Maximizing the Health Benefits of Clean Household Energy in Peri-Urban Nepal

Summary Report

CLEAN COOKING ALLIANCE

Photo credits

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Acronyms and Abbreviations

CCT conditional cash transfer
CVD cardiovascular diseases
FCHV female community health volunteer
LPG liquefied petroleum gas
M&E monitoring and evaluation
MFI microfinance institution
$PM_{2.5}$ fine inhalable particulate matter of 2.5 micrometers and smaller

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Executive Summary

In 2019, with support from the Norwegian Agency for Development Cooperation, the Clean Cooking Alliance successfully completed the two-year demonstration project "Maximizing the Health Benefits of Clean Household Energy in Peri-Urban Nepal," designed to support the Government of Nepal's objective to establish smoke-free kitchen communities and improve health outcomes through clean cooking. The project was implemented by LEADERS-Nepal, Junkiri Interactive, Ajummery Bikas Foundation, the Schatz Energy Research Center at Humboldt State University, RTI International, and the University of Houston, with support from Rooster Logic, Keivtech Technology, Mountain Air Engineering, and other experts and local partners. The project identified clean fuels and technologies that meet local needs and explored the best means of increasing access and encouraging their use.

Participant use of induction stoves lead to a significant reduction in the use of LPG and traditional stoves.

The project applied social and technological intervention strategies to support the wide-scale uptake and use of clean cooking practices across five wards from Kavrepalanchok (Kavre) district, Nepal. The study recruited 1,533 households in Panchkhal and Mandandeupur municipalities. A subset of 772 households were followed over a year, during which time the team gathered data to assess the effect of project activities aimed at increasing clean cooking practices or disuse of traditional biomass stoves. Another subset of 761 households located outside of areas exposed to intervention activities were followed for approximately five months.

Project activities were designed to address multiple factors affecting clean cooking expansion, ranging from household perceptions on the benefits of clean cooking to the distribution and physical access of clean cooking solutions (including electricity and biogas supply). These included repairs to biogas digesters and upgrades to household electrical wiring to accommodate electric cooking for those who requested it. Project activities also included various behavioral and educational activities, including behavior change awareness campaigns, induction cookstove market promotions, counseling provided to household members by female community health volunteers (FCHVs), and a pilot conditional cash transfer (CCT) program to encourage disuse of traditional stoves and fuels among a subset of intervention households. Induction stoves and other electric cooking appliances were made more available in local markets for purchase.

Data collection activities included the following:

- a baseline survey in all 1,533 households, with an endline survey in 1102 households
- surveys of kitchen electrical wiring systems
- biogas and feedstock assessment surveys
- continuous stove use monitoring in all households, allowing for pre-post comparisons for some intervention activities
- repeated 24-hour measurements of personal $PM_{2.5}$ exposure in 148 households
- Outdoor air pollution monitoring in Panchkhal and Mandandeupur municipality by two continuous $PM_{2.5}$ monitors
- blood pressure screening of cooks measured four times in 772 households, twice in 330 households, and once in 761 households
- fuel and energy source consumption surveys (energy audits) in 105 households, repeated three times over one year
- electricity usage monitoring over three to four months in 39 homes

Over the course of the study, 338 clean cooking solutions were purchased by households in the intervention area: 170 households purchased an induction cookstove, 23 households added liquefied petroleum gas (LPG), 27 constructed new biogas digesters, and 118 households added a rice cooker. A total of 345 biogas digesters were repaired, and the wiring of 78 households was upgraded to accommodate modern electric cooking appliances.

Several key findings emerged from the project. Participants purchased and widely used induction stoves, leading to a significant reduction in the use of LPG and traditional stoves. Community-based outreach programs, including counseling by FCHVs, were effective in increasing uptake of clean cooking solutions, and a conditional cash transfer program resulted in significant disuse of traditional stoves.

Primary cooks living in households using clean cooking solutions (LPG, biogas, induction) exclusively or in combination with solid fuels experienced lower median exposure to $PM_{2.5}$ relative to those using only solid fuels. A near-complete clean fuel transition would be needed, however, before substantial reductions in $PM_{2.5}$ exposure would be expected. This will require clean stove/device options that can be used for animal food preparation and water heating, which are traditionally performed only on open fires.

Community-based outreach programs were effective in increasing uptake of clean cooking solutions.

Primary cooks living in communities affected by intervention activities (N=772) experienced a sizeable 3.34 mmHg (95% CI: –0.81 to –5.19) reduction in systolic blood pressure, after adjusting for changes among cooks measured outside intervention affected communities. A more modest and insignificant increase in diastolic blood pressure was measured among cooks affected by intervention activities (1.10, 95% CI: –0.21 to 2.4, N=772) relative to those living outside intervention affected areas. While the systolic blood pressure results are promising, some caution is warranted in attributing these changes to any specific intervention measure.

To further increase the use of induction stoves, greater billing transparency, reduction in the upfront cost of the stoves and service cost of electricity, and improvements to electricity distribution infrastructure are required. Although transitioning to induction stoves can save money relative to LPG, anecdotal reports suggest that some households limit their induction use for fear of incurring high electricity bills. Efforts that improve household access to information on their electricity consumption and incurred costs will likely help alleviate these concerns. For most households in the study, the addition of an induction stove would increase peak electricity demand by several times. To ensure safe and reliable operation of the induction stoves, most houses required upgrades to electrical wiring. It is also likely that many of the transformers serving the area would need to be upgraded to accommodate the increased load that would result from large-scale induction stove use. Households located farther away from transformers were sometimes observed to have average voltage levels so low that the use of induction stoves would be prohibitive, or at the very least would affect the stove performance and operating cost.

The study found that many biogas systems were widely used but were typically unable to provide enough gas supply to meet daily needs, even after repairs were performed. Biogas was typically used until supply was exhausted and was then supplemented by other fuels (often LPG). More modern digester designs may provide greater gas production, helping to increase utilization of biogas and reduce reliance on other fuels.

Based on the findings, the project provided recommendations for next steps toward long-term transitions to clean cooking in Nepal. These recommendations highlight actions to be undertaken by a wide range of stakeholders to scale up electric cooking, biogas, and, if desired, LPG. Key recommendations include:

- addressing knowledge gaps affecting household perceptions of energy consumption, cost, and choice, particularly with respect to electricity
- scaling up community-based outreach program activities including utilization of Female Community Health Volunteers as part of programs to scale clean cooking across the country
- developing technology options to reduce exposure and emissions from animal food and other energy-intensive tasks that would otherwise be performed almost exclusively on traditional stoves for cost and logistical reasons
- supporting biogas digester re-designs and retrofits that increase gas supply and regular maintenance, with flexible financing for households as needed
- assessing and upgrading electricity grid infrastructure and household wiring
- undertaking market strengthening strategies to ensure consistent supply

Introduction

Over three-quarters of the energy consumed by households in Nepal comes from wood, dung, and agricultural residue.[1] These solid fuels are typically burned inefficiently in traditional open fires or mud stoves, resulting in high-pollutant emissions. These emissions lead to poor air quality inside houses and contribute to ambient air pollution, increasing the population's exposure to health-damaging air pollutants. In addition to the direct health risks, the amount of time required to collect fuels reduces the time available for leisure or economically productive activities. The task of gathering fuel is drudgery that, like pollutant impacts, disproportionately impacts women and young children.

