E-cooker network for Urban Slums:

Benefits and Barriers to Implementation

University of Southampton, United Kingdom

Corresponding Author: Dr. Tasmiat Rahman

Author List: Sunny Chaudhary, Arifur Talukder, Mahzabin Kabir , Mathew Loxham, Thomas Wilkinson, Kirk Martinez, Hamidul Haq, Intekhab Alam, Rezaul Islam, Rezwan Khan, Craig Hutton, Tasmiat Rahman

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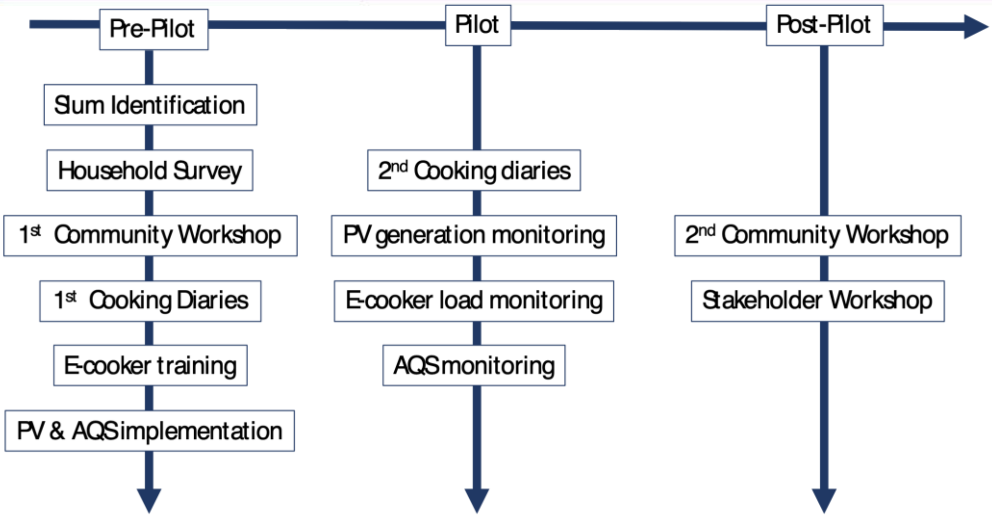
Executive Summary

Context:
Despite the fact that only around 40% of the world is directly exposed, household air pollution from biomass combustion (HAP) ranks fourth among all risk factors. Those in poor nations who cook with biomass or coal are the most affected. According to the most recent Comparative Risk Assessment of the Global Burden of Disease (GBD), HAP from solid cooking fuels imposes the world's greatest environmental health burden of any risk factor studied. Significant air pollutants in South East Asia are attributed to standard cooking fuels (biomass, kerosene, paraffin), particularly in developing countries which are more reliant on them. In Bangladesh, due to the ever-rising population density, people are forced to live in slums, exposing them to high levels of indoor cooking and ambient air pollution, as well as a high burden of disease from acute lower respiratory infection (ALRI) and burn risk, particularly among children.
Focused studies have shown that switching from biomass fuels to cleaner fuels could increase the number of World Health Organization Air Quality Target Days by 73%. As such, to speed up the development of certain areas, organizations such as the Clean Cooking Alliance, are attempting to implement electric cooking methods in place of current, more polluting cooking fuels. To develop the Bangladesh clean cookstoves market, The National Action Plan for Clean Cooking (2020 – 2030) was launched by the Power Division in Bangladesh in 2018. At a national level, Bangladesh has been driven to advance solar technology, considered the most viable renewable energy source. The country's efforts to develop a more sustainable energy mix was highlighted at the 26th Conference of Parties (COP26) to the United Nations Framework Convention on Climate Change (UNFCCC). The Mujib Climate Prosperity Plan (MCPP), the cancellation of twelve coal-based power plants worth $12 billion in foreign investment, the ambitious and updated nationally determined contributions (NDC), and finally the goal of 40% energy from renewable sources by 2041 are amongst other significant policies aimed towards cleaner energy.

Aims:
The aims of this project can be defined as follows:

- A contextual review to evaluate the impact of energy transitions from standard cooking fuels to electric cooking in developing countries. This includes exploration of the availability, reliability, sociocultural viability and cost of e-cooking technologies, including market research on locally available e-cookers. This also includes a consideration of national policies regarding MECS, modern and national fuel strategies and the housing energy initiative.
- To understand socio-economic and cooking behaviors of slum communities.
- The implementation of an e-cooker network.
- Full monitoring of e-cooking via cooking diaries as well as holding workshops with users at the end of the project to build qualitative understanding on the level of adoption as well as potential barriers.
- Undertake a respiratory health survey of the slum community (or use existing data) for both the e-cooker network and that of a control group that continues to use wood stove cooking, in order to monitor smoke-particulates within households in the e-cooking network. Respiratory health is to be measured using low-cost monitoring equipment.



