 2009). To illustrate this potential approach, the study team compared the BC and OC emissions estimates for the Sistema.bio project using laboratory and field-based emission factors from the literature. The assumptions made for calculating the emission estimates are described below.

### *Project Assumptions*

The team used fuel consumption for the baseline and project scenarios as reported in the project design document prepared by South Pole for Sistema.bio's Clean Development Mechanism (CDM) carbon offset project in Kenya.[20] The document forecasts that approximately 84,000 biogas digesters in a capacity range of 6–40 $m^3$ will be installed over the course of the five-year crediting period (2018–23).

The program assumed displacement of a mix of LPG and wood (based on household surveys), but does not state any assumptions about the amount of stacking implied. The amount of baseline wood and LPG consumption to be displaced over the five-year period was estimated at 928,941 t and 67,671 t, respectively.[21] These fuel consumption estimates were used to determine the amount of energy delivered using the thermal efficiency and net calorific values. The amount of biogas required to deliver the same amount of energy (3,455 TJ) was then calculated (table 2.2).

19 The quantity of fuel saved is estimated by applying the Kitchen Performance Test at both baseline and after the intervention. The emission factors for BC and other species are determined in a laboratory or field setting using a representative cooking situation before and after the intervention. BC emissions are difficult and costly to measure in the field compared to other types of stove performance testing in homes, while the laboratory-based emission factors may differ significantly from those determined through field measurements.

20 https://www.southpole.com/uploads/media/sistemabio-kenya-final-pdd-03062020.pdf.

21 Estimates in the project design document are based on assumptions determined separately prior to this study, for which the study team did not measure fuel consumption.

**TABLE 2.2**

Fuel consumption parameters for the Sistema.bio program

| FUEL | THERMAL EFFICIENCY (%) | NET CALORIFIC VALUE (TJ/t) | ENERGY DELIVERED (TJ) | TOTAL FUEL ENERGY (TJ) | TOTAL FUEL MASS (t) |
|---|---|---|---|---|---|
| Baseline Scenario | | | | | |
| Wood | 14 | 0.015 | 1,951 | 13,934 | 928,941 |
| LPG | 47 | 0.0473 | 1,504 | 3,201 | 67,671 |
| Project Scenario | | | | | |
| Biogas | 40 | 0.023 | 3,455 | 8,638 | 375,562 |

*Source:* World Bank.

**TABLE 2.3**

Emission factors for laboratory, laboratory-adjusted, and field-based approaches

| FUEL | LABORATORY | | | LABORATORY (ADJUSTED) | | | FIELD | |
|---|---|---|---|---|---|---|---|---|
| | BC (g/kg) | OC (g/kg) | $PM_{2.5}$ (g/kg) | BC/ PM | BC (g/kg) | OC (g/kg) | BC (g/kg) | OC (g/kg) |
| Baseline Scenario | | | | | | | | |
| Wood | 0.41 | 1.05 | 2.2 | 0.10 | 0.22 | 1.09 | 1.43 | 3.9 |
| LPG | 0.0023 | 0.014 | 0.08 | 0.028 | 0.014 | 0.08 | 0.014 | 0.24 |
| Project Scenario | | | | | | | | |
| Biogas | 0.0036 | 0.03 | 0.06 | 0.14 | 0.0084 | 0.039 | 0.004 | 0.12 |

*Source:* World Bank.

### *Emission Factors*

Various approaches were used to estimate the emission factors (table 2.3). Laboratory emission factors (assumed as a typical project developer approach) for wood and LPG were from a study applying current ISO testing protocols (ISO 2018b) at the U.S. EPA laboratory (Champion et al. 2021). The laboratory biogas emission factor for $PM_{2.5}$ was pulled from a Sistema.bio-commissioned laboratory study at Colorado State University. BC and OC were not measured directly in that testing, so the BC and OC emission factors were derived by applying the BC-to-$PM_{2.5}$ and OC-to-$PM_{2.5}$ ratios from the Bond et al. (2004) technology inventory for natural gas stoves.[22]

To ensure conservative laboratory-based emission factors, the Gold Standard methodology requires project developers to measure the BC-to-$PM_{2.5}$ ratio in the kitchens where the respective baseline and project technologies are being used. If the ratio indicates that the aerosol is less warming for the baseline technology (e.g., lower ratio of BC to $PM_{2.5}$) or more warming for the project technology (e.g., higher ratio of BC to $PM_{2.5}$), the emission factors must be adjusted to reflect these ratios. In this case, the BC-to-$PM_{2.5}$ ratios measured in the kitchens did result in adjustments (table 2.3), which decreased BC emission factors for wood and LPG (more cooling baseline) and increased the BC emission factor for biogas (more warming), and vice versa for

22 Biogas emissions are impractical to measure in the laboratory due to the required connection and proximity to the digester system. The emission estimates from the testing at Colorado State University and those in the Bond et al. (2004) inventory are from natural gas. The combustible component of both natural gas and biogas is almost exclusively methane ($CH_4$).

the OC emission factors. The laboratory-adjusted emission factors were used to calculate the BC equivalent (BCe) emissions using the Gold Standard methodology.

The field-based BC and OC emission factors for LPG and biogas were derived from a study in Nepal. To the study team's knowledge, this is the only published study of biogas stove emissions to date (Weyant, Thompson, et al. 2019). The wood stove emission factors were averaged from five field studies in Africa (Champion and Grieshop 2019; Coffey et al. 2017; Garland et al. 2017; Wathore, Mortimer, and Grieshop 2017; Weyant, Chen, et al. 2019). The study team did not directly measure field emissions for the baseline or project technologies due to budget constraints.

The net impact is estimated in the Gold Standard for the Global Goals methodology by converting the BC and OC into the BCe, which is analogous to $CO_2e$ since both normalize the warming impact of an emission species to the equivalent quantity of BC or $CO_2$, respectively. In this case, BC is simply multiplied by 1, and OC is multiplied by –0.1 as it has a cooling impact estimated at one-tenth the strength of BC's warming impact.[23] This means it takes 10 g of OC's cooling effect to offset 1 g of BC's warming impact.

## HEALTH IMPACTS

To assess the health impacts, the primary unit of quantification is the reduction in exposure to air pollution, indicated by measurement of particulates less than 2.5 microns in diameter or $PM_{2.5}$. This is used to quantify the reduction in expected illness through estimation of aDALYs. The aDALY metric has been judged as the best available one for estimating the health impact of cookstove interventions as it integrates real exposure measurements with comprehensive epidemiologic evidence of effects of the life course (ESMAP 2020b). The metric includes both the number of years lost to ill health and premature death. The methods used here are part of the Gold Standard–approved methodology to assess aDALYs attributable to interventions that reduce HAP from clean cooking technologies (Gold Standard 2017b).

Health benefit estimates were estimated using the Household Air Pollution Intervention Tool (HAPIT), which calculates the burden of disease attributable to HAP for five disease outcomes with established exposure-response relationships for $PM_{2.5}$ exposure in the epidemiologic literature: (1) lung cancer, (2) ischemic heart disease, (3) stroke, (4) ALRI in children aged 0–4, and (5) chronic obstructive pulmonary disease (COPD). The primary input to the HAPIT model is measured PE to $PM_{2.5}$ in the project and baseline group as $PM_{2.5}$ exposure reductions drive the averted disease burden.

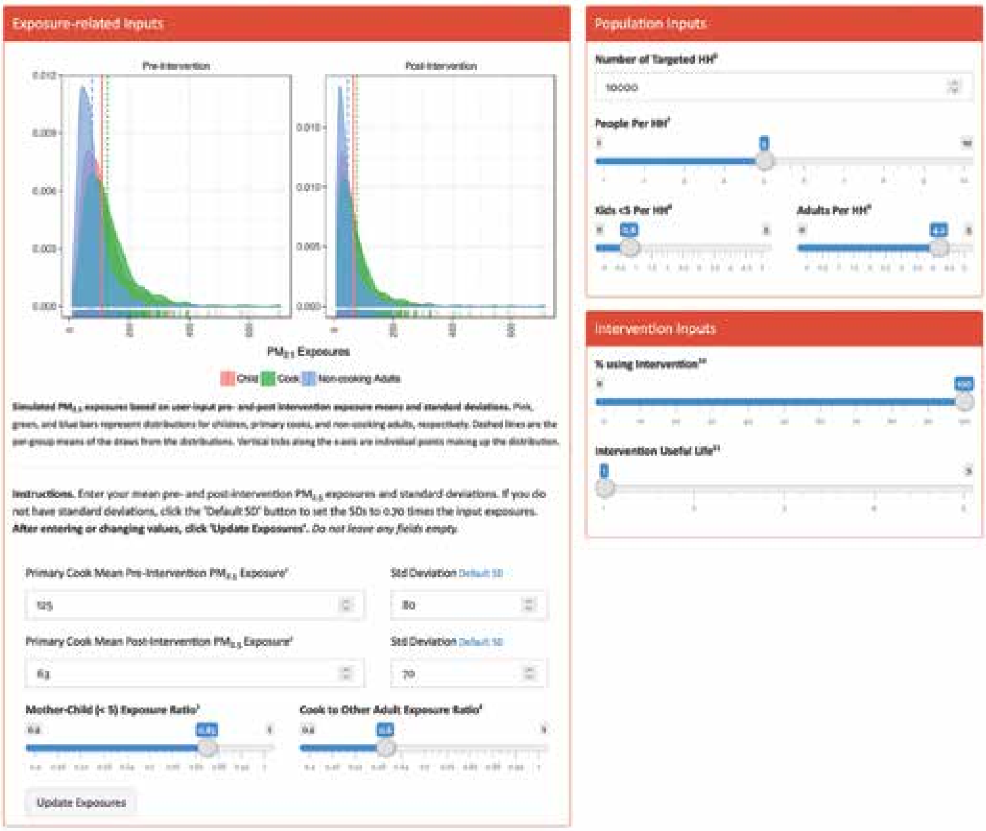
The exposure in each group is used to calculate aDALYs, using background country-level rates of underlying disease (drawn from peer-reviewed Global Burden of Disease databases) and the exposure-response curves derived from the above-mentioned epidemiologic literature. The HAPIT model also makes use of a number of additional inputs. The assumptions made for these are as follows: approximately 5 people per household, consisting of 4.2 adults and

23 Assumptions in the Gold Standard for the Global Goals methodology are based on 20-year global warming potentials from the Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2013: The Physical Science Basis,* "Anthropogenic and Natural Radiative Forcing" (chapter 8, table 8. SM.17).

0.8 children under 5 (default HAPIT estimates for Kenya);[24] exposure for children under 5 and non-primary cook adults estimated as 0.8 times and 0.6 times the value for primary cooks, respectively (based on prior epidemiologic literature and HAPIT defaults); 10,000 homes with operational biodigester units; and one year of operation (figure 2.6 and table 2.4).

**FIGURE 2.6**

Sample HAPIT Screenshot of Inputs




*Source:* HAPIT (https://householdenergy.shinyapps.io/hapit3/).

**TABLE 2.4**

Sources of parameters used in the Household Air Pollution Intervention Tool

| SECTION | INPUT | SOURCE |
|---|---|---|
| Exposure | Pre- and post-intervention particulate matter (PM) exposure in µg/m$_3$ (means and standard deviations) | Personal exposure (PE) monitoring in biogas and control homes |
| | Mother-to-child and cook-to-other-adult ratios | Default values for Household Air Pollution Intervention Tool (HAPIT) (Smith et al. 2014) |
| Population | Number of targeted homes | Assumed as 10,000, with the estimates scaled based on customer data over the project period |
| | Persons per household | Country default for Kenya |
| | Children under 5 per household | Country default for Kenya |
| Intervention | Fraction using the intervention | Set at 100%, with the estimates scaled based on customer data over the project period |
| | Useful intervention lifespan | Assumed as one year, with the estimates scaled based on customer data over the project period |

*Source:* World Bank.

24 The households surveyed had an average of 3.8 adults and 0.2 children per home. The study team applied the country defaults in HAPIT as the scaling of the project to a large population (closer to being representative of the national rural population) will result in different household demographics; and project developers are likely to use the country defaults, especially when favorable to the aDALY estimates.

## GENDER IMPACTS

The study defined gender impact as progress toward meeting Sustainable Development Goal (SDG) 5: "Achieve gender equality and empower all women and girls." A defined methodology for assessing the gender impact of cookstove programs is not yet established. A recent review of tools for assessing gender equality relevant to the clean cooking sector indicates that few systematic efforts have yet been made to attempt to translate any observed gender benefit into a quantitative gender impact that could be utilized in the framework of results-based financing (RBF) (ESMAP 2020b). This state of affairs is hampered by the lack of an evidentiary base to date on the relationship between cookstove projects and empowerment/gender-equality outcomes, hinging primarily on two factors: (1) many aspects of empowerment are difficult to measure as empowerment is "as much an intrinsically self-reflective condition as an extrinsically measurable characteristic" (ESMAP 2020b) and (2) evidence of empowerment or improved gender equality may take longer to emerge than the time frame of any single field study.