This study was developed to support the broader goal of promoting increased use of clean fuels in homes by testing proposed measures that could increase the use of clean cooking practices in peri-urban communities.

In 2017, the government of Nepal adopted the Biomass Energy Strategy (BEST), which outlines approaches for meeting Nepal's growing residential energy needs through renewable and efficient measures. The strategy sets a target for indoor air pollution-free kitchens by 2022 through the promotion of clean biomass stoves, domestic biogas digesters, and electric cooking appliances. In addition to reducing the impacts of solid fuel dependence, proposed clean energy solutions for cooking aim to reduce Nepal's reliance on imported fossil fuels, such as LPG and kerosene, which can be vulnerable to price and supply disruptions.

This report presents the findings of the health demonstration project, "Maximizing the Health Benefits of Clean Household Energy in Peri-Urban Nepal." This study was developed to support the broader goal of promoting increased use of clean fuels in homes by testing proposed measures that could increase the use of clean cooking practices in peri-urban communities.

The study addressed several core questions:

1. Can clean cooking solutions—LPG, biogas, and induction stoves—meet the needs of peri-urban homes, and would they be adopted?
2. Does the introduction of clean cooking solutions reduce and displace traditional device use, and if so, does this lead to measurable benefits for household air quality, exposure, and blood pressure?
3. Are measures[2] aimed at increasing uptake and use of clean cooking solutions, or discontinuing the use of traditional devices, effective at the household level?
4. Do project interventions lead to measurable changes in clean fuel use and impacts at the community level?
5. What are the potential barriers that may inhibit scale-up of biogas and electric appliances, and how can they be overcome?

In addition to addressing these core research questions, another goal of the study was to develop and implement monitoring and evaluation (M&E) procedures that could be used as part of larger clean cooking scale-up programs. The findings were used to develop a set of recommendations to support the scale-up of clean cooking solutions in Nepal.

Study Overview

The study enrolled a cohort of 1,538 eligible[3] households across 10 wards of Panchkhal (Wards 3, 4, 6, 7, and 8) and Mandandeupur (Wards 4, 7, 8, 9, and 12) municipalities of Nepal.[4] Households in this cohort cooked on one or more of the following technologies: traditional stoves (used to burn crop residue, firewood, charcoal, or sawdust), found in almost all homes; biogas; LPG (both found in most homes); and, less frequently, electric cooking appliances (mainly rice cookers and a few induction stoves). In areas where clean cooking activities (interventions) were implemented, 772 households were recruited. These activities were aimed at increasing clean stove use and reducing traditional stove use. In nearby communities that were not subjected to the intervention activities, 761 households were enrolled in the study, 330 of which were followed over the course of the study.[5] In total, 1,102 households were followed for up to one year and various measurements were gathered to assess the effect of project activities aimed at increasing clean cooking practices or disuse of traditional stoves.[6,7]

This was an observational cohort study. For most treatment measures, the assignment was based on self-selection as opposed to random allocation (experimental); households were given an option to receive repairs/upgrades, as opposed to being randomly assigned to have them. Similarly, the project supported procurement of new clean cooking appliances through measures to increase the supply, but uptake was dependent on the household choosing to buy it.

The study period spanned from May 2018 to October 2019. During this time, project activities aimed to increase access to and use of clean cooking solutions through behavior change and demand creation activities, market strengthening, and household repairs/upgrades. For those who opted into them, this latter category included repairing biogas digesters[8] and upgrading the electrical wiring of homes to accommodate energy-intensive electric appliances such as induction stoves.

Monitoring electricity consumption of induction stoves with a digital aggregate power meter. Consumption data were transferred over cellular networks using a mobile hotspot device.

The project's behavior change and demand creation activities were designed to inform households about clean cooking options through a variety of channels, including online/social media and radio messages, community events, publications (brochures and local stories in the newspaper), and interpersonal communication. These efforts reached an

Bhanchha app

The Android-based "Smart Bhanchha App" was developed as part of the study to enable induction stove users to monitor their energy consumption and cost of cooking in real time. Here a participant monitors real-time electricity consumption and billing data. This app was piloted in several homes and developed in response to participant concerns around incurring high electricity bills as a result of using electric cooking appliances.

Table 1. Project intervention activities

Activity	Scale
Behavioral and educational activities	Estimated reach of 600,000 people
Counseling to household members by female community health volunteers (FCHVs)	772 main cooks (3 times) and additional household members
Pilot conditional cash transfer (CCT) program	97 households over 1 year
FCHVs and mobile marketing agent reduced barriers to induction stove purchase through in-home sales and delivery	8 FCHVs and 3 mobile marketing agents visited 772 homes and facilitated sales and delivery of induction stoves. Upon request: 170 induction stoves
Biogas digesters repair	Upon request: 345 biogas digesters
Household wiring upgrades to accommodate modern electric cooking appliances	Upon request: 78 households

estimated 600,000 people with clean cooking messages. Community events included street dramas, mobile kitchen demonstrations (including induction stove market promotions), community movie screenings, celebrity events, rallies, picnics, tea stalls, and clean cooking-themed competitions for local students.

Over the course of the study period, 170 households purchased an induction cookstove—a 20-fold increase from the baseline prevalence.

The project also worked to improve supply chains to make induction stoves and other electric cooking appliances more available for purchase, with added incentives to retailers, and low interest loans to households to overcome high upfront costs.[9] Project partners connected local clean cooking retailers with wholesalers to negotiate favorable terms to ensure a consistent supply at fair prices. Main suppliers in Kathmandu in turn agreed to provide critical after-sales service for the target communities during and after product warranty periods. The project was also able to secure financing from a local microfinance institution (MFI) for project households, and marketing representatives helped to facilitate savings cooperatives, in addition to demonstrating the products. While study activities helped reduce barriers to clean cooking solutions, families had to purchase their clean cooking solutions themselves.[10]

Project activities also included counseling of primary cooks by female community health volunteers (FCHVs), who visited homes to monitor blood pressure and blood oxygen levels and provide clean cooking messaging to households, and a pilot conditional cash transfer (CCT) program to encourage disuse of traditional stoves.[11]

Over the course of the study period, 170 households purchased an induction cookstove—a 20-fold increase from the baseline prevalence. Over the same period, 23 households added LPG, another 27 constructed new biogas digesters, and 118 households purchased a rice cooker. Overall, 338 clean cooking solutions were added to homes in the intervention area. A total of 345 biogas digesters were repaired, and the wiring of 78 households was upgraded to accommodate modern electric cooking appliances. Some 97 households participated in the CCT pilot.