Methodology

Results:

The preliminary findings of the community survey revealed that approximately 95% of the households have lived in the slum since 1974, and the slum is very densely populated. The Slum Management Committee is in charge of the slum and is male run. All cooking participants in the project are female emphasizing a highly gendered context to the research. 99% of residences lived in highly cramped informal conditions amounting to a small tin-shed with poor sanitation. There is a lack of clean cooking, and the most common methods of cooking are wood burners and electric coil heaters. Community management (Mastaans) provided the community with an informal grid hook-up.

The typical household consists of two to four adults and one to two children. During cooking, exclusively conducted by women for domestic consumption, most people report various health complaints including headaches, coughs, eye problems and the risk of electric shocks. On average, two meals were prepared per day, cooking times ranging from 05.00 to 07.00 for breakfast, 11.00 to 13.00 for lunch and 19.00 to 21.00 or dinner. Additionally, some houses prepared an extra dinner between 17.00 and 19.00. Approximately 80% of the cooking was done outside the house. In general, boiled food was cooked first thing in the morning, fried food for lunch and reheated food for dinner. The most frequently prepared dishes were rice, lentils, fish or chicken curry and vegetables. Houses do not have any form of inbuilt ventilation designed to address cooking fumes.

Subsequent workshops on fuel types used revealed that wood was generally preferred by the community because it was thought to improve the taste of dishes. Aside from harmful respiratory effects, fire threat, overheating during the summer and the social tension caused by smoke invading neighboring spaces, wood is regarded as a convenient, readily available, reliable, affordable and diverse fuel. Gas was considered similarly, although it is more expensive, and the risk of explosion rendered it somewhat less preferable. As an alternative, coil heaters were among the most frequently used cooking devices because they were inexpensive, as far as the initial investment is concerned, healthier (due to a lack of smoke emissions) and highly versatile in that they could be used to cook nearly all dishes. However, they are reliant on electricity and are thus vulnerable to load shedding and blackouts, can only cook a small amount of food at a time and are more prone to sparks and electric shocks due to their open design.

Around 75% (where N (total number of people):60) of targeted beneficiaries are using induction cookers. The remaining 25% do not due to issues of inferior food tase, capital cost and, in a small number of cases, participants moving away from the area. In comparison to other means of cooking, induction cooking requires a significant capital outlay and is sensitive to load shedding. In terms of health, however, it is the superior option since it emits no smoke and poses no health risks from fire or electric shock.

There was a distinct shift in the proportion of wood users taking up induction cooking as opposed to electric coil users, with a higher proportion of coil users amongst those who left. In terms of socio-economic circumstances contrary to initial expectations, individuals leaving the usage of induction cookers were more likely to be in the less-poor category rather than the poorest. This is thought to represent that fact that coils are charge at a flat rate by the community management as were induction cookers. Thus, where households did not feel comfortable yet in relying wholly on induction and wanted to keep a backup, this became particularly expensive. This was not such an issue for wood users. There was also a slight but noticeable trend away from the process by less educated consumers. This could indicate that those who cannot read were disadvantaged in the process.

Approximate daily energy consumption was around 58 KWh, with average generation from the PV system at 53 KWh. Therefore, in the presence of energy storage, only 5 KWh would be required via the grid, saving about 92% of the cost incurred to the government due to informal tapping of the electrical grid. Induction cookers were used the most by those who were previously wood users. This shift was expected as wood cooking has a number of unpleasant side effects, particularly in regards to health. An induction cooker set is roughly ten times more expensive than a coil cooking set. Due to the large initial investment, as well as the requirement of maintaining two connections in certain houses, solar energy powered induction cooking has key economic barriers in the short term. However, at 13 ৳ per KWh, the current grid power supply cost is roughly three times that of a large scale optimal solar PV system at 4 – 5 ৳ for the levelized cost of electricity, making it a lucrative alternative.