The study team investigated several potential ways to assess the gender impact of the biogas program: (1) time use, (2) potential changes in family dynamics associated with the biogas system, and (3) empowerment indicators (e.g., input in household decisions and those related to time-use agency, such as satisfaction with leisure time). One should note that the study team assessed only the benefits that might accrue to women and girls as consumers of biogas; it did not evaluate the impacts of involving women and girls in other parts of the clean cooking value chain. These metrics were assessed using the household survey, and impacts were quantified by comparing the average values in the biogas and control groups and evaluating the potential difference between the groups for statistical significance. The team further explored aspects of potential gender impact using qualitative data-collection methods, primarily consisting of focus group discussions (FGDs).

## UNDERSTANDING FUEL-MIX SCENARIOS

Estimation of benefits depends heavily on the baseline fuel mix, as well as the extent to which the improved technology replaces traditional fuels (ESMAP 2019). Each fuel has its unique emissions profile, combustion by-product combinations that lead to differential air pollution exposure, and distinct processes related to procurement and preparation that affect time use. Furthermore, these fuels are frequently used in combination or stacked within households. The MTF in Kenya found that stove stacking is a common practice, with 35 percent of urban households and 28 percent of rural households using more than one fuel type. This study confirmed the high prevalence of stacking for households in both the intervention and control groups.

As this study is intended to inform the application of methodologies and expectations for co-benefits impact determination across a number of settings, the team analyzed the health and gender co-benefits at the baseline and in the project population according to the following hypothetical fuel-mix scenarios:[25]

25 It should be noted that, for the purposes of the SLCP methodology, the study team used the fuel consumption estimate from the Sistema.bio planning document for its carbon offset project, and did not measure fuel consumption as part of this study; thus, it did not examine scenarios for the potential SLCP impacts.

- *Full sample*—This included all participants in biogas- and control-group households, regardless of their fuel stacking behavior. In this report, all of the main findings derive from this comparison.
- *Hypothetical biomass baseline*—The study team excluded control-group households who used clean fuels, and evaluated the results by comparing all biogas adopters to the control subgroup that used traditional fuels (e.g., wood and charcoal) exclusively. (A few households used kerosene as a secondary or tertiary fuel.)
- *Hypothetical high contrast*—The study team compared the subset of biogas-using households who exclusively used clean fuels with the above-described control subgroup, which used traditional fuels exclusively. The comparison between these two groups represents the results that might be anticipated if a complete switch from polluting to clean fuels were to occur; however, one should note that, in practice, this situation is rarely observed.



# THREE PERFORMANCE RESULTS OF THE BIOGAS INTERVENTION

## Reduction in Short-Lived Climate Pollutants

**Using field-based emission factors as defaults, the estimated net reduction in black carbon equivalents (BCe) across Sistema.bio's carbon-offset program cycle is 963.4 tonnes.**[26] Wood combustion, which constituted the vast majority of black carbon (BC) and organic carbon (OC) emissions, drove the warming impact. For example, using published emission factors from field-based studies to estimate impact, wood combustion in the baseline scenario was calculated to emit approximately 900 times more BCe (961.0 tonnes) compared to the use of biogas (–3.1 tonnes) over the five-year program cycle. Liquefied petroleum gas (LPG) also had a minimal impact on short-lived climate pollutant (SLCP) emissions, contributing less than 1 tonne BCe to the baseline estimate (table 3.1).

Figure 3.1 illustrates the large difference in estimated BCe reductions using the current Gold Standard methodology (100 t BCe) compared to applying field-based emission factors from the literature (963 t BCe). The factor driving this difference is the much larger BC emission factor for wood stoves in the field compared to the laboratory (1.43 g per kg versus 0.22 g per kg). Both LPG and biogas had negligible BC and OC contributions as their emission factors were orders of magnitude smaller than from wood.

**TABLE 3.1**

Estimated impacts of BCe over Sistema.bio's five-year, carbon-offset program cycle

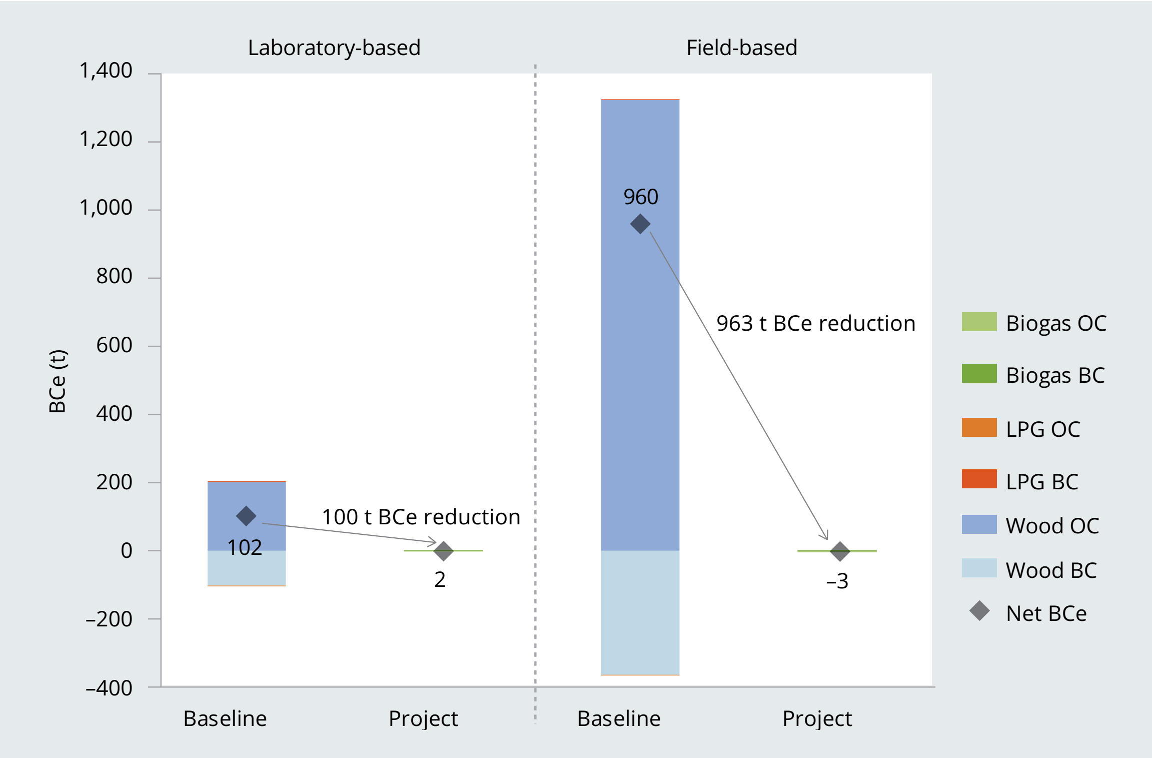
| | LABORATORY (FIELD-ADJUSTED) | | | FIELD | | |
|---|---|---|---|---|---|---|
| FUEL | BC (t BCe) | OC (t BCe) | NET BCe (t) | BC (t BCe) | OC (t BCe) | NET BCe (t) |
| Baseline Scenario | | | | | | |
| Wood | 203.2 | –101.6 | 101.6 | 1,323.7 | –362.8 | 961.0 |
| LPG | 0.2 | –0.1 | 0.1 | 0.9 | –1.6 | –0.7 |
| Project Scenario | | | | | | |
| Biogas | 3.2 | –1.1 | 2.1 | 1.5 | –4.6 | –3.1 |
| | | Difference | 99.6 | | Difference | 963.4 |

*Source:* World Bank.
*Note:* Estimated using laboratory and field-based emission factors.

26 For the sake of comparison with averted disability-adjusted life year (aDALY) estimates, which are on a per 10,000 homes per year basis, the estimate of impact on a similar scale would be 22.9 t BCe mitigated. (The project design document projected 84,226 biodigesters would be installed between 2018 and 2023.) Since the target population and specific biodigester sizes assumed for the carbon project likely differ from those in the household survey for the health study, care should be taken when assuming these exact BCe reductions for the purposes of estimating the climate and health co-benefits.

**FIGURE 3.1**

Laboratory versus Field-Based BCe Reduction Estimates for the Sistema.bio Project




*Source:* World Bank.
*Note:* Output from analysis of the fieldwork conducted by Berkeley Air Monitoring Group (BAMG).

## Personal Exposure Reduction

**Measured personal exposure (PE) to $PM_{2.5}$ decreased linearly according to the fuel-use behavior of primary cooks.** The highest average exposure (126.5 µg per $m^3$) was observed in households that used only biomass fuels. In the control group overall (about 18 percent of which were exclusive biomass users and the rest using a mix of biomass and clean fuels), exposure averaged 94.9 µg per $m^3$, which was approximately 31 µg per $m^3$ higher than the observed exposures in the biomass group overall, which averaged 63.2 µg per $m^3$. The subset of households that used biogas exclusively and/or stacked only with other clean fuels (e.g., LPG and ethanol) had the lowest exposure, at 53.5 µg per $m^3$ on average (table 3.2). Thus, the biogas group's overall $PM_{2.5}$ exposure was 33 percent lower than that of the full control group and 50 percent lower than that of households in the control group who only used biomass. In a hypothetical high-contrast situation comparing exclusively clean-fuel-using biogas households with exclusively biomass-using households in the control group, the exposure reduction was 58 percent (figure 3.2).

**The PE difference observed between households in the biogas and control groups as a whole would result in 323 aDALYs per year for each 10,000 homes with a functioning biodigester.** In a hypothetical scenario with a baseline composed solely of exclusive biomass users, the exposure differential measured would result in 492 aDALYs per year per 10,000

**TABLE 3.2**

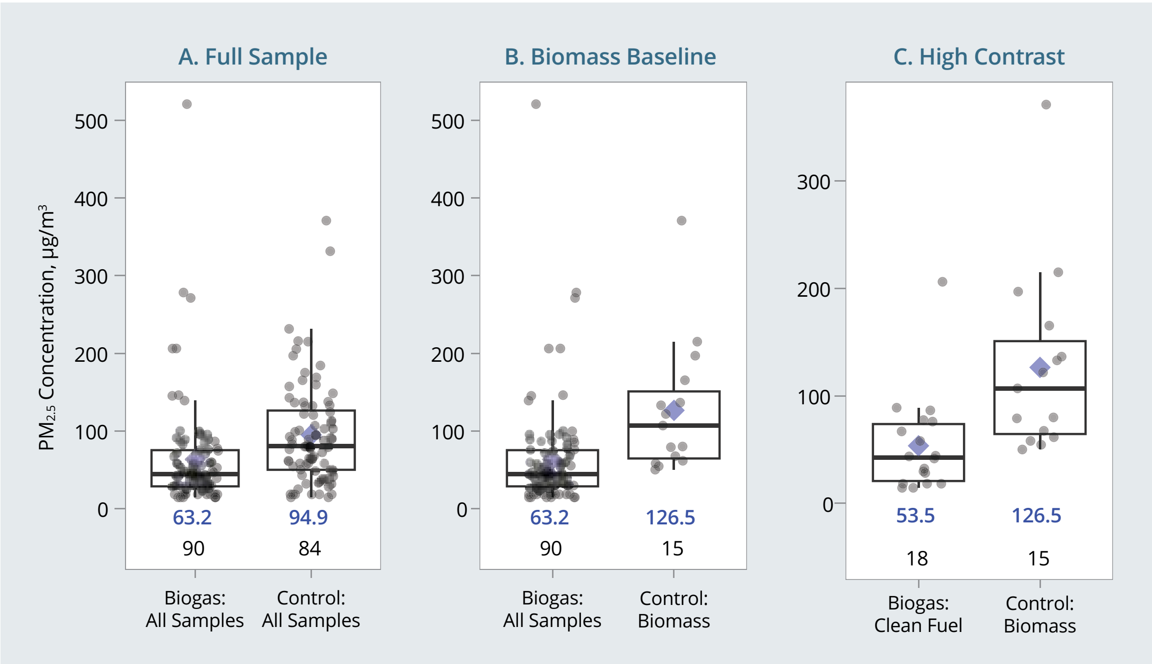
Personal exposure to $PM_{2.5}$

| FACTOR | CONTROL SUBSET (biomass only) | CONTROL (all) | CONTROL SUBSET (stack with clean fuel) | BIOGAS SUBSET (stack with biomass) | BIOGAS (all) | BIOGAS SUBSET (clean fuel only) |
|---|---|---|---|---|---|---|
| *N* samples (valid samples only) | 15 | 84 | 69 | 72 | 90 | 18 |
| Personal $PM_{2.5}$ concentration (μg/m³) | 126.5 (85.5) | 94.9 (66.3) | 88.0 (60.0) | 65.6 (74.8) | 63.2 (69.9) | 53.5 (45.8) |

*Source:* World Bank.
*Note:* Columns are arranged by expected burden of exposure and adverse health impact (high → low). Higher numbers are shaded in darker colors. The orange-bordered row indicates a gradient of burden that meets the expected pattern. All values are mean (standard deviation). Data was combined across Rounds 1 and 2, and only measurements from households that maintained the same category definition through both rounds were included.