To measure the impact of the study activities and characterize energy practices in the study community, a large-scale M&E program gathered data using questionnaires and low-cost air pollution and stove usage sensors. A baseline survey was undertaken in all 1533 homes, with an endline survey undertaken in 1091 homes.[12] Repeated 24-hour measurements of personal exposure were performed on the primary cook in a subset 148 homes. Exposure measurements were conducted for 24 hours, three times a year in each home, separated by three to four months.

Energy audits were conducted in 105 households over three seasons to measure the amount of energy that families were consuming, on which stoves, and for which tasks, using a modified Kitchen Performance Test procedure.[13] Electricity consumption monitors were deployed in 39 homes with induction stoves or rice cookers to understand their operational characteristics and track grid service quality over three to four months.

The blood pressure of cooks in all 1,102 homes was measured two to four times.

Temperature sensors were placed on stoves in all 1,102 homes to measure daily use for up to one year. Stove use was measured at 10- to 20-minute intervals every day for over 300 days in the average home. To measure changes in stove use due to uptake of clean cooking stoves or other study activities, the typical analysis was based on more than 250 days of data for each house. Using this historical record of stove use, the research team was able to quantify whether some of the study activities (i.e., introduction of induction stoves) altered the use of the traditional stove vs. the use of clean stoves.

Table 2. Data collection activities

Activity	Households	Frequency
Baseline survey	1,533 households	One time
Endline survey	1,102 households	One time
Surveys of kitchen electrical wiring systems	772 households	One time
Biogas and feedstock assessment surveys	374 households	One time
Stove use monitoring	1,102 households	Continuous monitoring for up to one year
Personal $PM_{2.5}$ exposure	108 households	24-hour measurements performed 2–3 times every 3–4 months
Ambient-level air pollution monitoring	2 outdoor $PM_{2.5}$ sensors in Panchkhal and Mandandeupur municipality	Continuous over (January 2018 to September 2019)
Blood pressure screening of cooks	772 households	Four times in 772 households; a separate 761 households received baseline measurements with a second measurement in 330 of those
Fuel and energy source consumption surveys (energy audits)	80 households	2–3 times
Electricity usage monitoring over three to four months in 39 homes	39 households	Continuous over 3–4 months

Data analysis overview

Several analytical approaches and data from monitoring instruments were applied to answer the study questions.

- Stove use monitors were used to examine the effect of biogas repairs and procurement of induction stoves on the hours of use and number of events performed on biogas stoves, traditional devices, and LPG.
    - To examine the effect of biogas repairs using a before-after approach, stove use data were used from 81 households (of the 345 that received repairs) for which data were available on biogas and at least one traditional stove for one day or more before and after the date of biogas repair. The effect of biogas repairs on the daily use (hours and events) of biogas, traditional, and LPG stoves was estimated using generalized estimating equations adjusted for season and household size , and accounting for repeated measures on homes. A similar analytical approach was used to estimate the before-after effect of induction stoves, with the exception that eligible households needed to have stove use data for all devices in their home (full coverage) for at least one day before and after procurement of induction (N=31 of 170 induction purchasers).
    - An observational analysis was also applied to measure differences in the use of traditional stoves based on ownership status of biogas, LPG, and induction. For this analysis, stove use data from a subset of 411 households (of 1,538) with at least one day of traditional stove use data were used. The effect of clean stove ownership (LPG, induction, biogas) on traditional stove usage metrics was estimated using generalized estimating equations, adjusting for household size and season, and accounting for repeated measures on homes.
- Differences in 24-hour personal $PM_{2.5}$ exposure concentrations were examined based on the stoves used during the exposure monitoring period. Differences across groups classified by stove types used were assessed using statistical difference in means tests and rank sum tests.
- Energy consumption for various stove tasks was estimated using a linear regression of directly measured 24-hour fuel consumption data on dummy variables for stove tasks reported during the monitoring period, accounting for repeated measures on homes.
- The association between exposure to study intervention activities and changes in diastolic and systolic blood pressure was estimated using generalized estimating equations, accounting for repeated measures. Blood pressure measurements from 772 cooks taken once before and three times after the implementation of community- and household-scale interventions were used for this analysis. To account for changes over time, repeated measurements (n=3) of 330 cooks living in nearby communities assumed unaffected by study activities were also included. Blood pressure measurements were taken every two to three months from the time of enrollment.
- An interrupted time series design was used to test the effect of the conditional cash transfer (CCT) program on the use of traditional stoves, LPG, and biogas. The effect of the CCT was determined using segmented regression analysis of continuous stove use monitoring data aggregated over six months at the community scale before and after the CCT program was implemented.[14]

For outcomes dependent on stove use, the magnitude of data available for each home enabled far more flexibility to assess not only the differences across groups but an actual change in the same homes. Linear regression models were applied to account for seasonality by leveraging variability in the time when treatments were administered and households that did not receive a treatment but were subject to seasonal (and other confounding) factors.

Summary of Key Findings

Induction stoves can reduce the use of both LPG and traditional stoves, and LPG can reduce the use of traditional stoves

The introduction of induction stoves was associated with significant reductions in the use of both traditional and LPG stoves. Reductions in traditional stove use are critical for realizing the benefits of clean cooking solutions, and reductions in LPG use are critical to achieving economic savings. Using an average of 305 days of data on stove use and the records of when induction stoves were procured, results suggest that the purchase of an induction stove was associated with significant reductions of 35 minutes (95% CI: 11, 60) of traditional stove use each day, and 0.63 (95% CI: 0.2, 1.0) traditional stove use events per day, after adjusting for season and household size. Moreover, among households that had used LPG and purchased an induction stove (n=104), the procurement of an induction stove was associated with a borderline significant reduction in LPG use of 11 minutes per day (95% CI: –1, 23), or roughly a 20% reduction in use.

As the typical family in the community operates their cooking devices for a total of one to three hours per day, these reductions represent a large impact on cooking practices. These results support the theory that introducing induction stoves can displace both traditional and LPG stove use. In turn, this may translate into economic and health benefits, if sustained.

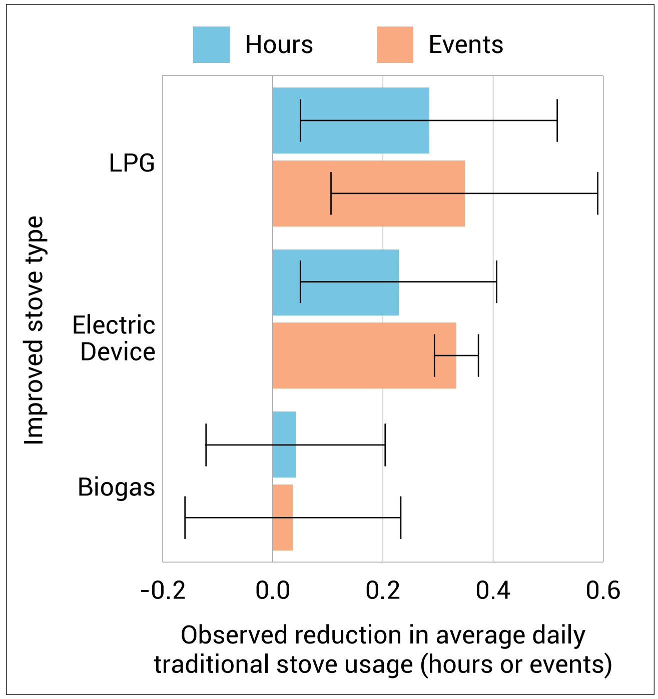

Figure 1. Differences in traditional stove use when various clean stoves are present (owned), measured in terms of hours or number of cooking events per day. Note: Error bars correspond to the 95% uncertainty interval of the mean.