The following table summarizes the key focal points:

Barriers	Positives +	Going Forward
PV systems • Lack of policy and infrastructure for formal PV installation in informal settlement • Local electric supply line upgrade • Lack of storage to support load shedding **Induction cooking** • Upfront Cost – cooker and additional pans • Susceptible to Load shedding • Competing with Coil (double connection) • Lack of awareness • Taste • Fixed rate charging of electricity based on appliance, and is not dependent on fuel consumption	**PV Systems** • Legal electricity supply • Provide grid reinforcement for low voltage issues • Reduce overall cost of e-cooking than pure grid connection • Prevent overloading of local grid when cooking • Promote renewable energy and future RE hubs for local consumption **Induction Cooking** • Air Quality Index – shift from unhealthy to moderate • Noticeable throughout community , leads to increased engagement! • At high power – able to cook quickly and variety of foods • Reduced cooking time for users (women) , increased productivity • Safe	**Policy –** • legal/formal utility connections? • Encouraging market growth of e-cookers through subsidy or tax **National Campaigning** Awareness of health benefits of e-cooking **Training on e-cooking** Distribution of cookbooks and training sessions **Prefeasibility** Survey community to understand current social context and fuel diversity (transfer barrier)

Images shown below highlight some of the key progression points: images **A** and **B** show the chosen Bhashantek slum location and prevalence of wood-based cook stoves; image **C** highlights the door-door household survey undertaken to understand cooking behaviors, and socio-economic status of the slum; image **D** illustrates the chosen e-cook stove based on induction cooking; image **E** shows the installed 18.5 kW PV system elevated above the slums; image **F** shows community users during the e-cooker training sessions and the safety manuals; and finally images **G** and **H** show two of the community users using the induction cook stove powered by solar PV.

All image credits: University of Southampton

Introduction

In 2017, Dhaka was ranked as the fourth least livable city in the world by the Economist Intelligence Unit's Global Livability Ranking. Every day, over 2,000 people settle in the Bangladeshi capital, Dhaka, travelling from more rural areas. The average population density in slum areas is 29,857 persons per km^2. More than two million people reside in slums; leading to poor infrastructure and low quality of public service delivery, subpar drainage systems, insufficient water supply and waste management, and significant pollution. Rapid population growth additionally has translated into housing shortages, further driving poorer residents into slums. Slum residents are therefore not benefiting from the "urban advantage" of gaining access to improved health-promoting services. Estimation shows that only 77.5% of household are found with electricity connections in their houses. However, majority of households have informal grid line connection controlled by *Maastans*, or middle-men and/or bypass electricity connection; the connection is charged extortionately based on number of electrical appliances within each dwelling. Of this, electricity is intermittent with blackouts frequently. In terms of pollution, residents experience high levels of indoor and ambient air pollution exposure, as well as a high burden of disease from acute lower respiratory infection (ALRI), and burn potential, particularly amongst children. Furthermore, the negative health impact of CO exposure includes low birth weight, delayed behavioral development of infants and children, exacerbation of chronic cardiovascular and pulmonary conditions, and, in extreme cases, coma or death. Household sources of indoor PM2.5 and CO include combustion of biomass fuel (wood, bamboo, charcoal, agricultural residue) within the alley-ways of packed tin-housing, which can be exacerbated by the use of poor quality biomass-burning stoves for cooking or heating. Moreover, biomass fuel burning in one home affects the air quality in neighboring homes, community-wide interventions may be necessary to sufficiently improve indoor air quality. In addition to pollution, this also results in immense heat which makes living conditions, in an already hot climate, even more unbearable. Gas cookers with an initial capital cost of Tk. 3000 and Tk. 1000 on monthly gas cost thereafter are present for some shop owners and more affluent dwellers, whilst electric cookers come in the form of unsafe, exposed coils.

In recent years, the reduced cost of solar photovoltaics (PV) has greatly increased the rate of penetration of PV-based electricity supply. The challenge in cooking with Solar PV is the amount of power required at an acceptable cost and cultural context. This can be explored with a systems approach of distributed energy for e-cooking. The aim is to offer energy independence, whilst tackling air pollution, by delivering e-cooking solutions powered by solar PV systems as an alternative to biomass cook stoves. However, the main challenge in solar e-cooking is the reliability of solar insolation. As cooking is an essential element in a household, its effectiveness will be greatly impacted if there is no backup power.

In many low income settings, the kitchen is the center of family activities and propagate behaviors which either undermine or enhance health. Women clearly understand intermediary (psychosocial, material and behavioral) determinants of the health conditions identified above, such as poor ventilation, cooking on open fires, over-crowding, and lack of adequate child supervision. However, fire, the hearth and tradition play an important role in social context and a sense of cultural belonging and are important factors in understanding the uptake of alternative energy supplies for cooking. The end state for the community would be to make use of a centralized local energy system that is shared in order to distribute costs and be more resilient. This project will deliver a functioning pilot network to gain knowledge about how these systems work.