**FIGURE 3.2**

Personal Exposure Results




*Source:* World Bank.
*Note:* Output from data analysis of the fieldwork conducted by Berkeley Air Monitoring Group (BAMG). The numbers in blue and central blue diamonds represent the mean personal exposure (PE) in each group, while the central line shows the median, the box ends show the 25th and 75th percentiles, and the whiskers the 5th and 95th percentiles. Sample sizes are in black below each individual box plot.

homes. The most extreme hypothetical scenario compares the cleanest group in terms of exposure—namely, biogas adopters who used clean fuels only—with households in the control group who used biomass fuels exclusively. As expected, greater health benefits are observed in this comparison: 538 aDALYs per year per 10,000 homes (table 3.3).

Since total PE to air pollution is a metric of all air pollution encountered by an individual throughout the 48-hour monitoring period, the study team also measured ambient air pollution in a number of the study communities to get an idea of background concentrations in the region (figure 3.3).

**TABLE 3.3**

Health impact estimation

| IMPACT | FULL SAMPLE POPULATION SCENARIO<br>Control (all) versus Biogas (all) | HYPOTHETICAL BIOMASS-BASELINE SCENARIO<br>Control (biomass only) versus Biogas (all) | HYPOTHETICAL HIGH-CONTRAST SCENARIO<br>Control (biomass only) versus Biogas (clean fuel only) |
|---|---|---|---|
| **Personal $PM_{2.5}$ concentration, μg/m³**<br>Mean difference [95% CI], (p-value between biogas and control) | **–31.6<br>[–52.0, –11.3]<br>(0.003)** | **-63.2<br>[–112.3, –14.2]<br>(0.01)** | **–72.9<br>[–124.1, –21.7]<br>(0.007)** |
| **Estimated aDALYs (per year per 10,000 homes with a functioning biodigester)**<br>Mean [minimum, maximum] | 323<br>[190, 403] | 492<br>[299, 605] | 538<br>[330, 659] |

*Source:* World Bank.
*Note:* Differences between biogas and control groups are shown according to population scenario. A positive mean difference indicates the biogas group mean value is higher than that of the control group, while a negative one indicates it is lower. Differences that are statistically significant (p-value < 0.05) are bolded.

**FIGURE 3.3**

Monitoring Ambient Air Pollution

*Source:* © Eco Research Ltd.

Ambient air pollution was in a range of 9.6–32.6 μg per m³ across these samples (average of measurements during Round 1: 20.9 μg per m³; Round 2: 20.1 μg per m³) (supporting tables and figures available upon request). Like most places in the world, few of the samples met the latest guidelines established by the World Health Organization for $PM_{2.5}$ air quality (5 μg per m³ for an average annual concentration and 15 μg per m³ for a 24-hour mean) (WHO 2021), suggesting the need to address other leading sources of air pollution in order to maximize health benefits.

## Measurements of Women's Empowerment

### TIME-USE OUTCOMES

**Female primary cooks in biogas-using households reported spending less time on cooking and drudgery and greater satisfaction with time available for rest and leisure.** Like HAP exposure, time spent on cooking changed more or less linearly according to the household's fuel mix, with those using biomass exclusively spending the most time on cooking tasks and clean-fuel-only ones the least. However, no significant differences in time allocated to productive or leisure activities or clear (increasing or decreasing) patterns were observed among the fuel-user groups (table 3.4).

A comparison of the full sample population shows that biogas-using households reported spending an average of 35 minutes per day less on cooking than those in the control group. They also reported spending 7.7 fewer hours per week on tasks considered drudgery, and

**TABLE 3.4**

Gender-relevant parameters

| PARAMETER | CONTROL SUBSET (biomass only) | CONTROL (all) | CONTROL SUBSET (stack with clean fuel) | BIOGAS SUBSET (stack with biomass) | BIOGAS (all) | BIOGAS SUBSET (clean fuel only) |
|---|---|---|---|---|---|---|
| *N* = Observations | 50 | 283 | 233 | 220 | 283 | 63 |
| Cooking time (all tasks, minutes/day) | 258.1 (111.9) | 231.3 (113.1) | 225.4 (112.8) | 203.4 (87.6) | 196.5 (83.8) | 172.6 (64.2) |
| All fuel-related tasks (minutes/day) | 12.1 (28.0) | 10.5 (26.4) | 10.1 (26.1) | 12.7 (28.7) | 12.8 (27.2) | 13.2 (20.9) |
| Income-generating activities (minutes/day) | 249.2 (144.6) | 255.8 (152.2) | 257.3 (154.1) | 244.9 (166.5) | 243.5 (168.2) | 238.6 (175.1) |
| Producing goods would otherwise buy (minutes/day) | 83.4 (82.0) | 96.3 (101.0) | 99.1 (104.6) | 81.3 (95.6) | 78.4 (92.0) | 68.5 (78.0) |
| Rest and leisure (minutes/day) | 125.4 (93.0) | 139.5 (98.9) | 142.5 (100.1) | 142.4 (116.4) | 148.6 (118.3) | 170.4 (123.3) |
| Quality time (minutes/day) | 458.1 (187.0) | 484.5 (200.9) | 490.2 (203.7) | 468.6 (212.8) | 470.6 (204.5) | 477.5 (173.7) |
| Time spent on activities considered drudgery (hours/week) | 27.5 (18.5) | 29.4 (19.8) | 29.8 (20.1) | 21.7 (19.3) | 21.7 (19.2) | 21.9 (19.0) |
| How satisfied with time available for leisure (1 = low, 10 = high) | 6.3 (3.3) | 6.8 (3.4) | 6.9 (3.5) | 7.5 (2.9) | 7.8 (2.8) | 8.5 (2.4) |

*Source:* World Bank.

*Note:* Columns are arranged by the expected direction of time use (high → low). Cell shading is by row, with highest values shaded the darkest and smallest values the lightest. Orange-bordered rows indicate a gradient of time use that meets the expected pattern. All values are mean (standard deviation). Data was combined across Rounds 1 and 2, and only measurements from households that maintained the same category definition through both rounds were included.

rated their satisfaction with rest and leisure time nearly 2 points higher (on a 10-point scale) than those in the control group (table 3.5).

When investigating such scenarios as biogas users compared to a hypothetical biomass-exclusive baseline or a hypothetical high-contrast scenario comparing clean-fuel-only biogas users with exclusive biomass users, the results, for the most part, were in the expected direction. The clearest picture emerges for time saved from cooking, which appears to increase nearly linearly, depending on the amount of clean fuel versus biomass fuel utilized. For example, the time savings related to cooking time increased from 35 minutes per day when biogas households were compared to the full control group, to 62 minutes per day when biogas users were compared to the subset of control homes who were exclusive biomass users (the hypothetical biomass baseline), and to 86 minutes per day under the hypothetical high-contrast scenario comparing only biogas users who did not stack with biomass fuel with the biomass baseline (table 3.5). The amount of time available for rest and leisure, as well as satisfaction with this time availability, also appears to increase according to the proportion of clean fuel versus biomass fuel used for cooking.

**TABLE 3.5**
Gender impact estimation by population scenario

| FACTOR | FULL SAMPLE POPULATION<br>Control (all) versus Biogas (all) | HYPOTHETICAL BIOMASS BASELINE<br>Control (biomass only) versus Biogas (all) | HYPOTHETICAL HIGH-CONTRAST SCENARIO<br>Control (biomass only) versus Biogas (clean fuel only) |
|---|---|---|---|
| **Mean difference [95% CI] (p-value) between biogas and control** | | | |
| Cooking time (all tasks, minutes/day) | **–34.8 [–51.3, –18.3] (< 0.001)** | **–61.7 [–94.9, –28.5] (< 0.001)** | **–85.6 [–121.0, –50.2] (< 0.001)** |
| All fuel-related tasks (minutes/day) | 2.3 [–2.1, 6.8] (0.3) | 0.8 [–7.8, 9.3] (0.9) | 1.2 [–8.3, 10.6] (0.8) |
| Income-generating activities (minutes/day) | –12.3 [–38.8, 14.1] (0.4) | –5.7 [–51.1, 39.6] (0.8) | –10.6 [–70.2, 49.0] (0.7) |
| Producing goods would otherwise buy (minutes/day) | **–17.9 [–33.8, –1.9] (0.03)** | –5.0 [–30.5, 20.6] (0.7) | –15.0 [–45.1, 15.2] (0.3) |
| Rest and leisure (minutes/day) | 9.1 [–8.9, 27.2] (0.3) | 23.2 [–6.4, 52.9] (0.1) | **45.0 [4.7, 85.3] (0.03)** |
| Quality time (minutes/day) | –13.9 [–47.5, 19.6] (0.4) | 2.5 [–45.5, 70.5] (0.7) | 19.4 [–48.7, 87.5] (0.6) |
| Time spent on activities considered drudgery (hours/week) | **–7.7 [–10.9, –4.5] (< 0.001)** | **–5.8 [–11.5, –0.1] (0.045)** | –5.6 [–12.6, 1.4] (0.1) |
| How satisfied with time available for leisure (1 = low, 10 = high) | **1.9 [0.5, 1.5] (< 0.001)** | **1.4 [0.4, 2.4] (0.005)** | **2.2 [1.1, 3.3] (< 0.001)** |

*Source:* World Bank.
*Note:* A positive mean difference indicates the biogas group mean value is higher than the control. Negative mean difference indicates the biogas group mean value is lower than the control. Differences that are statistically significant (p-value < 0.05) are bolded.

Patterns related to time spent on activities considered drudgery, on the other hand, are less consistently associated with the fuel mix. Contrary to expectation, the reduction in hours per week on drudgery falls from 7.7 to 5.6–5.8 when the alternative fuel-use scenarios are explored. This outcome may be attributable to the fact that both control (all) and biomass (only) households consider "caring for my cows," followed by "working in my garden" as the main drudgery activities (supporting tables and figures available upon request). Biogas adoption, which depends on livestock and produces fertilizer for farm crops, would not be expected to reduce these activities directly. Nonetheless, primary cooks in biogas-using households as a whole reported spending less time across the spectrum of activities considered drudgey than did those in the control homes.

## TIME-USE AGENCY

Deriving gender impact from these results, however, is less straightforward than simply calculating time saved. A premise of this study, as explained in ESMAP (2020b), was that time savings is not, in itself, sufficient to expand women's empowerment by increasing their "ability to make strategic life choices in a context where this ability was previously denied to them" (Kabeer 1999). Although time use is one of the most commonly measured outcomes of cookstove adoption as it relates to gender impact (Jeuland et al. 2021; Krishnapriya et al. 2021), researchers have noted that time savings cannot be directly equated with empowerment. Time is best construed as a resource rather than an outcome directly related to empowerment (van Eerdewijk et al. 2017). That is, the availability of discretionary time is necessary for the reallocation of time in more desired ways, but the achievement of an individual's goals related to their actual time use requires having agency over the allocation of that available time (Sinharoy et al. 2021). Time use is "a behavioral outcome resulting from the combined influences of the contextual environment, the amount of discretionary time that is available as a resource, and the extent to which individuals exercise time-use agency. Therefore, we caution against measuring time use as a proxy for empowerment related to time" (Sinharoy et al. 2021).

A construct more directly related to empowerment is agency (Alsop and Heinsohn 2005; Kabeer 1999; Sen 1985), with time-use agency reflecting individuals' "critical awareness of, confidence in, and influence over the allocation of their time" (Sinharoy et al. 2021). Women who are empowered to use time as they choose are able to align their activities with their goals and aspirations, without the undue physical and mental burden of externally imposed time pressure. This study observed that "satisfaction with the amount of time available for leisure" was rated significantly higher among biogas users than those in the control group. In this study, this measure is most closely related to time-use agency, suggesting that the biogas system was yielding important improvements for time-use agency and thus empowerment among its users.

## FACTORS UNRELATED TO TIME USE

### *Input in Household Decisions*

Quantitative elements in this study designed to assess other aspects of women's empowerment did not indicate clear differences between the biogas and control groups. For example, the study team found no difference between the biogas-using and control groups in terms of self-reported levels of input in household decisions (table 3.6).

**TABLE 3.6**

Level of input in household decisions

| HOUSEHOLD DECISION TYPE | CONTROL SUBSET (biomass only) | CONTROL (all) | CONTROL SUBSET (stack with clean fuel) | BIOGAS SUBSET (stack with biomass) | BIOGAS (all) | BIOGAS SUBSET (clean fuel only) |
|---|---|---|---|---|---|---|
| *N* = Observations (female primary cooks only) | 25 | 144 | 119 | 115 | 146 | 31 |
| Cookstove purchasing (1 = full, 5 = none) | 3.9 (1.1) | 4.1 (1.0) | 4.2 (1.0) | 4.1 (1.0) | 4.1 (1.0) | 4.1 (0.9) |
| Types of food to cook (1 = full, 5 = none) | 4.7 (0.5) | 4.7 (0.6) | 4.7 (0.6) | 4.8 (0.6) | 4.7 (0.6) | 4.6 (0.7) |
| Expenditures > 10,000 KSH (1 = full, 5 = none) | 3.8 (0.7) | 3.9 (0.9) | 3.9 (1.0) | 3.8 (1.0) | 3.8 (1.0) | 3.9 (0.8) |

*Source:* World Bank.