A comparison of stove use across households grouped by the types of stoves owned suggests a decrease in traditional stove use when LPG or induction stoves are owned. This supports the previous analysis that leveraged induction stoves delivery dates, suggesting that this effect is occurring in the broader population, not just households that purchased induction stoves during the study. Owning an induction stove was associated with a 14-minute (95% CI: 3, 24) reduction in daily traditional stove use, and a reduction of 0.3 (95% CI: 0.1, 0.5) traditional stove use events, after adjusting for season and household size (figure 1). Owning an LPG stove was associated with a 17-minute (95% CI: 3, 31) reduction in traditional stove use per day and a reduction of 0.4 (95% CI: 0.1, 0.6) traditional stove use events. There was no measurable effect of owning a biogas stove on traditional stove use, which may point to distinct niches that each stove fills or to the potential effect of gas supply constraints on biogas stove use.

Repairs to biogas systems are doing little to improve gas supply

Stove usage data for households that received repairs on their biogas digesters showed no measurable change in the number of cooking events or hours of use of biogas or traditional stoves. These results suggest that current repair strategies are doing little to improve biogas yield, on average. Moreover, unlike LPG and induction stoves, ownership of a biogas system was not associated with a difference in traditional stove use after adjusting for season and household size. Stove use measurements, however, showed that households widely accept biogas stoves, using them almost daily. Interviews with households indicated that many households used their biogas until gas supplies were exhausted.[15]

These results suggest that repair strategies do not alleviate gas supply constraints in homes. Resources to help users maintain the health of their digester systems are needed, but alternative digester designs or modifications may also be required to displace traditional stove and LPG use. Inadequate gas supply arises in part from digester design; most digesters in the community are more than 10 years old and are inefficient and outdated relative to current design standards. The current small fixed dome design has seen little modification in 30 years of deployment, and the system only works well at altitudes up to 1500m.[16]

All household biogas systems will require some level of user maintenance to operate optimally. Most system owners were aware of the importance of digester health and the role of feedstock. However, they had no way of knowing the carbon-nitrogen ratio, which is an indicator of the health of the digester system. Some 95% of samples were far below the optimal range.[17] The high value of nitrogen in the feedstock enhances the production of ammonia gas, which can increase the pH, threatening micro-organisms and inhibiting the anaerobic digestion process. Deteriorated pipes, valves, digester walls, and water traps, which could potentially lead to gas leakage, were also observed. These observations highlighted the need for improved after-sales services and quality assurance standards for both repairs and construction, and the need to establish biogas repair shops with parts supply outlets for the sustained use of biogas.

Biogas and induction stoves are suitable replacements for LPG, but only if some tasks are performed on traditional stoves

Similar tasks were performed on LPG, biogas, and induction stoves, suggesting that they may be suitable replacements for one another. Stove use monitoring of biogas, induction, and LPG stoves showed daily use of these devices in most households where they were present. Over the full duration of the study, biogas or LPG stoves accounted for 73% of total minutes of stove operation and 83% of individual cooking events. When more than one clean cooking solution was available to a household, a greater percentage of daily cooking was performed on clean devices, but total cooking times (all stoves) were 30% higher on average. These results suggest that bundling clean solutions may result in increased benefits over promoting a single clean device. Additional efforts to understand major energy-consuming tasks that may not transition to clean solutions remains critical.

For several important stove tasks, LPG, biogas, and electric appliances will not be suitable replacements for a traditional stove. Animal food and water heating tasks are predominantly performed on open fires using large pots and are energy intensive, requiring two to three times more energy than an average meal. In other words, one animal food or water heating event can require as much energy as all the meals of the day combined. Fuel audits showed that these tasks are performed almost exclusivity on open fires.

Each animal food or water heating event, which are performed almost exclusively on open fires, can require as much energy as all the meals of the day combined.

Although these tasks are often performed outside of the kitchen (but not always), addressing emissions will likely be critical for addressing ambient air quality in these communities. Satisfying these service needs for the foreseeable future will likely require the use of solid fuels or other freely available (or inexpensive) energy sources. Efficient biomass stoves with chimneys that reduce emissions and shift smoke away from homes may be one solution to partially reduce exposures, but this solution will do little to address community air pollution. Addressing these needs should be considered an area of importance in scale-up strategies of clean cooking solutions in Nepal.

A near-complete clean fuel transition may be needed to realize meaningful reductions in $PM_{2.5}$ exposure

Households reporting use of only clean fuels (LPG, biogas, electricity) during the 24-hour monitoring period had an average personal exposure level (100µg/m³) of approximately half that of cooks within homes using clean solutions in combination with traditional stoves (230–270 µg/m³), or only traditional stoves (230 µg/m³).[18] The magnitude of these differences points to potential health benefits of clean fuel transitions, if sustained. A comparison of the theoretical exposure reductions to integrated exposure-response functions suggests that the magnitude of exposure change would be associated with substantial risk reduction for several health outcomes, including acute lower respiratory infections and chronic obstructive pulmonary disease.

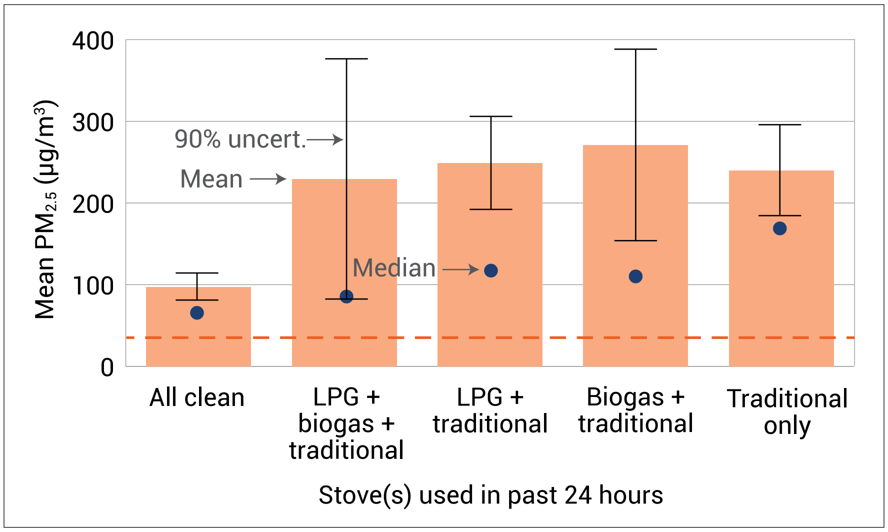

Figure 2. Average 24-hour $PM_{2.5}$ exposures grouped by stoves reported as used during the measurement period. Note: 300 samples from 108 intervention households. Bar heights correspond to the average exposure, dots the median, and error bars the 90% uncertainty interval of the mean. The dashed line is for reference and corresponds to the World Health Organization (WHO) interim indoor air quality guidelines: household energy combustion 24-hour $PM_{2.5}$ concentration of 35 µg/m³.