Identifying the potential barriers to the uptake and utilisation of MECS in the high-density informal settlement slum areas of Bangladesh, is to directly address the associations of biomass and gas fuel utilisation with poor health and environmental outcomes. As such the approach directly addresses the DFID theme of tackling poverty and addressing the needs of some of the world's most vulnerable populations. These slum areas are home to diverse communities, often representing migrant populations that have moved to be able to improve livelihoods and welfare of their families. However, high population and housing densities expose slum dwellers to respiratory stress and the potential for fire and fire injury hazard, particularly for young children, that can offset or even reverse these benefits. The research proposed here will highlight the need and, critically, barriers to uptake for the utilisation of PV as a clean, reliable and affordable fuel source.

The aim of this project is to research on the willingness to pay for access to the e-cooking network as well as to understand the complex social and cultural issues which may act as a barrier to uptake. This involves first understanding their current expenditure on biomass cooking, and in-some cases gas cookers, through semi-structured interviews and workshops with users.

A network of network of 60 users are given specific training to use e-cookers and raise awareness around biomass fuel burning, and environmental and health issues with flame cooking. We then interview the actual users to understand the level of adoption and potential barriers to uptake as a function of time and experience. The aim is to have a centralised system, that is socio-economically and socio-culturally feasible against gas alternatives, and complimentary to the electric main-grid.

The objectives in this project can be separated into 5 key areas:

1) Contextual Review

    a. The impact of energy transitions from standard cooking fuels to electric cooking in developing countries.
    b. The availability, reliability, sociocultural viability and cost of e-cooking technologies (including market research on locally available e-cookers.
    c. National policies regarding MECS, modern and national fuel strategies and the housing energy initiative / institutional organogram.
2) Understanding socio-economic and cooking behaviors in slum communities
    a. HH survey of the wider slum community
    b. Baseline workshop with 60 users.
    c. Pre-pilot cooking diaries.
3) Implementation of the e-cooker network
    a. Development of elevated PV system within slum.
    b. E-cooker training and distribution of induction cookers.
4) Monitoring of e-cooking
    a) Cooking diaries with all network users for quantitative analysis.
    b) Workshop with users at the end of the project to build qualitative understanding on the level of adoption and potential barriers to uptake as a function of time and experience.
5) Undertake respiratory health survey of slum community (or use existing data) for both the e-cooker network and that of a control group that continue to use wood-stove cooking.
    a. Monitor smoke-particulates within households of the e-cooking network
    b. Asses the respiratory health using low-cost respiratory monitoring equipment.
    c. Analysis of smoke and health data, and potentially determine links to COPD and COVID-19

Background

Global Context

Developing countries offer opportunities for sustainable development, such as the transition to affordable and clean energy (UN, 2020; UN 2018). Air pollution exposure in Southeast Asia is in large part attributed to standard cooking fuels (biomass, kerosene, paraffin), particularly in those developing countries that are more reliant on these fuels (Chafe *et al*, 2014). Clean cooking fuels (electricity, liquid petroleum gas (LPG), biogas, natural gas) offer health and environmental benefits compared to standard cooking methods. Energy transitions can be placed on a ladder from less desirable standard cooking fuels to cleaner cooking fuels as households improve their socioeconomic and urban statuses (Israel-Akinbo *et al.*, 2018; Rahut *et al.*, 2017). To speed up the development of certain areas, organizations, such as the Clean Cooking Alliance, are attempting to implement electric cooking methods in place of current, less healthy, cooking fuels (UN, 2018). Electric cooker (EC) adoption has previously been somewhat unsuccessful and led to fuel stacking with other fuels (Boso *et al* 2020; Gould *et al.*, 2018). Compared to traditional cookers, ECs produce fewer GHGs, including carbon dioxide (CO_2), carbon monoxide (CO), and nitrogen dioxide (NO_2) (Martínez-Gómez *et al.*, 2016; Paulin *et al*, 2014) and are even better compared to clean cooking fuels. In case-control study, ECs produced eight times less particulate matter (PM2.5) than biomass cookers, and significantly less than kerosene and LPG cookers. This rate of emission reduction could help regions achieve international air quality targets if communities transitioned to ECs (Pokhrel *et al.*, 2015). In support of this, transitions to ECs in Southeast Asia could reduce local GHGs by 74.3% from 2010 to 2050 based on international data (Pradhan *et al.*, 2019). Since EC adoption in developing countries has only been very recent, study methodologies are inconsistent but similarly support the air quality benefits of ECs. Studies on unsuccessful transitions highlighted multiple fuel type usage (stacking) as a reason for reduced GHG reduction potential (Gould *et al*., 2018; Gould *et al*., 2020). These unexpected outcomes highlight the need for more longitudinal studies on EC transitions. In dense urban living, $PM_{2.5}$ and CO concentrations indoors can be raised by biomass burning in neighboring houses (Weaver *et al*., 2019; Snider *et al*., 2018). Urban houses were found to have a higher accumulation of GHGs from biomass cooking than rural houses due to a lack of ventilation (Agarwal *et al*, 2020). This is one of few studies that successfully compares emissions in urban and rural areas but is limited to only PM2.5 measurements.