*Note:* Responses to questions about "To what level are you involved in decisions related to…" (cookstove purchasing, types of food to cook, expenditures > 10,000 KSH). 1 = all decisions, 2 = most decisions, 3 = some decisions, 4 = very few decisions, 5 = no input. Presented as mean (standard deviation); all p-values for comparisons > 0.05.

*Shifts in Cooking-Related Gender Roles*

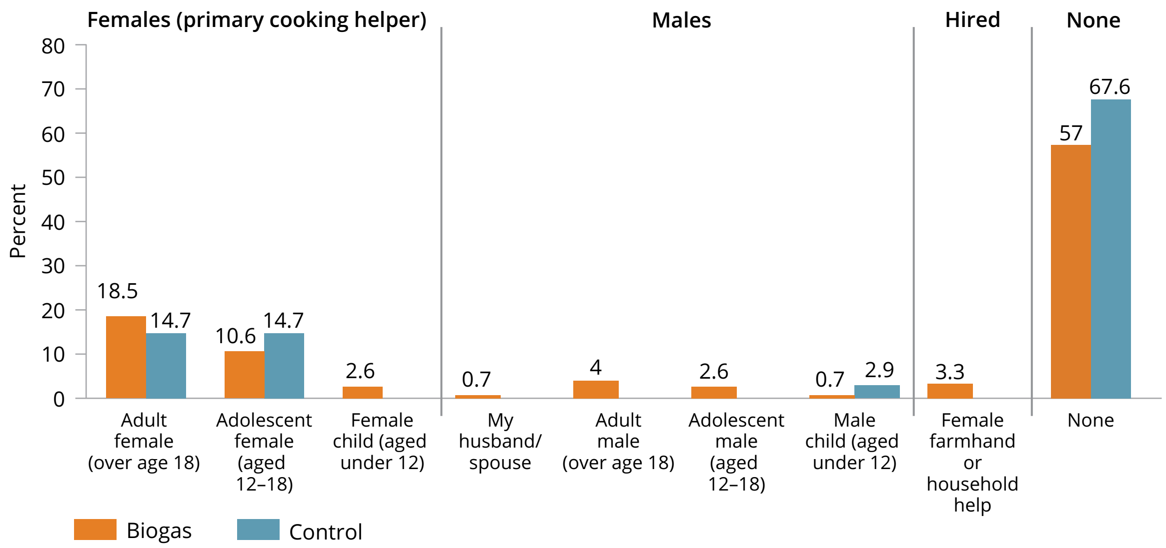
The study team observed no quantitative evidence that the adoption of biogas led to a shift in household roles related to cooking. For both the biogas and control groups, cooking helpers, where present, consisted mainly of other females in the household (figure 3.4).

Notably, however, comments made during focus group discussions (FGDs) among small subsets of participants and their male partners revealed small shifts toward men taking on cooking tasks associated with the adoption of the biogas system. One female primary cook in a biogas-using household said, "Even our husbands now light the stove and warm their bathing water if I am late to arrive home." Another noted, "Our husbands can cook tea for themselves, warm their food since it's easy to light the fire and there is no smoke."

The opinions of male partners in biogas-using households were somewhat contradictory. Some responses confirmed the shift in norms toward more cooking for men enabled by the biogas technology. For example, one said that "biogas stove is good because if you feel you want to take a cup of tea, and the wife isn't around, you don't have to chop wood fuel or the gas has run out. You will just light it and cook tea." Another said, "It's about culture. Our culture does not allow men to light fire and cook. Culture does not allow men to go to the kitchen. But now, you can cook tea from the main house, and no one will find you cooking. This has changed only to those who own a biogas." Other male respondents, however, reiterated the "hold" of culture over women's roles. One said, "We have our culture and things falls into place naturally. . . . It's hard for a woman to go to cow shed as she cooks, that's culture. It's our culture, a woman has her duties...everybody knows their lanes." Still another male partner said, "A woman is like a buffalo, they never rest. . . . She wakes up early

**FIGURE 3.4**

Cooking Helpers[a]




*Source:* World Bank.

*Note:* Output from data analysis of the fieldwork conducted by Berkeley Air Monitoring Group (BAMG).

a. Responses to the question "Apart from you, who cooks the most in this household at this time of year?" The responses shown are for Round 1; Round 2 responses, which were similar, are available upon request.

in the morning, prepares breakfast for the children, the husband. She goes to the utensils, next the house . . . also lunch and all such things."

Nonetheless, the finding that biogas has enabled at least some male partners to take on cooking tasks, where previously they would not have, is a positive indication of the potential for the technology to shift the needle on gender norms. Although the cooking tasks described in the FGD as being done by men were relatively light and minor (e.g., "cooking tea" and "warming food"), this points to the potential for a larger shift in norms given more time and further expansion of biogas cooking in the area.

### *Perceived Impact on Quality of Life*

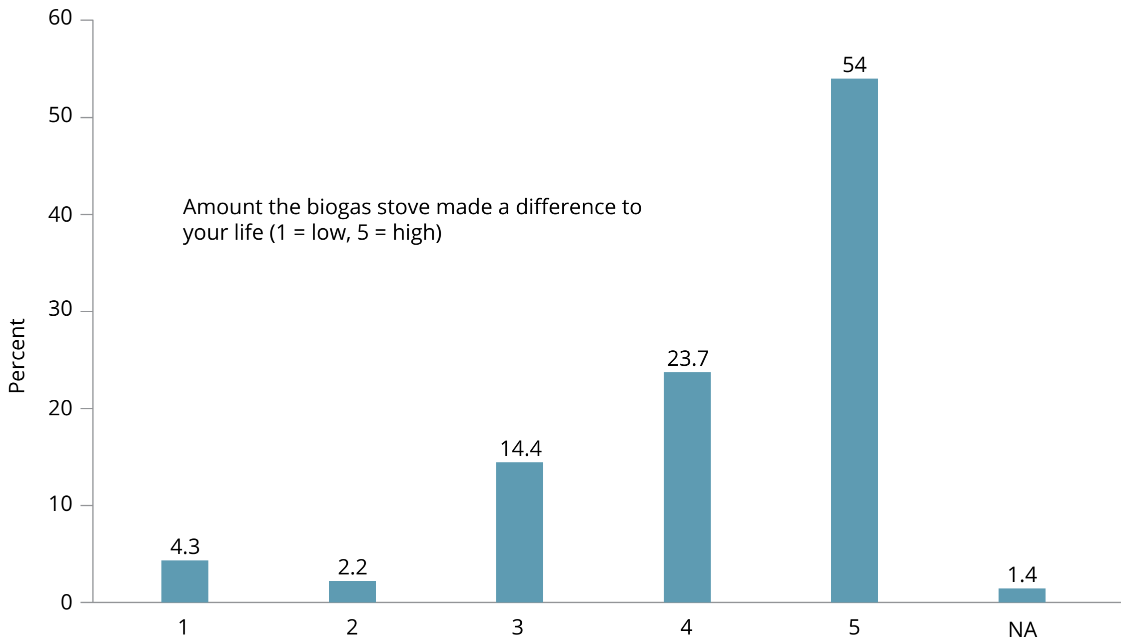
To assess customers' perceptions of the impact of the biogas stove intervention on their lives holistically, two additional questions were posed to biogas-only customers near the start of the Round 2 survey. The first one asked, "On a scale of 1 to 5 (low to high), how much of a difference has the biogas stove made for your life?" The second question was open-ended, asking, "How has the biogas stove made a difference to your life?"

Nearly 78 percent of the participants responded "4" or "5" to the first question (figure 3.5), suggesting that the biogas stove had had a substantial or "huge" impact on their lives. Responses to the second question were overwhelmingly positive (table 3.7).

The findings on reductions in stress, worry, tiredness, and general "hustle" (themes 8–10) were further elaborated in the open-ended answers. One female primary cook in a

**FIGURE 3.5**

Overall Impact of the Biogas Stove




*Source:* World Bank.
*Note:* Output from data analysis of the fieldwork conducted by Berkeley Air Monitoring Group (BAMG).

**TABLE 3.7**

Top 10 responses to the question "How has the biogas stove made a difference to your life?"

*N* = 139 biogas respondents (multiple themes possible per respondent)

| THEME | TOTAL RESPONSES (no.) | RESPONDENTS MENTIONING THIS THEME (%) |
|---|---|---|
| 1. Cooking (including lighting) fast | 70 | 50 |
| 2. Saves money (from fuel or fertilizer) | 68 | 49 |
| 3. Cooking easy/convenient/reliable | 54 | 39 |
| 4. Bio-slurry is nutritious to crops/farming improved | 37 | 27 |
| 5. Smoke exposure reduced/health improved | 25 | 18 |
| 6. Kitchen/utensils/house/food cleaner | 18 | 13 |
| 7. Firewood/charcoal/LPG reduced | 17 | 12 |
| 8. Peace of mind/less worry/less stress | 16 | 12 |
| 9. Life is easier/don't have to do certain disagreeable tasks/less "hustle" | 14 | 10 |
| 10. Less tired/less energy spent/ more rest | 13 | 9 |

*Source:* World Bank.

biogas-using household responded, "Mentally, it has given me rest as I am not constantly worrying about preparing the firewood, both in terms of energy and time." A second one said, "I do not stress and hustle to fetch firewood," while a third noted that "it has made my life physically and mentally easier as I don't get tired getting firewood, and I am not constantly worrying about sources of fuel." These findings suggest the benefit of biogas adoption to women's overall well-being, which may not be fully captured by measuring the time spent on tasks. Improved mental energy, reduced stress and worry, and peace of mind are all important aspects of well-being that may improve women's lives on the whole and, as such, provide a pathway to reduced inequality between the sexes.

Numerous previous studies have documented time savings related to cleaner cookstove adoption (Anderman et al. 2015; Gurung and Thakali 2014; Krishnapriya et al. 2021; Petrokofsky et. al, 2021; Prah et al. 2020). For example, a recent analysis of Multi-Tier Framework (MTF) datasets found an overall time savings of 34 minutes per day on cooking-related tasks associated with adoption of any improved cookstove (Krishnapriya et al. 2021).

## Influence of Stacking

The practice of stacking—using multiple stove-and-fuel cooking combinations within a household—is common. This field study found that most households with a biodigester in the counties of Kiambu and Nyandarua, Kenya considered biogas as their primary fuel; in Rounds 1 and 2, 85.4 percent and 91.4 percent, respectively, reported using biogas as their primary stove. That said, rates of stacking with wood or charcoal were high, reported by 78.1 percent of biogas-using households in Round 1 and 76.3 percent in Round 2.

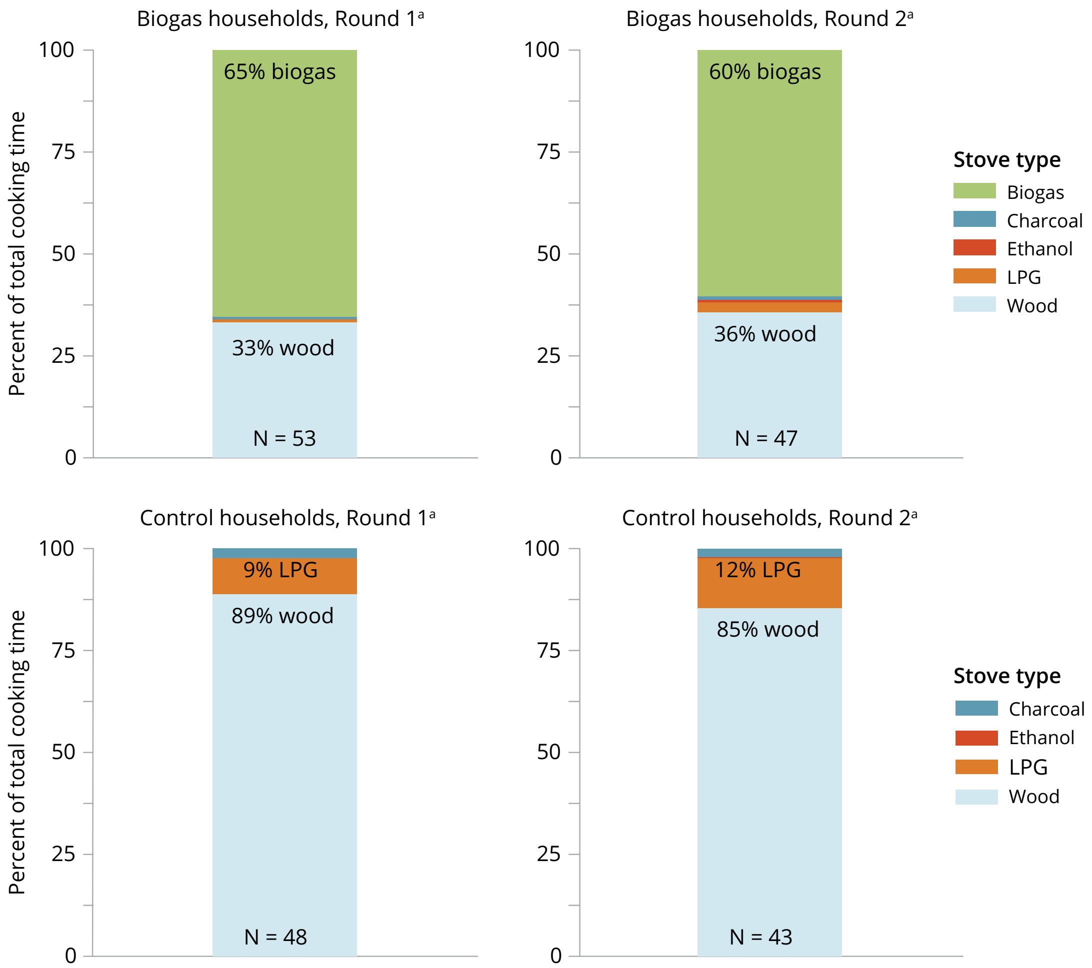
The study team also found substantial LPG use among both the biogas and control-group households. The rate of LPG use in both groups was higher than had previously been reported for Kenya. It is important to note that this study was based on a group of Kenyan farmers considered early adopters of the new technology at full retail price (i.e., with no or very limited price subsidies); this fact, at least in part, explains these customers' greater financial means and correlated higher rate of LPG use (Othieno and Awange 2016). The potential risk of the biogas technology would occur in the future when financial incentives are in place to promote adoption among households with lower socioeconomic means. Because biogas requires access to land, water, and livestock, it is unlike that this technology will be adopted by the poorest households, who lack these resources.