Mean personal exposure levels for cooks using clean cooking solutions in combination with traditional stoves did not show any difference from those using only traditional stoves. Disaggregating further, evidence suggested that homes using induction and LPG stoves with traditional devices may benefit from reduced exposure in comparison to homes that depend only on traditional devices. However, a larger sample of measurements would be needed to measure a statistically significant benefit related to changes in exposure among households that purchased an induction stove, LPG, or biogas stove.

Consistent with data from stove use measurements, there was no evidence that biogas usage leads to a reduction in exposure when used in combination with traditional devices. This result likely relates more to the strength of traditional devices in driving exposure than to biogas not being clean. It underscores the importance of traditional stove displacement and the potential need to combine multiple clean cooking solutions to maximize the displacement of the traditional stove.

Ambient air pollution ($PM_{2.5}$) is still an important contributor to exposure. Despite significantly reduced exposure concentrations when only clean fuels were used in homes, no stove group was able to achieve the WHO 24-hour $PM_{2.5}$ guideline concentration at all times of the year, partly due to ambient air pollution exposure. The annual average $PM_{2.5}$ concentrations at the Panchkhal and Mandandeupur measurement sites were 40 µg/m³ and 26 µg/m³, respectively. These levels were within the national ambient air quality standard for $PM_{2.5}$ of Nepal (40 µg/m³) but exceed ambient WHO guidelines (25 µg/m³). Over 20 months of monitoring, no statistical change in $PM_{2.5}$ concentrations were measured, after adjusting for season and serial correlation of measurements.[19] Ambient air pollution profiles showed strong diurnal and seasonal variation, with the highest concentrations occurring at midday and during the winter season (from November to January). These results are consistent with the strong influence of non-kitchen cooking practices affecting ambient air pollution. However, some of this air pollution may be transported pollution from the Kathmandu Valley.

Cooks exposed to intervention activities experienced reductions in systolic blood pressure

High or elevated blood pressure is the most significant risk factor contributing to the rise in Nepal's cardiovascular disease and deaths.[20,21] Household air pollution from the burning of solid fuels is a known risk factor for elevated blood pressures in women.[22,23]

Clinical and epidemiological evidence suggests that even a modest (1 mmHg) reduction in systolic blood pressure can help prevent cardiovascular mortality.[24] Primary cooks living in communities affected by intervention activities (N=772) experienced a sizeable 3.34 mmHg (95% CI: –0.81, –5.19) reduction in systolic blood pressure, after adjusting for changes among cooks measured outside intervention affected communities. A more modest and insignificant increase in diastolic blood pressure was measured among cooks affected by intervention activities (1.10, 95% CI: –0.21, 2.4, N=772) relative to those living outside intervention affected areas. While the systolic blood pressure results are promising, some caution is warranted in attributing these changes to any specific intervention measure.

Among cooks living in areas affected by intervention activities, the prevalence of normal systolic blood pressure (<120 mmHg) increased from 62 to 67% between the beginning and end of the study, while the prevalence of normal diastolic blood pressure (<80 mmHg) increased from 54 to 56%. In areas not exposed to intervention activities, prevalence of normal systolic blood pressure remained the same between baseline measurements and the end of the study (72%), while the prevalence of normal diastolic blood pressure (<80 mmHg) increased from 55 to 68% over the same period.

Adopting induction stoves and other efficient electric appliances can save consumers money, but energy supply constraints and knowledge gaps need to be addressed

Results from field observations and energy use monitoring data suggest that customers may not be utilizing electric appliances as often as they could be for fear of incurring high bills. An analysis of data from energy power monitors placed on six induction stoves for a period of five months (April to August 2019) shows that usage (and energy consumption) decreases in the middle of the month, which coincides with monthly visits by the Electricity Authority to read the meter. Although the sample size is small, these results support field observations that fear of incurring high electricity bills led households to limit the use of their induction stoves. For many families already relying on LPG, transitioning to induction cooking can save money given the large efficiency gains, although the economics depend on numerous factors. Helping households bridge this knowledge gap so they can make more informed decisions about their energy choices may help alleviate concerns about increased electricity use and in turn accelerate displacement of LPG and biomass, which would otherwise serve similar roles.

It is not unreasonable for households to be concerned about their electricity consumption. Unlike other purchased fuels, electricity is not purchased in physically tangible units (e.g., cylinders of LPG, kilograms, or bundles of wood), which makes it difficult to know how much is consumed and will eventually be billed. For most families in the community, the induction stove will be the largest electrical load by a large margin and will lead to a noticeable increase in their electricity expenditure. Measurements of induction stoves operated in homes indicated an average power draw of 811 watts during operation. As a point of reference, the typical LED bulb draws less than 10–15 watts. For a typical household in the community with few electric appliances,[25] using an induction stove for 30–60 minutes per day could easily double their electricity bill. To complicate this, electricity pricing in Nepal increases in tiers, so customers pay more per unit of electricity as consumption increases.[26] Although expenditures on other fuels like LPG may fall as a result of induction stove adoption, potentially even saving money overall, navigating these financial calculations is neither intuitive nor straightforward. The importance of empowering customers by making billing structures more transparent and providing real-time feedback on their energy consumption (and bill) must be emphasized as part of efforts to scale electric appliances.

For induction stoves to displace LPG, biomass, and other fuels to their fullest potential, changes in electricity pricing structures may also be needed to increase affordability. This may include increasing the basic lifeline cap—the lowest electricity pricing tier corresponding to the lowest fees—or using other pricing tariff structures that lessen the financial burden to homes.