As well as transitioning to ECs, significant emissions can also be avoided by investing in renewable energy nationally. These policies are important for developing countries with high economic and population growth. This has been shown in Honduras where transitioning to a combination of LPG and electric may not significantly reduce emissions compared to biomass cooking due to the country's reliance on fossil fuels. A rapid transition to electric cooking and renewable energy could avoid these emissions (Ver Beek *et al.*, 2020). Pressure for electrification by increasing EC usage could improve national air quality and have wide-scale health impacts (Pradhan *et al*., 2019). Earlier studies have predicted electrification pressures from energy transitions, triggering more efficient energy grids (Amirnekooei *et al*., 2012). However, these benefits still rely on national or local renewable energy adoption, as predicted in Thailand (Kongwanarat and Limmeechokchai, 2014).

The impact of burning biomass on health is well known to cause cardiovascular and respiratory illness in LMICs, particularly Southeast Asia. The resultant poor air quality contributes to global morbidity and premature mortality (Cohen *et al*., 2017). By measuring $PM_{2.5}$ concentrations in rural Chinese homes, it has been suggested that switching from biomass fuels to clean fuels could increase the number of World Health Organisation Air Quality Target days to 73% and save 124,000 premature deaths yearly (Snider *et al*., 2018). Under-5 mortality is also significantly reduced by this transition in Africa (Owili *et al.*, 2017). These studies lack specificity on the impact of electric cooking alone by not distinguishing electric from other "clean" fuel types. However, one study that isolates electric cooking found the health benefits of switching to be lower than expected due to fuel stacking, suggesting partial transitions have limited health benefits (Buthelezi *et al*., 2019). The health hazards of burning biomass have been studied far more than the health benefits of transitioning to cleaner fuels, likely due to a lack of longitudinal and international studies.

Low-income informal urban houses (slums) face smoke accumulation from neighboring houses, though the health implications of this have not be assessed (Weaver *et al*., 2019; Snider *et al*., 2018). Dense housing also comes with a high fire risk when cooking with a flame due to a lack of space to control or prevent fire, and an inability to access fire and rescue services. However, in Tanzania, ECs have been avoided due to unreliable and unsafe electrical connections, suggesting ECs require suitable infrastructure (Mtani and Mbuya, 2018). Health hazards in these settlements are compounded by households' low income, dense-living, and a lack of childcare provision (Elsey *et al*., 2016).

Despite better ventilation, indoor air pollution still causes sight and breathing issues for primary cooks in rural housing (Ketlhoilwe and Kanene, 2018). Air quality is unexpectedly high in rural housing due to persistent use of firewood for cooking, more so than urban households (Maji and Kandlikar, 2020). In rural households, the women in charge of collecting firewood complain of body pain from carrying firewood over long distances. Introducing improved cookers may relieve the health burdens of firewood collection (Lewis *et al* 2017). Rural residents in India (particularly women) who cook more with firewood are more likely to develop rheumatic musculoskeletal disorders than urban residents (Guevara-Pacheco *et al.* 2016). However, it is only an assumption that reducing the burning of firewood would reduce the mentioned health burdens in these studies.

However, health benefits are limited by stacking with poor adoption and stacking insignificantly improving cardiovascular health in rural residents (Clark *et al*, 2019; Jagger *et al*., 2019). Poor adoption may be the result of a traditional belief that firewood is beneficial for health, especially for new mothers and their babies (Tamire *et al*., 2018). There are mixed views on the health impacts of cleaner cooking fuels (Elsey *et al*., 2016; Malakar *et al*., 2018; Gould *et al*., 2020,). However, the impact of these views on the rate of EC adoption is not fully understood.