Data from stove use monitors (SUMs) indicates that homes with biodigesters used their biogas stoves an average of 60–65 percent of all cooking time, while wood stoves were used 33–36 percent of the time (figure 3.6).

One should note that these fractions of stove-use time, as detected by SUMs, do not directly correlate to the amount of food prepared on each type of stove. Wood stoves take longer to

**FIGURE 3.6**

Stove-Use Time as a Fraction of All Stove Use, in Homes with SUMs

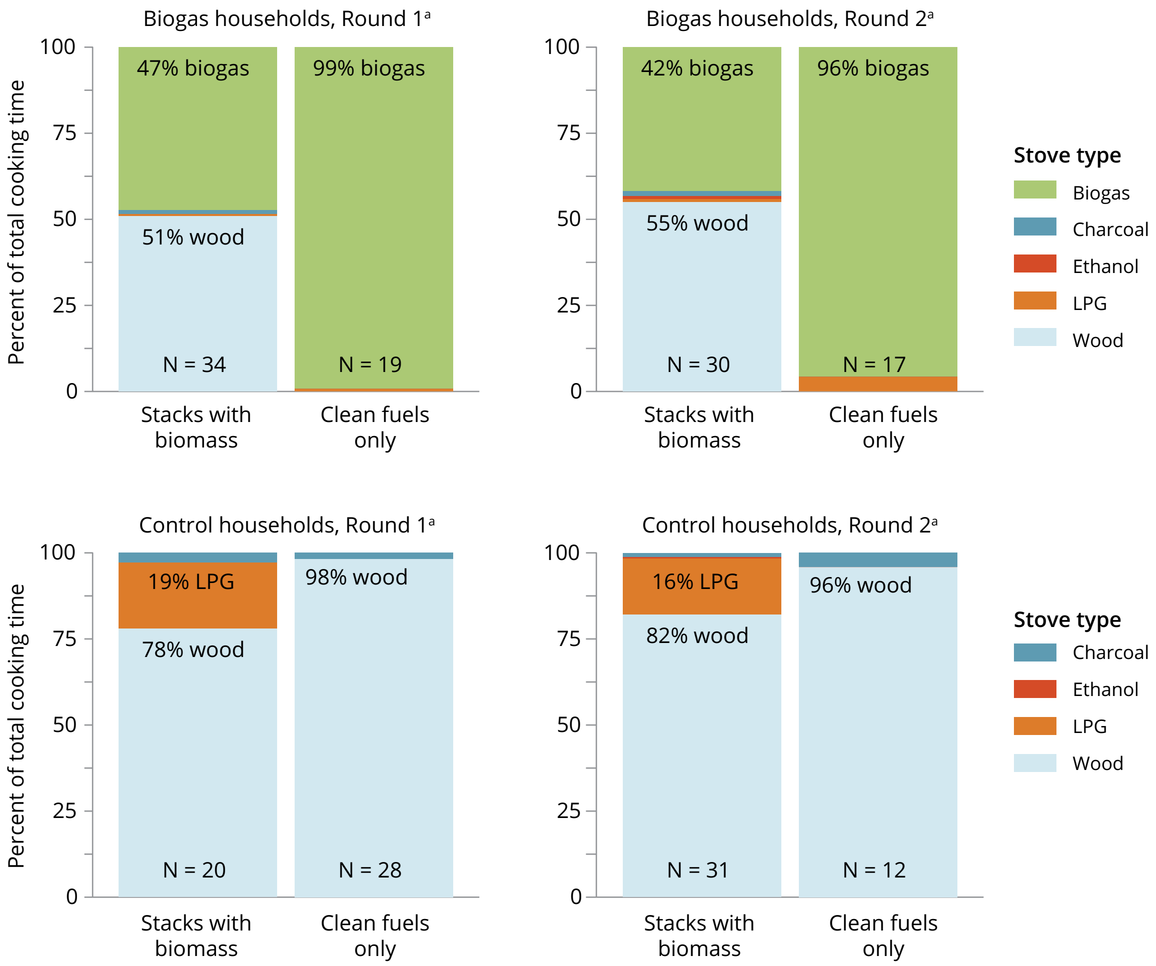



*Source:* World Bank.
*Note:* Output from data analysis of the fieldwork conducted by Berkeley Air Monitoring Group (BAMG).
a. Percentages represent the average fraction of stove-use time detected on each stove type (weighted by the number of households using each stove type).

light and cool down than do biogas stoves; in addition, they are sometimes preferred for slower-cooking foods. It is likely that more food preparation tasks occurred on biogas despite the approximate balance of stove-use time between biogas and wood as detected by the SUMs. It would also be expected that biogas-using households burning wood stoves for substantial periods of time would have a higher exposure to $PM_{2.5}$. Furthermore, as lighting time is a significant contributor to total cooking time, the ongoing use of wood fuel would also contribute to longer times required for cooking-related tasks in these households. On the other hand, the clean-fuel-only subset of biogas households used their biogas stoves 96–99 percent of total cooking time, while LPG was used for the remainder (figure 3.7).

**FIGURE 3.7**

Stove-Use Time as a Fraction of All Stove Use, in Homes with SUMs, Disaggregated by Stacking Category

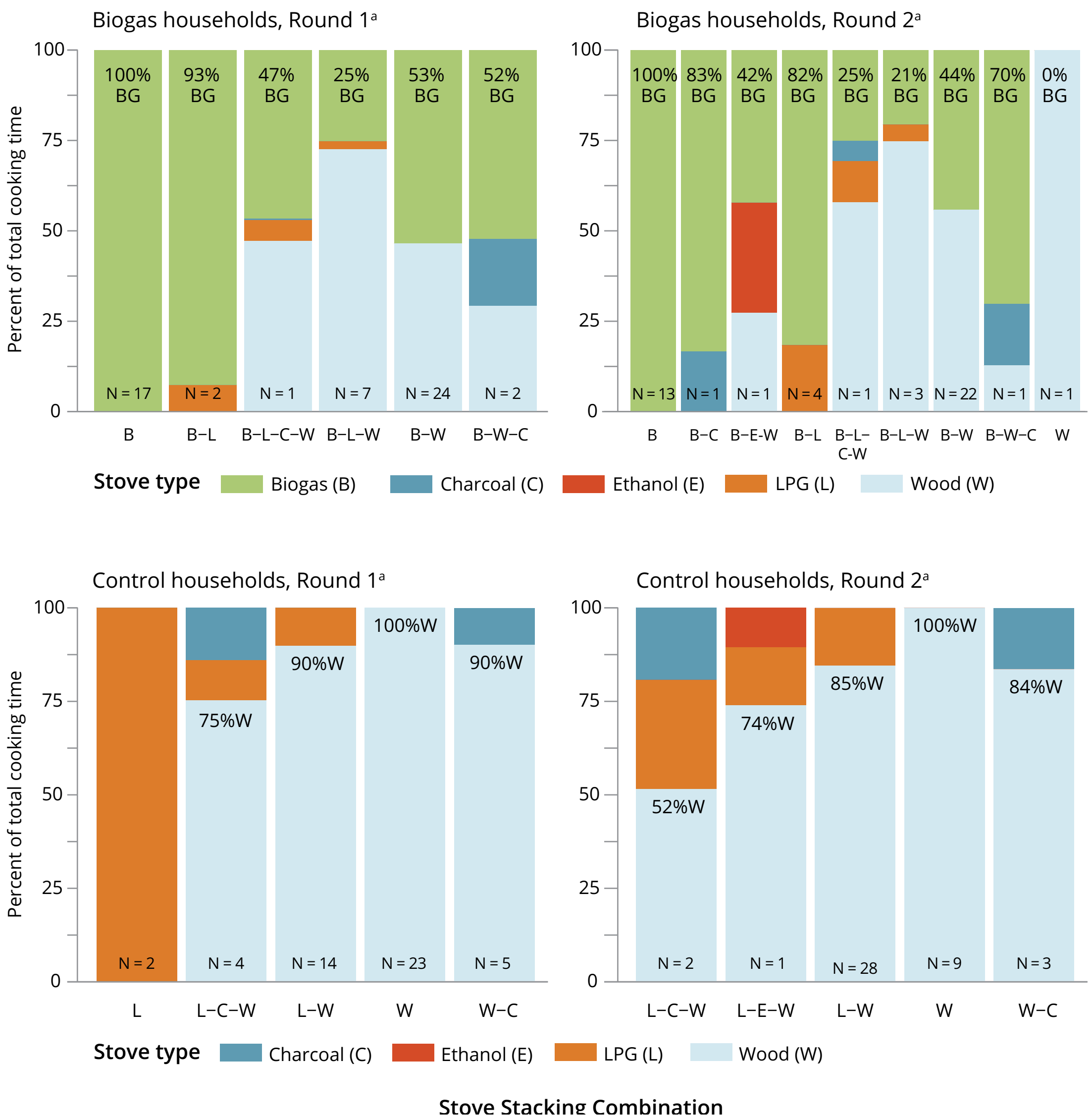



*Source:* World Bank.
*Note:* Output from data analysis of the fieldwork conducted by Berkeley Air Monitoring Group (BAMG).
a. Percentages represent the average fraction of stove-use time detected on each stove type (weighted by the number of households using each stove type).

Figures 3.6 and 3.7 also demonstrate that stove-use events on wood-burning stoves dominated total stove-use time in the control households, with wood stoves comprising 85–89 percent of total stove-use time as detected by the SUMs. In control households that stacked with clean fuel, LPG use accounted for 16–19 percent of total stove-use time. Charcoal was not a dominant fuel in either the control or biogas group, representing only a small fraction of total stove-use time. Finally, a small number of households (*N* = 1 in each of the biogas and control subsets) adopted ethanol stoves between data collection in Rounds 1 and 2. Figure 3.8 shows the stacking patterns among households with various combinations of stove types.

**FIGURE 3.8**

Stove Use for Biogas and Control Households, Showing Stacking Combinations




*Source:* World Bank.
*Note:* Output from data analysis of the fieldwork conducted by Berkeley Air Monitoring Group (BAMG).
a. The representations of stove-use time are averages among households with the same stove-stacking combination.

As shown earlier in this chapter (table 3.2), PE was slightly higher among primary cooks in biogas-using households that stacked with biomass fuels than in those that used biogas alone or stacked with clean fuels. The means in each group were 53.5 μg per $m^3$ in clean-fuel-only households versus 63.2 μg per $m^3$ in households that stacked with biomass fuels.[27] Stacking in the biogas group also affected time use (table 3.4). Cooks in biogas-using households who stacked with biomass fuels reported more time spent on cooking (31 minutes per day, p-value = 0.003) and lower satisfaction with time available for rest and leisure (1 point lower on this 10-point scale, p-value = 0.009) than households who used clean fuels only. Other differences in time use between the groups of biogas-using households were not statistically significant. Clearly, reducing the prevalence of stacking with biomass fuels among biogas adopters would improve the impact of its adoption across the spectrum of climate, health, and time-use benefits.

27 This difference is not statistically significant (p-value = 0.4).


BIOGAS

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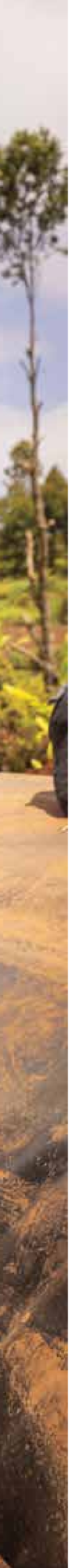
# FOUR
# METHODOLOGICAL FINDINGS



## Challenges and Opportunities in Measuring the Co-Benefits

### SEQUENCING OF ACTIVITIES

The Phase 1 methodology review and resulting study design recommendations suggested that all of the data-collection measures employed in this field test case could be conducted in each household at the same time (ESMAP 2020b). In practice, however, this was not possible. While partially attributable to COVID-related adjustments, the primary cause was the different time scales of the measurements, prerequisites for the household selection and survey preparation processes, and the range of skills needed to complete all of the data collection. The household survey, for example, was conducted by a group of enumerators who had received training in how to administer it, whereas the technical measurements for personal exposure (PE), household air pollution (HAP), and the stove use monitors (SUMs) were completed by the technical team, who had received in-depth instrument training and a substantial in-field practicum.