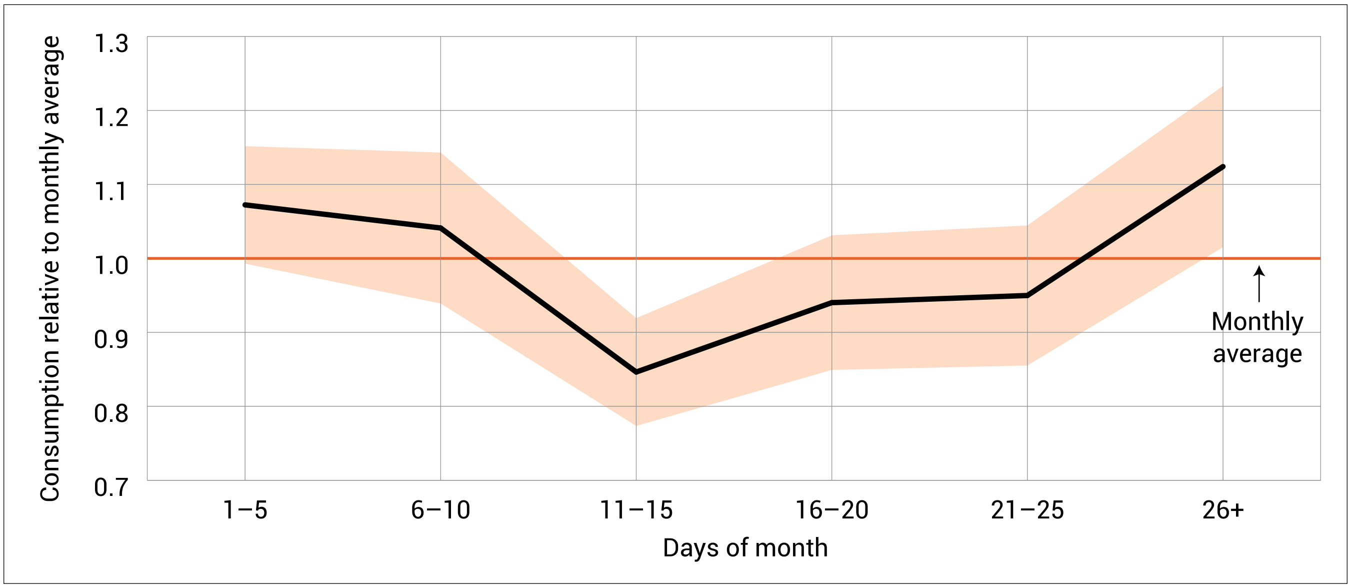

Figure 3: Induction stove use and electricity consumption by period of the month. Electricity consumption of stoves falls around mid-month, coinciding with visits by the Nepal Electricity Authority to read meters and collect payment. Error bands correspond to the 95% uncertainty interval of the mean. Results are based on daily measurements performed in a subset of six homes measured daily for five months.

Given the high efficiency of induction relative to other device types,[27] it takes about two hours to cook morning and evening meals on an induction cookstove. For four-person family homes, for example, this equates to a monthly consumption of electricity for cooking of approximately 49 kWh (units); this would be higher for large families. Currently, customers who use less than 20 units of electricity per month (set as the basic lifeline cap) receive the best price due to tiered pricing[28]. Increasing the basic lifeline cap from 20 units to 100 units could provide peace of mind to induction or rice cooker users and ultimately increase electricity consumption. Additionally, the introduction of a dynamic pricing tariff could encourage homes to use electricity during off-peak hours.

Existing infrastructure in the majority of homes was incapable of meeting modern electrical cooking appliance requirements. The large increase in electrical load resulting from operation of electric cooking appliances also puts strain on the infrastructure used to deliver electricity to households. Upgrades to household wiring to safely operate electric cooking appliances may be needed at the household. A survey of electrical wiring in 772 households enrolled in the study indicated that 90% of households would require wiring upgrades and 85% would require higher amperage breakers.[29] As part of this study, electrical upgrades were performed in 78 houses at the request of the homeowner; all of these households purchased an induction cookstove during the study.[30]

Service providers will play a critical role in enabling regular use of clean cooking appliances. Widescale uptake of induction stoves will place unprecedented demands on distribution, transmission, and generation infrastructure. As an extreme case, if induction stoves are deployed across Nepal (~5.7 million homes) the total electricity demand during peak cooking hours could be as high as 4.6 Gigawatts, which is roughly four times more than the current installed capacity of 1 Gigawatt.[31,32]

Strategies for improving the voltage quality of the grid may also be required, especially for households living far from distribution transformers. Induction stoves and other electrical appliances can be damaged or break when voltage fluctuates. Households farther from the transformers can suffer from having lower voltage levels, in addition to more variable voltage. Such effects were measured in a small sample of households. The voltage of one study home located 1200m away from a transformer was, on average, 15% lower than a home located 100m from the same transformer. These voltage drops were of a magnitude that would likely affect the performance of an induction cookstove without voltage stabilizers. Household monitoring of electricity consumption patterns and appliances, along with grid performance characteristics, will help to provide critical insights for informing electric cooking appliance scale up.

Behavior change communication activities, together with efforts that strengthen the market and supply chain for clean cooking appliances, can support their uptake

The project's behavior change activities promoted clean cooking solutions through a variety of channels, including online/social media and radio messages, community events, publications (brochures and local stories in the newspaper), and interpersonal communication, reaching over 600,000 people with clean cooking messages. Initial research indicated that community-level events would serve as one of the most effective channels to help communicate clean cooking benefits to the target communities and persuade households to purchase these more expensive products. As such, the project held numerous community events that were well-received, including street dramas, mobile kitchen demonstrations, community movie screenings, celebrity events, rallies, picnics, and tea stalls. One of the more popular events involved well-known actress Karishma Manandhar, who shared clean cooking messages while using an induction cookstove to prepare a local snack.

Cookstove and fuel suppliers participated in the events to explain technical attributes of the products and the best ways for households to finance and purchase the product that suits their needs and preferences. The project also engaged local students through clean cooking-themed competitions, including drawing for primary students, essay writing for middle school students, and extemporaneous speech for high school students.

The project also worked with three locally hired female marketing representatives to engage directly with the community through household visits and at events. These marketing representatives also helped to facilitate savings cooperatives, in addition to demonstrating the products. Of the 504 households visited by the marketing representatives, 95 purchased induction stoves, 51 using consumer finance.

In addition to demand-creation activities, the project worked to ensure supply through market- strengthening strategies. This was key because most local suppliers did not stock large quantities of clean cooking projects, and study participants were responsible for procuring and paying for their own products.

The project increased incentives for local retailers to stock clean cooking solutions by helping them develop promotional materials, coupons, product packages, and improved business skills. By connecting local clean cooking retailers with wholesalers, the project was able to negotiate favorable terms to ensure a consistent supply at fair prices. Main suppliers in Kathmandu in turn agreed to provide critical after-sales service for the target communities during and after product warranty periods. The project was also able to secure financing from a local MFI for project households.

The project trained three retail store owners and six marketing/sales agents on strategies for selling electric appliances. By the end of the study, these businesses had sold 30 induction stoves to households in the community. Local retailers originally pre-ordered induction stoves in small quantities; however, by the end of the project, they were confident enough in their demand to order larger volumes. The project attributes the dramatic increase in the purchase of clean cooking solutions to the combination of these demand-creation and market-strengthening activities.

Female community health volunteers can support uptake of clean cooking solutions

Female community health volunteers (FCHVs) played a critical role in facilitating the uptake of clean cookstoves in the study community. They visited homes to monitor blood pressure and blood oxygen levels and provided clean cooking messaging to households. They encouraged the use of clean cooking solutions by discussing their benefits, and they discouraged the use of traditional stoves and fuels. They also supported the sale of clean cooking fuels and technologies by working with sales agents to enhance their marketing strategies.