When tested in the laboratory, cooking the same meal with an EC cost 95% less than with an LPG cooker (Martínez-Gómez *et al*., 2016). Outside of the laboratory, electric cookers have been shown to consume twenty times less energy per meal than biomass cookers due to more efficient heat transfer and better temperature control (Clements *et al.,* 2020). When considering initial, maintenance and operational costs, electric cooking was cheaper than LPG in Latin

America (Acuna *et al.*, 2016). However, fuel prices constantly change, making this study very time- and location-dependent.

In some circumstances, economic gains are a pulling factor in adopting electric cookers in place of traditional methods (Ahmad and de Oliveira, 2015). However, there is more evidence of high initial costs being a deterrent for those wanting to transition in rural and urban areas and household income positively relating to cleaner fuel adoption (Clements *et al*., 2020; Ahmad and de Oliveira, 2015). With high conversion costs and absent government subsidization, electric cookers have been costly and neglected by households in Ecuador (Gould *et al.,* 2018; Gould *et al*., 2020). However, initial costs may be paid back due to the longer lifespan of ECs than alternative cookers (Pradhan *et al* 2019). Transitioning to electric cookers may therefore result in no net financial savings for users (Lombardi *et al*., 2019). The individual economic impact is clearly complex and relies on several factors.

Despite possible individual and local detriments, some countries, such as Ecuador, may benefit from selling CO_2 carbon credits and reducing LPG subsidies. Ecuador's government could save US$973.42 million from 2014 to 2022 by widely adopting ECs (Martinez *et al*., 2017). Similarly, in India, economic growth could reach 5.8% from 2013-2050 if renewably powered ECs are widely adopted (Gupta *et al*i., 2019). Electrification expansion may be more costly than using renewable-powered microgrids, supporting arguments that suggest that infrastructural changes may be required to economically support a transition to ECs (Kongwanarat and Limmeechokchai, 2014; Clements *et al.* 2020; Lombardi *et al*., 2019). However, studies can only make predictions from small data sets due to the fact that wide-scale EC adoption in developing countries has been very recent and may therefore be inaccurate.

Diminishing the need to collect firewood for cooking can give people more time for other activities. Women in rural Africa, commonly the primary cooks in their households, revealed in interviews that they would spend their new free time resting or increasing their business' productivity (Johnson *et* al., 2019). Since women are responsible for household activities in developing countries, household electrification often has gender-differentiated impacts. As a result of the adoption of electric cooking appliances, women's employment opportunities have expanded and diversified outside the home in Nicaragua (Grogan *et al.* 2013). These effects have a greater impact on women than men and improve women's social and economic equality by balancing gender roles (Nwaka *et al*., 2020; Matinga *et al*., 2019). By transitioning to improved cookers, including ECs, women in rural India could reduce the daily time spent collecting firewood from 2.9 hours per day to 1.4 hours (Lewis *et al*., 2017).

However, interviews with women in rural India identified various social benefits from firewood collection, with women seeing this time as a traditional routine that provided an opportunity to talk to other women (Malakar *et al*., 2018). However, depleting sources of firewood have meant that women must travel further and to different places for firewood, which has meant decreased opportunities for socializing, something that will only continue as resources decline further (Ketlhoilwe and Kanene, 2018). In Ecuador, older people especially have found these distances a barrier to the use of firewood and could be persuaded to use cleaner, more accessible fuels (Gould *et al*., 2018). The use of in-depth and open interviews with women in this study has been beneficial in identifying unique and unpredicted social impacts, including observations on heritage and traditional beliefs.

Biomass cooking has traditional desires and commonly used at family gatherings, particularly in rural areas where such sentiment is a barrier to EC adoption (Young *et al*., 2019). Multiple studies suggest ECs are not adaptable to local dishes and alter their taste, particularly those foods that are usually cooked on biomass cookers (Clements *et al*, 2020). Despite participants being aware of other benefits of ECs, they choose to continue using biomass cookers for flavor (Malakar *et al*., 2018; Jürisoo *et al*., 2019). Participants in a controlled study preferred the taste of food cooked on electric rather than LPG cookers, though there is no evidence against biomass cooking (Martínez-Gómez *et al*., 2016). Further issues arise from the supposed difficulty controlling cooking speeds and temperatures using ECs (Jürisoo *et al*., 2019). This may be enhanced by ECs' lack of adaptability to traditional pot shapes, which comes at an expense for those purchasing improved cookers (Gould *et al*., 2018).

National Context

In 2013, the first-ever Country Action Plan (CAP) for Clean Cookstoves was launched by the Power Division in Bangladesh, with support from the Clean Cooking Alliance, in order to develop the country's clean cookstoves market. This was reviewed again in 2018 and formed The National Action Plan for Clean Cooking (2020 – 2030) to develop aligning strategies in accordance with the recent shifts in the sector in terms of different economic and social aspects of the country.