The technical team was able to begin sampling in customer homes immediately after training and recruitment; however, deployment of the survey was blocked by a chain of prerequisites. First, data from the screening questionnaire used to recruit participants from Sistema.bio's customer list was analyzed in order to characterize the customer group and establish criteria to recruit a well-matched control group. Once customer and control groups were recruited, a subset was invited to participate in the exploratory focus group discussions (FGDs), after which the FGD results were analyzed and the findings integrated into the survey tool. As a result of these dependencies, the survey was conducted over three months after the technical measurements began (summary of field activities available upon request).[28]

### DATA COLLECTION COSTS

The research activities conducted for this study were clearly more costly than what would be expected for a typical Results-Based Financing (RBF) project monitoring the three co-benefits, as they incorporated many experimental design elements and methods. Nonetheless, this study, together with the team's previous monitoring experience in low-and-middle-income countries (LMIC), can provide insights into the typical costs for this type of activity. The on-the-ground price tag for complex field surveys of time-use patterns and gender impacts for a sample size of approximately 200 households is in a range of US$10,000–30,000. This estimate typically includes data collection by experienced enumerators using electronic data-collection platforms, field supervision, direct costs for maintaining the team in the field, and first-line quality control on the data collection, including data checks and follow-ups, as well as translation of survey tools and responses. In many places, field partners may also be able to provide data cleaning and analysis services, but these are not included in the price range given here. Some training and oversight are needed from the project implementer or an experienced third party to ensure that the study objective is clearly understood by the field partner and the monitoring methodologies are carefully followed.

28 The Sistema.bio case study suggests how aligning the co-benefits with ongoing carbon finance monitoring may provide opportunities to streamline the data-collection needs for these multiple endpoints (box 4.1).

The costs and human resource requirements for PE monitoring generally exceed those for household surveys. Enumerators who have some scientific or health background or prior experience in collecting any kind of physical samples or sensor data will have an easier time learning how to collect PE data than those who have only worked with surveys. Sometimes scientific or technical university units can be well positioned to undertake this type of fieldwork. The costs associated with employing technical enumerators also vary widely, but a range of US$12,000–40,000 for a sample of 30–50 households provides a general estimate. At the top end of the scale, it can be expected that fewer additional inputs are needed from an expert third party for training and analysis; currently, however, few LMIC organizations may be qualified to undertake these measurements and analyze the data without some expert guidance.

In addition to the labor costs, as well as the above-mentioned attendant costs, PE requires specialized instruments and supplies, totaling approximately US$15,000–20,000. Finally, as noted elsewhere, gravimetric filter analysis requires shipment of filters to and from a specialized weighing facility. The filter preparation and analysis costs approximately US$2,000 per 100 samples, and shipping charges vary according to location. Generally, the fastest and most reliable freight services are advised in order to minimize the risk of damage to the samples.

The cost of other methods or data streams would be additional to the estimates listed above; these include costs for SUMs, FGDs, and time-tracking applications. Since an important factor in the success of RBF is anticipating—and where possible, reducing—the transaction costs of collecting field data, these activities should be carefully chosen and planned. Yet, the need for reduced costs must also be balanced with the mandate for credible evidence of impacts. As discussed elsewhere, using literature-based default values may be a feasible alternative to filter-based gravimetric analysis to estimate reductions in short-lived climate pollutants (SLCPs); such an approach, however, is not available as an alternative to PE assessment for health benefit estimation.

Leveraging or combining fieldwork activities, when possible, reduces logistical, training, and data-management burdens. For example, any RBF program that is pursuing multiple benefits could reduce costs by collecting data for the different impacts at the same time, maximizing use of the training sessions and enumerators, using common data-collection platforms, utilizing literature-based default emission factors as applicable, and other efficiencies. Importantly, care should be taken to ensure that synergies are practical and will not negatively impact collection. For example, while overall fieldwork infrastructure will help reduce costs associated with collecting the various data streams required to measure the co-benefits, household visits should be thoughtfully planned and spaced to mitigate potential participant fatigue. It is not possible to precisely estimate the cost savings associated with leveraging fieldwork activities as each situation will differ, but it is likely that the above costs would not be strictly additive.

## DATA ANALYSIS

The data collected for this study are quite rich, resulting from the multiple modalities employed to collect it (PE, HAP, and ambient air pollution data; SUMs; extensive household surveys; and FGDs). While the richness of the data is interesting, its complexity increases the time needed for all aspects of its collection, alignment, and analysis. It also increases the complexity of the required choices (e.g., which variables to include, align, and prioritize). If the methods employed here are to be deployed at scale by RBF projects moving forward, a key challenge is that most program implementers will unlikely have the required time and budget to collect and analyze this amount of data. To succeed at scale, strategies to streamline and refine the data collection process will be needed (chapter 5).

## STOVE-USE MONITORING

The SUMs added significant complexity to the field campaign. The SUM protocol requires download visits every two weeks at the start of the study to ensure proper placement and operation, followed by monthly maintenance. In this study, the SUMs were installed days to weeks before the field visits to collect PE and HAP data, but these installations could feasibly be done on the same day. It might also be feasible to conduct the survey at the same time as the SUM installation (or during a data downloading visit), although keeping the survey separate from the PE/HAP visit is advisable in order to reduce participant fatigue and ensure that participant activities and behaviors during the PE measurement period are not impacted by other study activities. The SUMs were left in the households for the duration of each data collection round, but a shorter duration of SUMs recordings would not likely harm the representativeness of the findings.

On balance—comparing the added expense and complexity of the SUMs with the value of the data collected—the case for including SUMs for all RBF projects is not persuasive (table 4.1). It is also important to note that other tracking systems may provide useful data in a cost-effective and efficient manner, depending on the context and fuel. For example, electric cookers that log their own power usage or systems that track customers' LPG or ethanol

**TABLE 4.1**

Stove Use Monitors in the RBF context: Strengths and weaknesses

| INDICATOR | STRENGTH | WEAKNESS |
|---|---|---|
| Stacking | Shows how long each of the household's stoves was used over a given period | The time each stove is lit is measured rather than the proportion of food or meals cooked using each stove. This can distort the stacking picture, especially if the longest-cooking foods are still cooked on the baseline biomass technology. |
| Personal exposure (PE) | Could theoretically help explain PE results by showing which stoves were used during monitoring | The SUMs would need to be installed in every PE home, which may be cost-prohibitive. Concurrent analysis of SUMs and PE data adds a layer of complexity and cost, and operationalizing this information is not straightforward. |
| Cooking time savings | Provides an objective record of how long each stove was used, avoiding recall bias | This cannot determine whether the cooking was attended, leading to time being counted as cooking time when the cook may actually have been doing other tasks. |

*Source:* World Bank.

purchases can provide important information on household energy transitions. These systems should be used when practical, as they require a minimal burden of additional fieldwork and provide objective data. At the same time, these methods do not necessarily account for the displacement of traditional technologies, and characterizing stove stacking is important in quantifying many co-benefits of household energy transitions.

## DEFINING TRANSITION PATHWAYS

The study team observed many potential biogas customers in the household control group that had already adopted LPG to meet at least some of their cooking needs. As clean fuels become more accessible globally, it is hoped that ever more households will be able to adopt them and thus reduce the damaging health and environmental impacts of biomass fuel combustion. However, this raises the question of what impacts can be anticipated (e.g., when evaluating the impact of biogas adoption among such users). Nearly any amount of continued traditional fuel use is expected to result in higher-than-optimal exposure to $PM_{2.5}$ and other associated adverse impacts (Johnson and Chiang 2015). The adoption of clean fuels, even if partial, can reasonably be expected to lessen the contrast from the baseline in expected impacts attributable to clean fuel transitions (chapter 5).

## CO-BENEFIT INTERACTIONS

The climate, health, and gender benefits of clean cookstove adoption are not wholly independent. In fact, synergies between them suggest opportunities for benefits that cross several of these domains. For example, while the health benefits of reduced exposure to HAP accrue to both sexes, the reductions preferentially benefit women, who are disproportionately exposed to higher levels of $PM_{2.5}$ from cooking due to their traditional roles in food preparation. The health co-benefits of clean cooking technologies can thus be viewed, at least in part, as a gender co-benefit since they reduce gendered inequalities related to air pollution exposure from cooking and its associated health impacts.

Cross-cutting benefits related to general well-being may blur the boundary between the health and gender impacts. For example, SDG target 5.4 for gender relates to unpaid care and domestic work, and indicator 5.4.1 reflects the "proportion of time spent on unpaid domestic and care work, by sex, age, and location." Reductions in time spent on this work directly benefit women, but may also result in greater well-being that relates to SDG target 3.4 for health, which seeks, in part, to "promote mental health and well-being." As discussed in chapter 3, the study team observed that open-ended responses from women using biogas stoves often reflected an increase in well-being, as suggested by reductions in stress and worry, less physical and mental burdens, and more time for rest (table 3.7). Improvements in mental health driven by a reduction in time spent on unpaid domestic work would be important benefits to consider, independent of the health benefits provided via reductions in exposure to $PM_{2.5}$.

Another way in which the co-benefits interact is via reduced consumption of biomass fuel. This has a beneficial impact on SLCPs, but also potentially increases household income (e.g., if the fuel was previously purchased or hired labor was paid to collect it). Biogas-using households may likewise experience increased income resulting from a reduced need to purchase fertilizer. The increases in household income may have gender co-benefits, particularly if the money saved is put toward uses that benefit women (e.g., investments that reduce women's unpaid labor and drudgery or that improve their health and agency).

## INTEGRATING TESTED CO-BENEFIT METHODS INTO EXISTING CARBON FINANCE SCHEMES

Box 4.1 illustrates how the co-benefit methodologies tested in this study could, in theory, be integrated into the framework of Sistema.bio's existing carbon finance activities. The Cardano Development Project demonstrates the actual demand for clean cooking co-benefits beyond GHG emission reduction credits, which could likely increase as the integration of methodologies to measure and quantify them advance (box 4.2).

**BOX 4.1**

### SISTEMA.BIO MONITORING CASE STUDY

Sistema.bio registered its biogas program with the Gold Standard in 2018. Like most clean cooking programs selling carbon offsets certified as meeting the Gold Standard, Sistema.bio has followed the methodology entitled "Technologies and Practices to Displace Decentralized Thermal Energy Consumption, Version 3.1" to quantify its climate impacts (Gold Standard 2017a). Quantifying impacts for Sustainable Development Goal 13 (SDG 13), expressed in terms of avoided carbon dioxide equivalents ($CO_2e$), is the central mandatory goal of this methodology. The Gold Standard also requires Sistema.bio to comply with gender-sensitive requirements as part of its mandatory Safeguarding Principles and Requirements.

Another Gold Standard requirement is that the project proponent must include at least two additional SDGs as part of its monitoring framework. To this end, Sistema.bio also assesses the impact of its Kenya-based operations on energy access (SDG 7) and job creation (SDG 8). While the assessment of these supplemental impacts does not result in the generation of additional saleable assets under the Gold Standard beyond tonnes of avoided $CO_2e$, it demonstrates the additional sustainable development impacts of the carbon credits.

To date, Sistema.bio's carbon-offset monitoring activities have focused on a survey, used to collect data to quantify fuel consumption in the baseline and project scenarios, as well as to measure the extent to which the baseline

## BOX 4.1, *continued*

technology is still used and gather feedback on operation of the new technology and drivers of continued baseline technology use (if any). The survey is conducted annually according to the "sampling and surveys for Clean Development Mechanism (CDM) project activities and program activities, Version 04," although not all parameters must be included every year, as some must only be assessed biannually.

Sistema.bio conducts a diagnostic survey in all prospective customer households on a rolling basis, prior to installation of the biodigester. The survey is conducted by sales agents to collect essential data (e.g., number of animals; availability of space, water, and manure; fuel consumption; fertilizer use; and basic household characteristics).

Table B4.1.1 highlights the potential for expanding the monitoring infrastructure of Sistema.bio's current monitoring activities to include the co-benefits for climate, health, and gender.