> **Female community health volunteers played a critical role in facilitating the uptake and adoption of clean cooking solutions in this study.**

As trusted members of the community, FCHVs in Nepal currently play a significant role in advocating for healthy behaviors of mothers and promoting safe motherhood, child health, family planning, and other community-based

health promotions and service delivery.[33] They have also been shown to be trusted educators of key health messages about air pollution and the benefits of clean cooking. Our study suggests that FCHVs can be trained to screen blood pressure, identify the cooks or other household members who are at high risk of developing cardiovascular diseases (CVD), and provide appropriate risk factor counseling.

Female community health volunteers played a critical role in facilitating the uptake and adoption of clean cooking solutions in this study, and could likely play a similar role at a national scale. With the right mobilization and support, these services would complement their role in the prevention of CVD risk in communities. Their expanded role in facilitating access to clean cooking energy technologies and the primary prevention of non-communicable disorders such as CVD should be explored.

A conditional cash transfer may help to reduce the use of traditional stoves.

A pilot study explored the use of a conditional cash transfer (CCT) program to encourage households to stop using their traditional stoves. A total of 97 households were enrolled across the two communities,[34] with sensors measuring traditional stove use to determine whether households met the conditions for receiving a cash transfer, and at what level (NRS100–250 (US$0.89–$2.23) for each month of reduction in traditional stove use compared to pre-trial levels, for reductions of 40–60%, 60–80%, or 80%+). One month after the intervention, the average monthly use of traditional stoves fell by 70% and 40%, respectively, in the two study communities relative to expected use based on the previous six months of data ($p < 0.05$). These reductions corresponded to a total displacement of 900 hours of traditional stove use. They also corresponded to a statistically significant increase in LPG consumption.

The analysis showed that financial incentives can increase the disuse of a traditional stove or increase the use of LPG and potentially electric cooking appliances. However, they may not work for biogas, as the gas yield highly depends on the temperature, and households do not have control over the production of biogas during the winter.[35]

Recommendations for Next Steps

Develop and test measures that address the critical knowledge gaps affecting household decisions around energy use and choice. Knowledge gaps appear to be a major barrier affecting the decision to increase utilization of induction stoves and maximize the supply of biogas. Mobile applications and other real-time knowledge resources to help households understand their electricity consumption and bills may help alleviate concerns over billing. The Android-based application "Smart Bhanchha," developed under this project, explored one potential solution. This and other solutions merit exploration. In-home monitoring tools that inform owners of the health of their biogas digesters may serve to increase gas supply, as well as improve the reliability of systems.

Combine efforts that address knowledge gaps with steps to reduce economic barriers affecting household adoption of electric cooking appliances and biogas. These might include programs that exchange LPG canisters or stoves for induction stoves and altering tariff rates tied to induction stoves or other clean cooking measures. For biogas, the government of Nepal provides a subsidy to offset the cost of installing a biogas digester. However, the remaining upfront costs are still significant for low-income families. Developing flexible financing mechanisms may help to address initial cost constraints that affect both biogas and electric appliances.

Mobilize FCHVs and other health workers in community-based outreach programs to deliver counseling and general support as part of clean energy programs. In this study, FCHVs played a critical role in educating community members on various parts of the program. They also played a role in delivering clean cooking devices to households.

Develop stoves that can be used to prepare animal food and perform other energy-intensive tasks that traditional stoves currently handle. Solutions for meeting non-cooking service needs will be important for addressing outdoor air pollution in peri-urban communities. At present, neither LPG, biogas, nor the induction stoves are likely to satisfy these needs. New solutions that utilize either solid fuel or clean energy sources are needed.

Pilot new biogas digester designs and retrofitting strategies to improve supply, and develop a quality assurance framework that supports reliable digester designs and after-sales support. Biogas presents a unique opportunity to displace the use of LPG and traditional stoves. However, results from this study suggest that current repair strategies are doing little to alleviate supply constraints. Pilot testing of alternative digester designs and more substantial retrofitting steps to existing systems are merited. The development of a quality assurance program that supports good system designs and after-sales support has been effective for other energy programs and is likely to be beneficial for biogas as well.

Take measurements and conduct modeling to understand how future uptake of electric cooking appliances could impact load profiles and grid performance. The sustained use of electric appliances is predicated on the availability of reliable and high-quality energy services. Monitoring networks that assess grid performance and electricity consumption in households may be useful for predicting how the scale-up of induction stoves might alter community demand and prioritize infrastructure improvements. These assessments may also help in the design of implementation strategies by identifying the most viable locations for transitions.

Stakeholder Recommendations

Induction and Electrical Appliance Scale-up

Stakeholder level	Actions
Households/End-Users	Perform upgrades to household wiring so that larger load appliances can be operated safely.
Program Implementers	• Engage local health workers (e.g., FCHVs) to promote induction and other electric cooking appliances. • Develop strategies to address knowledge gaps affecting uptake and sustained use of induction stoves and other electric cooking appliances. • Identify viable areas for program implementation given household and grid infrastructure constraints.
Manufacturers and Energy Service Providers	• Establish after-sales services to provide repairs and fulfill warranties of appliances to prevent market spoilage. • Develop flexible financing mechanisms that help reduce upfront costs. • Continue to make improvements to grid performance, including measures that stabilize voltage and minimize load shedding (National Electricity Authority).
Policymakers	• Establish quality and performance benchmarks for induction stoves and other electric appliances imported into Nepal. • Support programs that help households upgrade their electrical wiring to support new electric appliances. • Develop policies that reduce the upfront and operating costs of electric appliances.
Development Agencies and Research Agencies	Support research aimed at filling critical knowledge gaps and sizing the potential welfare benefits of technology transitions.

Biogas Stove Scale-up

Stakeholder level	Actions
Households/End-Users	• Perform regular maintenance on the biogas digesters.
Program Implementers	• Implement quality assurance programs to support repair and installation of systems. • Explore use of more modern digester designs as a means to increase supply to households.
Manufacturers and Energy Service Providers	• Establish after-sales service (i.e., technicians) outlets to provide repairs and fulfill warranties to prevent market spoilage. • Develop tools for monitoring digester health.
Policymakers	• Provide incentives for installing and maintaining biogas systems. • Adopt quality assurance standards to ensure that components and procedures are consistent across certified service providers.
Development Agencies and Research Agencies	• Support the development and testing of measures aimed at addressing knowledge gaps around the proper use and maintenance of biogas systems. • Support the development of tools and instruments for supporting proper digester maintenance and operation (i.e., sensors for monitoring carbon-nitrogen ratios, notification systems).

LPG Scale-up (if desired)

Stakeholder level	Actions
Households/End-Users	• None
Program Implementers	• Develop educational materials highlighting the safety, economic benefits, and tradeoffs between LPG and other clean cooking solutions. • Test and implement flexible financing mechanisms that align purchase quantities with cash flows.
Manufacturers and Service Providers	• Introduce smaller LPG cylinders that better align with consumption rates and user cash flow (e.g., 6 kg, 50 kg). • Provide flexible financing mechanisms to better align service costs with user cash flow; pilot pay-as-you-go models that are currently being used elsewhere, or other flexible financing mechanisms.
Policymakers	• Strengthen local safety regulation for LPG use.
Development Agencies and Research Agencies	• Support R&D around flexible financing mechanisms.