In Bangladesh cooking mostly relies on a combination of biomass, biogas, liquid oil gas (LPG), natural gas, and electricity. Depending on the socio-economic status of the household, cooking technology varies. 'Stove Stacking' is a rather common phenomenon, where more than one cooking technology is used in one household depending on time, comfort, and fuel costs. Due to the commercial import of LPG from 2011-12, the cooking fuel scenario in the country has shifted significantly. LPG stoves are preferred because of their convenience of usage. However, biomass is still widely used in cooking, especially in rural and pre-urban areas. The thermal efficiency of biomass stoves is relatively low whereas emissions of CO_2, CO and PM are significantly high compared to other fuel options. Due to the swiftly-declining natural gas reserves of the country, the government suspended the provisions of new piped natural gas connections to households since 2016-17 which has led to an increase in demand for alternatives. Biogas stands as the most environmentally friendly and clean cooking fuel option. Most of the biogas is produced from the manure of cows and chickens and102,808 biogas digesters have been installed in Bangladesh till 2018. However, due to high initial investment costs and other specific requirements, biogas is yet to be the most popular choice for cooking fuel. The use of pellet and briquette fuel is still relatively uncommon. These fuel-based cooking solutions have encountered limited success for a variety of reasons, such as the manufacture and availability of pellets and briquettes, the relatively high cost of stoves, people's cooking habits, etc.

To achieve the goal of clean cooking, strong centralised government leadership will be needed to implement rules, laws, and policies. Generating the favorable conditions necessary for inclusion of clean cooking in all national policies, establishing a workable and long-lasting national platform, and opening doors for funding a cutting-edge center for ICS testing and certification, amongst other things. Building awareness is crucial for persuading households dispersed in accessible locations with little social networking of the many advantages of ICS. Further, strong emphasis should be provided on emission-free cooking by reducing household air pollution and maintaining a national commitment with regard to ICS. Long-term sustained expansion of supply-side company development is believed to be possible due to the presence of mutually reinforcing demands. LPG cooking is safe and secure in all areas of Bangladesh, with the exception of isolated locations where, from a private-sector perspective, the feasibility is unjustified. Due to factors like ease, temperature variation and fine-tuning, cleanliness, and space efficiency, homes should prioritise induction cooking appliances as used in Asian and other nations. The tendency to stove stacking will persist as long as household income, source assurance, and taste perception are not at a level that would permit the use of only one fuel. An impact analysis to determine whether the decrease in HAP contributes to lower health costs or better environmental conditions is crucial.

Bangladesh has clearly been driven to advance solar technology on a national level. At the 26th Conference of Parties (COP26) to the United Nations Framework Convention on Climate Change (UNFCCC), the country's efforts to develop a more sustainable energy mix was highlighted. These included the Mujib Climate Prosperity Plan (MCPP), the cancellation of twelve coal-based power plants worth $12 billion in foreign investment, the ambitious and updated nationally determined contributions (NDC) and the goal to provide 40% energy from renewable sources by 2041.

The MCPP includes a detailed examination of the electricity industry as well as a vision for the next ten years in terms of major climate-related sectors. The most viable renewable energy source is still solar, as the nation experiences average daily sun radiation (GHI 4.5 kWh/m^2) in this region. 950 MW of utility-scale projects have been committed and simulations indicate a requirement of 8 GW by 2030 in order to reach the government's 10% target. With current PV and inverter prices of US$21 per Wp (Peak Watt) and US$8 per W, respectively, the cost of solar panels will continue to decline. In 2030, floating solar is expected to cost USD 0.5 million per MWp. A continuous increase in solar rooftop projects is witnessed, with an anticipated capital cost per megawatt peak (MWp) of solar PV rooftop project of USD 0.49 million. Weak grid infrastructure, which results in reduced generation in existing RE PV power plants, is one of the main obstacles to the growth of the PV sector. Instead of PV performance, this grid interruption is the reason for productivity drop, resulting in losses for the plants or higher government payments for idle capacity.

E-cooker Market Availability

Hotplates, induction cookers, infrared cookers, and rice/multi-cookers were among the electric cooking equipment alternatives that were taken into consideration for the slum dwellers. The advantages and disadvantages of each appliance are given in the table below.