**TABLE B4.1.1**

Hypothetical integration of additional co-benefits into Sistema.bio's monitoring scheme

| CO-BENEFIT | METRIC | CHANGE/ADDITION TO CARBON FINANCE MONITORING | RESOURCE REQUIREMENTS |
|---|---|---|---|
| Climate (using existing method) | Black carbon (BC) emissions (baseline and project scenarios) | Kitchen concentrations of $PM_{2.5}$ measured alongside personal exposure (PE) monitoring used to determine BC-to-PM ratios | Specialized analysis of the filters, commonly conducted at filter-weighing facility |
| Climate (using proposed/ updated methodology) | BC emissions (baseline and project scenarios) | No additional measurements required | Default emission factors applied from published field-based studies |
| Health | PE to fine particulates ($PM_{2.5}$) (baseline and project scenarios) | PE measurements needed for a subset of 30 baseline and project households, like in conjunction with diagnostic and monitoring surveys | • Specialized technicians and instruments<br>• Access to filter weighing facility<br>• Ethics clearance |
| Gender | Not fixed, but may include quantity of time spent on cooking-related tasks, rest and leisure, and drudgery, or satisfaction with time use (baseline and project scenarios) | Questions can be added to the existing diagnostic and monitoring surveys, with gender data collection from 100 households | May require focus group discussions (FGDs) or open-ended survey questions, requiring specially trained enumerators, to fully contextualize gender impacts |

*Source:* BAMG.

**BOX 4.2**

## MONETIZING CLEAN COOKING CO-BENEFITS TO SUPPORT BUSINESS SCALE-UP: CARDANO DEVELOPMENT PROJECT

The clean cooking solutions that lead to health improvement have not yet penetrated most markets, especially in rural areas. They remain beyond reach for many customers who cannot afford the up-front costs. At the same time, early stage or small-scale suppliers have limited access to capital that would allow them to prefinance the solutions for their consumers. The lack of affordable working capital to finance large inventories for low-income consumer demand restricts growth of clean cooking companies.

In order to reach these underserved customers with clean cooking solutions, Cardano Development and its partners initiated the Clean Impact Bond (CIB), which aims to create additional revenues through quantifying, certifying, and monetizing the health and gender benefits of clean cooking solutions alongside the environmental impact they generate. Monetizing the co-benefits is the first step in transforming them into tradeable commodities that clean cooking companies could use as collateral to get a working capital loan to finance their scale-up.

Cardano Development pioneered the first CIB transaction, with Sistema.bio as the company generating the credits (through sale of its biodigesters in Kenya), South Pole as purchaser of carbon credits (owner of the Gold Standard certified carbon project with Sistema.bio), and the Osprey Foundation (via impact manager Frontier Finance Solutions) as the outcome buyer of the health (averted disability-adjusted life year [aDALY]) and gender co-benefits. BIX Capital, the investor, prefinances Sistema.bio to scale up its operations in Kenya. The International Finance Corporation (IFC), as a BIX Capital investor, provided technical assistance to the pilot transaction, which included advising and managing the field survey for ex-ante estimation of the health and gender co-benefits performed by Berkeley Air Monitoring Group (BAMG).

The IFC-supported measurement of the health and gender co-benefits of the biodigesters in both control and treatment sampling groups, conducted by BAMG, showed demonstrably positive results using the Gold Standard methodology for measuring these impacts. The findings provide the proof of concept

**BOX 4.2,** *continued*

needed to take the pilot transaction forward under the CIB. Both BIX Capital and Cardano Development are committed to replicating similar transactions with new outcome buyers, which they expect to be more streamlined, given the pioneering work done in developing the methodologies and tools for it.

*Source:* Cardano Development and BIX Capital.

## Performance of Measurement Methods for Short-Lived Climate Pollutants

A comparison of laboratory and field-based emission factors for estimating black carbon equivalents (BCe) shows that, when simple wood stoves are the baseline technology, substantial differences in SLCP impacts are possible and indeed probable. In this case, the current laboratory-based approach appears more conservative, yet application of field-based estimates is likely more accurate and could demonstrate more substantive impacts. Perhaps most critical, application of the default or literature-based emission factors reduces the burden of collecting field data, helping to mitigate a major transaction cost associated with implementing the Gold Standard methodology.

Currently, an effort by the Climate and Clean Cooking Consortium (also known as 4C) is under way to provide countries with household energy programs included as part of their climate commitments under the Paris Agreement guidance on monitoring, reporting, and verification.[29] Part of this effort entails a systematic review of emission factors from normal stove usage in homes to synthesize evidence for black carbon (BC) and organic carbon (OC) emissions for common stove-and-fuel combinations. Once those guidelines are published, the study team recommends applying them as default values, potentially with a conservative adjustment (e.g., use of 90 percent confidence bounds). The team anticipates that sufficient data for several common stove-and-fuel combinations will be available (see, for example, the compilation in ESMAP 2020b, Appendix D).

When emission factors are specific to a region, as well as a technology, those should be applied. That said, application of field-based defaults is still recommended, even when they are not available for a specific region, as the error introduced by assuming emissions performance from the laboratory is generally greater than regional differences. This approach,

29 https://cleancooking.org/events/webinar-achieving-climate-goals-through-clean-cooking/.

which could be readily integrated into the Gold Standard methodology, would help lower transaction costs, provide more realistic estimates, and ensure a level playing field with all projects using the same set of emission factors, as is currently done for many methodologies and sectors.

## Health Impact Estimation

The method chosen for assessing the health impact was averted disability-adjusted life year (aDALY). This choice was based on the best available scientific evidence that relates reductions in exposure to air pollution to multiple health outcomes.

The aDALY methodology was practical and feasible to implement in the field. The study team believes that the extensive training it provided on the collection of personal air pollution measurements was key to this success. These measurements are technical and specialized, and most LMIC data-collection teams would not be expected to have prior experience with them. As Berkeley Air Monitoring Group (BAMG) has decades of experience with these types of instruments and data, the team was able to train enumerators new to these processes and support them throughout the data-collection process.

Beyond the required technical skill, the methodology is costly to implement on a per-household basis. Personal exposure (PE) monitors are expensive and require a minimum of two visits per household to deploy and collect. The analysis of PE data incurs additional cost and risk, as the filters used to collect particulates must be weighed on a specialized scale in a highly controlled environment before and after they are deployed in the field, and stored in a cool environment prior to being weighed for the second time. Filter-weighing capacity in Africa is minimal, although efforts to address this need are currently under way in Kenya, Uganda, and potentially elsewhere. In cases without a proximate facility, filters must be shipped to an overseas facility in cool and stable packaging, incurring significant expense and risk of lost or damaged filters.

Despite these limitations, alternative approaches to estimate exposure reductions and associated health benefits are not likely to provide results with confidence. For example, exposure models based on proxy or other predictors of exposure have proven difficult to develop and are context-specific (Carter et al. 2017; Clark et al. 2013; Hill et al. 2019; Johnson, Piedrahita, et al. 2021; Sanchez et al. 2020; Shupler et al. 2018). Similarly, unless a high-quality study has been conducted on the intervention in the area of interest, it is not recommended to generalize results from other studies as large variations in exposures have been documented, even for similar technologies and/or regions (Pope et al. 2021; Quansah et al. 2017). Lastly, public health experts widely agree that measuring averted morbidity and mortality using established relationships between exposures and disease is highly preferable to tracking self-reported health symptoms. The aDALY approach allows proponents to calculate the return on investment from cooking energy transitions compared to other types of health interventions and quantify the health impacts in terms of reducing the national health-care burden. Understanding the relative cost-effectiveness of cookstoves as a health intervention encourages further investment in the sector and allows for a more rapid scale-up.

The current guidance on exposure sampling is likely already at a minimum of what could be expected to provide reasonable $PM_{2.5}$ estimates. The current Gold Standard methodology requires a minimum sample size of 30 households in each of the baseline and target groups, and the study team would not recommend reducing sample sizes below this number. Furthermore, the cost savings of processing fewer samples at this level would be nominal. As the minimum sample-size requirement does not change as program scale increases, the cost of PE monitoring for 30 households in each group would pose the highest barrier to small-scale implementation efforts. In the context of larger-scale programmatic efforts, the costs would be more manageable.

In situations where the current aDALY approach is impractical due to the cost implications of quantifying exposures, it may be advisable to consider a scheme in which a project is deemed nominally beneficial to health and provide a program-level certification similar to the SDG certification approach the Gold Standard currently uses. In such a case, the indicator would still be exposure to $PM_{2.5}$, but more limited measurements implying those reductions could be employed. For example, projects with low emissions technologies (e.g., at or above ISO Tier 4 for $PM_{2.5}$ and CO) could apply for certification based on SUMs-based evidence of displacing traditional technologies by 50 percent or more, potentially supplemented by a small sample of kitchen concentrations with simple light-scattering measurements. This approach would not provide the inputs required for health modeling and the corresponding aDALY estimates; however, it could provide a considerably sound foundation of implied benefits that could justify a certification scheme.

Use of the Household Air Pollution Intervention Tool (HAPIT) is relatively straightforward, and, with simple instructions, can be applied by non-technical personnel; however, little guidance is available on when to use or adjust the default estimates for demographic information. More prescriptive guidance on the use of estimates from household surveys versus the defaults would aid the user in choosing the appropriate demographic estimates.[30]

## Gender Indicators

The present study is among the first to explicitly investigate the use of metrics to assess the gender co-benefits of clean cookstove adoption for the purpose of RBF. Thus, the results presented here must be viewed as preliminary. Ongoing and future research on this topic will greatly add to the developing evidence base.

The study team's findings on time use are encouraging and support recent methodological developments in the field that did not exist at the time the present study's data-collection instruments were being developed. The recent construct of time-use agency "goes beyond measuring time use to understand the gendered dynamics around controlling one's time use

30 It is important to note that HAPIT is being succeeded by the Air Pollution Burden of Disease Explorer (**ABODE**). Updates to background burden of disease estimates, exposure-response curves, and other enhancements and maintenance will only be done on ABODE; thus, this tool is recommended for use moving forward.

to advance [one's] own strategic goals and highlights any barriers one faces in doing so" (Eissler et al. 2021). As a multi-dimensional concept, time-use agency incorporates individuals' "critical consciousness of time-use inequities, rights, and personal aspirations; confidence in their ability to (re)allocate their time; expression of voice about the allocation of their time; and actual influence over decisions about the allocation of their time across the full range of needs- and choice-based activities, in line with their personal aspiration" (Sinharoy et al. 2021).

As discussed in chapter 3 (tables 3.4 and 3.5), primary cooks in biogas-using households spent less time on cooking and drudgery and had greater self-reported satisfaction with the amount of time available for rest and leisure, which increased with the proportion of clean fuel used for cooking. Previous research has found that increased self-directed leisure time is associated with a greater feeling of agency (Jagoe et al. 2020). In the present study, satisfaction with time use correlates well with time-use agency using the novel assessment tool developed and tested by Sinharoy et al. (2021). The study team's findings strongly support the hypothesis that biogas stove adoption is related to women's empowerment via an increase in time-use agency, with the caveat that the findings are preliminary and may not be representative. Along with recent methodological developments in the field, the results suggest that future RBF efforts will be able to deploy survey tools that can capture the benefit of clean cookstove adoption for time-use agency across all dimensions of impact underlying this construct.

The data collected in this study also suggest avenues for exploring alternative indicators of gender impacts from cookstove adoption. Qualitative data, particularly the results of focus group discussions (FGDs), indicate that the biogas system might be providing gender benefits outside the realm of time use (figure 4.1). Table 4.2 summarizes potential indicators of the gender co-benefit, along with thoughts on their RBF application.

**FIGURE 4.1**

Focus Group Discussion with Biogas Customers

*Source:* © Eco Research Ltd.

**TABLE 4.2**

Potential indicators of gender co-benefit

| METRIC | MONETIZABLE UNIT? | CAN BE OPERATIONALIZED FOR RBF AT SCALE? | INHERENTLY A GENDER BENEFIT? |
|---|---|---|---|
| Time savings | Yes; for example, minutes per day on cooking-related tasks | Yes, via time-use survey | An intermediary benefit on the pathway to potential gender benefit (provides the resources needed to potentially use time in other ways) |
| Productive time | Yes; for example, minutes per day on tasks related to income generation | Yes, via time-use survey (may need adjustment for context) | Complicated, as income-generating or "productive" tasks may also be considered "drudgery" and may be transferred to hired help if income is sufficient for doing so (reducing the time spent by primary cooks on these activities) |
| Time-use agency | Yes, in increments on a validated scale | A validated survey tool has recently been developed (Sinharoy et al. 2021) | Yes, agency is related to empowerment (defined as "the expansion in people's ability to make strategic life choices in a context where this ability was previously denied to them" (Kabeer 1999) |
| Rest and leisure time | Yes; for example, minutes per day | Yes, via time-use survey | Likely, as discretionary time is a necessary resource for the reallocation of time in preferred ways; however, a tool to measure time-use agency directly would provide more robust indications of this benefit |
| Satisfaction with time available for rest and leisure | Yes, increments on a 5- or 10-point scale | Yes, via self-reporting in survey | Likely, as it relates to time-use agency (although a tool to measure it directly would provide more robust indications of this benefit) |
| Economic benefits | Yes, local or international currency | Yes, via survey to assess income and expenditures | Possibly, depends to whom in the household the benefits accrue |
| Drudgery alleviation | Yes; for example, minutes per day on activities considered "drudgery" (note that the term is subjective; here defined as "regular household-related activities that are very hard work, either physically or mentally, and time consuming, and repetitive, and unavoidable" | Yes, via survey (may need adjustment for context as no standard definition of drudgery exists) | Yes, related to agency over time and activities. A tool to measure time-use agency would likely be able to capture this benefit |
| Stress reduction | Yes, in increments on a validated scale | Unclear; validated stress scales exist, but may require adaptation to local context | Yes, benefits women's well-being. Risk of double-counting if also considered a health co-benefit |
| Shifting of gender norms; for example, men more willing to take on cooking tasks | No monetizable unit currently exists | Unlikely, as these shifts in norms usually occur on much slower timescales than can be captured over a project's monitoring lifespan | Yes, directly related to women's equality and empowerment |

*Source:* World Bank.