Notes

1. Government of Nepal, Ministry of Population and Environment, *Biomass Energy Strategy 2017.* 2017
2. Behavior change awareness campaigns and educational activities; induction cookstove market promotions and improvement to supply chains; counseling by Female Community Health Volunteers (FCHVs); repairs to biogas digesters; household electrical upgrades; and a conditional cash transfer.
3. Households were eligible to participate if (a) they had their cookstove indoors or cooked indoors during at least some parts of the year; (b) the main cook was 18 years of age or older, and (c) they were willing to allow field workers to measure cookstove emissions, monitor stove use and household air pollution in the kitchen, and measure blood pressure of the main cook.
4. The intervention areas included wards 3, 4, and 6 of Panchkhal, and 7 and 9 of Mandandeupur municipalities. In the second wave of recruitment in areas outside of intervention activities, this included wards 3, 7, 8, some parts of ward 6 of Panchkhal municipality, wards 4, 7, 8, 12, and some parts of ward 9 of Mandandeupur municipality.
5. This second wave of recruited households was meant to serve as a comparison group for households living in areas subject to intervention activities. Based on the baseline household surveys conducted in all 761 households enrolled in the second wave, 330 households were followed based on a propensity score matching exercise.
6. Health benefits from the adoption of clean fuels/devices are predicated on the displacement of the polluting practices that lead to high exposures.
7. Human subjects approvals were obtained from the institutional review boards at Nepal Health Research Council and Humboldt State University.
8. This includes the structural components (inlet tank, outlet chamber, and digester), the piping system (gas pipeline and valve), biogas utilization system (biogas stove and biogas lamp), and effluent disposal system (digestate storage and reuse).
9. Cookstove suppliers provided incentives to the sales agents of ~US$1.50 for each induction stove sold. Women's clean energy savings and credit groups formed and provided low-interest loans to households for induction stoves, utensils, or gas appliances (LPG). The project also provided after-sales service for induction stove, repairing 32 during the project period.
10. While stoves themselves were not subsidized, a subset of study participants received financial compensation of 1000 NRs for their participation in a cooking competition and/or an electricity consumption and quality study. For transactional ease, this was disbursed as a discount on the stove purchase.
11. The pilot conditional cash transfer (CCT) program paid stove users NRS100–250 (US$0.89–$2.23) for each month of reduction in traditional stove use compared to pre-trial levels, for reductions of 40–60%, 60–80%, or 80%+. Enrollment criteria were based on geography, usage patters of traditional stoves, and SES thresholds.
12. A total of 772 households were enrolled at the beginning of the study. Approximately one year later, an additional 761 households were enrolled from the same municipalities but outside of the areas subject to intervention activities. Only 330 households surveyed from the 761 households recruited in the second wave were followed until endline.
13. Described in: N. L. Lam et al., "Seasonal Fuel Consumption, Stoves, and End-Uses in Rural Households of the Far-Western Development Region of Nepal," *Environmental Research Letters.* 12, no. 12 (2017): 125011.
14. Methods described in Robert B. Penfold and Fang Zhang, "Use of Interrupted Time Series Analysis in Evaluating Health Care Quality Improvements," *Academic Pediatrics* 13, no 6 (2013): S38–S44.
15. As part of the study, 27 new biogas stoves were installed. However, the number of measurements on these devices was too small to determine whether there were significantly higher levels of gas production relative to older stoves.
16. S. Bajgain and I. Shakya, *The Nepal Biogas Support Program: A Successful Model of Public Private Partnership for Rural Household Energy Supply*, ed. M.S. Mendis (The Netherlands: Ministry of Foreign Affairs, SNV-Netherlands Development Organization, 2005).
17. The optimal range is 20:1 to 30:1; the ratios ranged from 0.34:1 to 26:1.
18. Stove usage for this analysis was based on self-report collected as part of surveys at the end of the 24-hour monitoring period. This analysis allowed a great number of households to be included in analysis as compared to relying on stove use monitors in the subset of households that received exposure monitoring.
19. Panckhal: –17µg/m^3 (95% CI: –39µg/m^3; 17µg/m^3); Mandandeupur –12µg/m^3 (95%CI: –46µg/m^3; 10µg/m^3)
20. S. Sanjib Kumar, et al., "Prevalence of Hypertension, Obesity, Diabetes, and Metabolic Syndrome in Nepal," *International Journal of Hypertension* 2011: 267–75.
21. Institute for Health Metrics and Evaluation (IHME), *What causes the most death and disability combined?* (12/28/2019). http://www.healthdata.org/nepal.
22. B. N. Young, et al., "Exposure to Household Air Pollution from Biomass Cookstoves and Blood Pressure among Women in Rural Honduras: A Cross-Sectional Study." *Europe PMC* 29, no. 1 (2019): 130–142.
23. J. Baumgartner, et al., "Household Air Pollution and Measures of Blood Pressure, Arterial Stiffness and Central Haemodynamics," *Heart* 104, no. 18 (2018): 1515–21.
24. S. T. Hardy, et al., "Reducing the Blood Pressure-Related Burden of Cardiovascular Disease: Impact of Achievable Improvements in Blood Pressure Prevention and Control," *Journal of the American Heart Association 4 (2015): e002276.*
25. Assumes 12–24 kWh of electricity per month; this is similar to what was observed from measurements performed on a subset

of households with induction stoves. Based on data from power meters, about 60% of the monthly electricity consumption in these households was attributed to the induction stove.

26. Pricing tiers are based on the amperage rating of service panel and consist of a marginal energy cost (NRS/kWh) and fixed service cost, both of which vary depending on the consumption tier. Currently, the lowest tier (basic lifeline) cutoff is at 20 kWh per month.
27. M. Sweeney, et al., "Induction Cooking Technology Design and Assessment," in *ACEEE Summer Study on Energy Efficiency in Buildings* (Washington, DC: Energy Power Research Institute, 2014).
28. The basic lifeline cap for the first 20 units for residential customers as set by the electricity authority is Rs. 4.5/unit (5-ampere system) and Rs.6.5/unit (15-ampere system), respectively.
29. From low current-carrying capacity electrical wiring to standard/preferred 22 AWG (American wire gauge) (3/22-gauge) cable.
30. The cost of upgrading amperage and electrical wiring in kitchens is around US$15–$20. For around US$25, the amperage in the house could be upgraded and a voltage stabilizer added in the kitchen.
31. Nepal's population based on 2011 census is 26 million. And the average household family size is 4.6 people; estimated homes total ~5.7 million.
32. R. S. Shrestha, et al., "A Power Paradox: Growth of the Hydro Sector in Nepal," Hydro Nepal, *Journal of Water, Energy & Environment* 23 (2018): 5–21.
33. Annual Report, 2074/75, Ministry of Health and Population, Nepal.
34. Kafledi area of Panchkhal municipality and Naubise area of Mandandeupur municipality.
35. The induction stove was not included in the CCT because of ongoing power interruption/load-shedding in the community.

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