## Other Findings

An important feature of this study design was the combination of quantitative and qualitative methods to assess gender impacts. Two exploratory FGDs were held at the beginning of the study, resulting in important refinements to the survey tool, as well as anecdotal information on the effects of COVID-19 on households and their cooking practices and energy choices. The rest of the qualitative data, which mainly took the form of additional FGDs but also included a few open-ended questions found in the survey tool, was primarily used to contextualize and explain the quantitative results. In this regard, the qualitative data proved valuable because it provided the suggestion of household benefits that were not successfully captured through the survey tool (e.g., stress reduction, benefits toward household finances, and slight shifts in gender norms related to cooking).

Another hallmark of this study was the implementation of two data-collection campaigns, which were initially designed to assess the extent of seasonal differences, but ultimately served the more useful purpose of allowing for the fine-tuning of the data-collection tools. While the two rounds had few statistically significant differences, at least in this case, the evidence did not point persuasively to a substantial seasonal effect that would necessitate two rounds of data collection as standard practice. Some suggestive evidence exists that baseline exposures were higher during the "dry" season, but small sample sizes and high internal variability made it difficult to draw definitive conclusions. Seasonal effects on HAP have been reported in other contexts, due to such factors as background concentrations, changes in behavior (e.g., more time spent indoors during heating seasons), use of wet/dry fuels, and others (Carter et al. 2016; Gurley et al. 2013; Keller and Clark 2022; Khalequzzaman et al. 2010; Ni et al. 2016). Results from this study do not offer a clear picture of the times of year when pressures on women could be greatest, such that an RBF protocol could recommend those seasons as the most conservative timeline for monitoring. Finally, despite having a data-collection timeline that is likely longer than feasible for most RBF programs, it is likely not long enough to see definitive shifts in measures of women's empowerment or equality, should these result from a change in cooking energy.



# FIVE
# CONCLUSION

This study confirms that the Gold Standard methodologies for quantifying the co-benefits of cookstove programs to mitigate short-lived climate pollutants (SLCPs) and reduce adverse health impacts are robust, feasible approaches. The methodologies for assessing gender co-benefits are less robust, and the pathways to measure them are less prescribed; for example, the Gold Standard does not have an approved methodology, and, at the time this study was being conducted, no validated tool to assess time-use agency in LMIC contexts was available. This study explored multiple methodological options, bearing in mind the constraints of Results-Based Financing (RBF) indicators, which must be cost-effective, scalable, replicable, robust, operationally feasible, and ideally compatible with carbon methodologies.

## Recommended Actions

### IMPROVE THE FEASIBILITY AND COST-EFFECTIVENESS OF CO-BENEFITS MONITORING

***Diagnostic research should be conducted prior to the start of co-benefits monitoring to characterize the customer group, develop the screening criteria for a matched control group, and pre-qualify potential participants for the research.*** The starting point would be to design a cost-benefit co-benefit monitoring plan informed by diagnostic research that measures such elements as stove-and-fuel mix, fuel procurement practices, seasonal adaptations, and socioeconomic status. (The Multi-Tier Framework [MTF] survey is an example of a diagnostic tool that could serve this purpose.) From these results, a theory of change should be developed so that the follow-up study is used to confirm the causal pathway for each targeted co-benefit. These activities will ensure that all players in the RBF ecosystem understand the characteristics and practices of the baseline and customer groups and select the most likely impacts for RBF schemes. Furthermore, since the initial parameters will be well-defined, these diagnostic activities will reduce the workload related to data collection. Adopting this recommendation would help cookstove program developers reduce cost outlay for specialized monitoring services and ensure early alignment with investors and donors, with spillover benefits to investors from well-vetted opportunities and reduced transaction costs.

***The ongoing investigation of stacking should be incorporated into any co-benefits investigation (as in carbon finance).*** Stove use monitors (SUMs) are the most robust way to investigate stacking, as they can provide very valuable information to program managers on stove adoption and uptake, as well as potentially determining when maintenance or repairs are needed. If it is found that stacking is significant, incentives for uptake of the cleaner technology should be provided, with disincentives for the concurrent use of more polluting and/or time-consuming systems. At a bare minimum, project developers should check that the project technology offers sufficient fuel and burner space for the cook to carry out all of the necessary energy-requiring tasks, potentially including such ones as water heating, beer brewing, and production of animal fodder, in addition to cooking the family's meals. If stacking persists, project teams should consider conducting qualitative research activities that can help elucidate barriers to a more complete transition to clean cookstove use. SUMs should only be required for larger-scale projects, as they are not cost-effective for smaller ones. Modern cooking devices with self-embedded meters for measuring cooking fuels used to enable the pay-as-you-go business model offer opportunities for better and more cost-effective measurements.

***Results-based carbon finance projects should consider concurrent measurements of SLCP, health, and gender co-benefits.*** This study found strong synergies among these measurements, suggesting that concurrent measurements could be more cost-effective than measuring each outcome independently. However, this recommendation would most likely apply to large-scale projects in the interim. For many small- and medium-sized carbon projects, the resource and capacity demand of these assessments may prove prohibitive.

***Donors should build monitoring capacity, relationships with institutional review boards, and household air pollution (HAP) filter-weighing facilities in the regions where cookstove programs are under way or anticipated.*** They should work on strengthening the network of the already existing Regional Knowledge and Testing Centers, which currently provide cookstove and fuel performance testing in some 12–15 sites in LMIC. These centers could be expanded to offer a core of trained enumerators and an equipment library for personal exposure (PE) measurements. Building localized monitoring capacity with the support of more experienced researchers can reduce costs for program developers, allowing them to carry out the co-benefits monitoring methodologies more efficiently and effectively.

## IMPROVE THE MEASUREMENT OF CO-BENEFITS

***The Gold Standard should amend its black carbon (BC) methodology by updating the requirement for a laboratory test of emission factors paired with measurement of field-based ratios.*** Today, in contrast to the time the methodology was first developed, peer-reviewed values from field-based emission tests are available for a sufficiently wide range of stove-and-fuel combinations. Field emission factors are more accurate than lab-based estimates, and using these factors as defaults will simplify and reduce the cost of data collection.

***The Gold Standard should update its averted disability-adjusted life year (aDALY) methodology by using Air Pollution Burden of Disease Explorer (ABODE) as the modeling tool.*** ABODE is the successor model to Household Air Pollution Intervention Tool (HAPIT). While still available, HAPIT is no longer updated or supported. ABODE incorporates the most up-to-date, internally consistent evidence linking exposure to health impacts. Donors can request this change to facilitate RBF transactions to the benefit of the entire RBF ecosystem, which will ensure that the health impact modeling is optimized.

***Based on the limitations of gender metrics, discussed extensively in this report, the study team recommends using the data collected in the diagnostic research results to develop hypothesized causal pathways for gender co-benefits.*** To assess the gender benefit in relation to time-use changes, a validated scale, such as the one described in Sinharoy et al. (2021), should be used to measure time-use agency. Project developers and auditors should also consider adding quantitative or qualitative research methods that can elucidate benefits that relate to gender impact outside the arena of time use (e.g., changes in traditional gender norms related to cooking, cost savings, and/or impacts on stress and overall well-being). In addition, there is an urgent need to fund and make available research on gender co-benefit assessment and quantification; and build the gender-assessment capacity of project developers and RBF investors.

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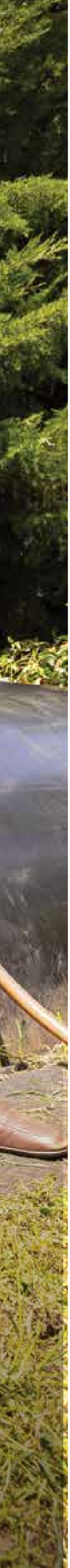
# APPENDIXES



## APPENDIX A

# Additional Materials

*More detailed information about the field study is available upon request.. The topics covered are listed below:*

- Additional Tables and Figures
- Sampling and Screening Procedures
- Summary of Field Activities
- Sample Size
- Visual Aids
- Table of Response to the Open-Ended Question, "How has the biogas stove made a difference to your life?"
- Focus Group Discussion Summary Themes and Findings
- Data Collection Challenges
- Timeline of COVID-19 Restrictions in Kenya
- Climatology of the Study Region

**APPENDIX B**

# Sampling and Screening Procedure

Identification of biogas customer households in the research setting was conducted in collaboration with Sistema.bio, using customer records (detailed procedures available upon request). First, a list of potential participants for the customer group was provided by Sistema.bio. This list was restricted to the geographical area of interest and included households who had a Sistema.bio biogas stove installed 6–30 months prior to the study. These households were first contacted by a Sistema.bio representative by phone to ask permission for an Eco Research team member to visit their home to conduct a screening survey. The Eco Research team then used this list to visit homes and ask the primary cook a series of screening questions.

For the biogas customer group, the screening questions were primarily designed to determine whether the household was available for the study procedures (i.e., not planning to move or be away from home for the next several months) and met the inclusion criteria (age of primary cook over 18 years old and stoves in the household not primarily used for commercial purposes). Additional questions were asked of these households to enable the construction of a customer profile that was then used to identify a control group as similar as possible to the biogas customer group.

In order to match the two groups, the screening questions applied to the customer households covered the following:

- Asset ownership and level of education to enable the calculation of a Living Standards Measure (LSM) score.[31]
- Number of adults age 14 years or older for whom each primary cook typically prepares an evening meal.

A customer profile was created from the customers' responses to the screening questionnaire to determine the eligibility criteria for non-customer households (non-biogas owners) in the same villages. For non-customer households, inclusion criteria included various factors

31 An LSM was calculated using a procedure developed by Marketing & Social Research Association-Kenya (MSRA-Kenya) that the project team previously used for projects in Kenya. The measure, which borrows heavily from ESOMAR South Africa, has been customized for Kenyan households.

that would enable them to have a biodigester (e.g., sufficient livestock ownership and access to water and land); an LSM score and primary cook age above the 10th percentile and below the 90th percentile of the customer households; and cooking an evening meal for at least two adults.

Smoking status was also assessed. Current smokers (more than once per week) were very rare (n = 1 at screening). While smokers were not excluded from the household survey, they were excluded from selection of the subset undergoing monitoring of air pollution exposure.

Although the original intent was to sample randomly from the Sistema.bio customer households on the list of potential participants, an insufficient number of available households were eligible and willing to use this approach. As a result, the study team contacted all reachable households on the customer list and enrolled all those who were eligible and willing, but were still unable to achieve the desired sample size. Thus, the team further expanded the recruitment into geographically proximate areas to complete the customer sample. For non-customer controls, a nearest-neighbor sampling approach was used, whereby the Eco Research team approached the nearest neighbor of each enrolled customer household who did not have a Sistema.bio stove. If the neighboring household was available and willing to complete the screening and eligible and willing to participate in the study, it was enrolled. If the criteria were not met, the next nearest neighbor was approached.

**APPENDIX C**

# Data Collection Procedure

To ensure that data collected in the field was as robust as possible, the following measures were taken:

- At the start of each data collection campaign, the study manager and quality control coordinator in Kenya accompanied the study team to ensure everything proceeded according to protocol and noted/helped resolve any challenges.
- A field supervisor accompanied the field team at all times.
- After initial installation, the placement of stove use monitors (SUMs) was checked twice monthly (and subsequently monthly) to ensure that the sensors remained in the correct position.
- On the day data was collected, SUMs and survey data were uploaded to online platforms and checked by Berkeley Air Monitoring Group (BAMG) staff. Feedback was provided in a timely fashion (every day at first, decreasing to every few days once initial issues had been addressed) to ensure that potential problems were caught and addressed early.
- Study managers regularly held debriefing sessions with the team to resolve any problems, with special attention paid to technical issues with instrumentation and survey questions or sections the team had difficulty administering.
- Any questionable survey data was flagged and then verified, corrected, and/or marked as invalid through call-backs and/or re-visits with respondents.

For air pollution data, filters and Ultrasonic Personal Air Sampler (UPAS) data files were examined. Data was deemed valid if the flow rate and logged duration were within 10 percent of the targets (1 lpm and 48 hours, respectively) and there were no physical issues (e.g., rips or tears) with the filter itself. Field blanks were deployed to correct collected field values, and the limit of detection (LoD) was calculated as three times the standard deviation of the field blanks. Any corrected mass deposition that fell below the LoD was replaced with LoD/sqrt(2).

**Energy Sector Management Assistance Program**

The World Bank
1818 H Street, N.W.
Washington, DC 20433 USA
esmap.org | esmap@worldbank.org