Type of Cooking Equipment	Advantages	Disadvantages
Coil and Hotplate	No special cookware is required. Robust design. Less expensive than other electric cooktop. Compact cooking. High portability. High affordability.	Less energy efficient. *Safety issue* - The coils could spark, smoke or shock. Uneven heat distribution. High maintenance.
Rice Cooker	Automated, easy to use. Energy efficient. Low maintenance. High portability.	Finite number of dishes can be cooked. High initial investment.
Electric Pressure Cooker	Energy efficient. High portability.	Finite number of dishes can be cooked. High initial investment. *Safety issue* – Possibility of explosion due to pressure.
Infra-red Cooker	Better heat distribution. No special cookware is required. *Safety* – No heat radiation. Robust design. Most dishes can be cooked.	Slower cooking. High maintenance. High initial investment. Learning curve.
Induction Cooker	Very energy efficient. (*25% more efficient than IR)* Concentrated heat, faster cooking. Low maintenance. High portability. Most dishes can be cooked.	High initial investment. Requires special cookware. Learning curve.

Table 1. A comparison of all the available alternatives showed that the induction cooker was the most effective and quickest to use, and it could cook practically all the slum dwellers' dishes. It did, however, also call for specialised

cookware made of steel or aluminium. However, over time, the improved efficiency—which was 25% better than an infrared cooker—would offset the costly initial outlay.

Methodology

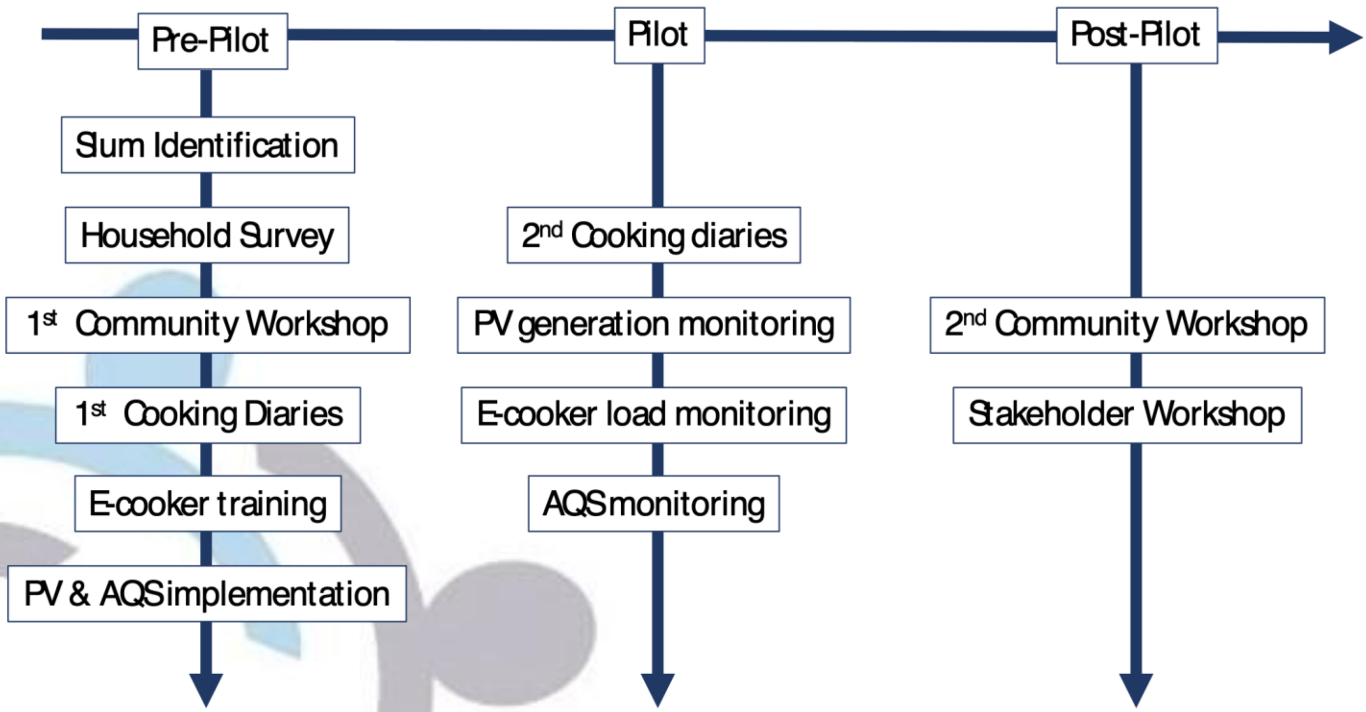


Figure 1. Flow diagram illustrating different methods throughout the project for implementation and monitoring.

Pre-pilot data collection

Slum Identification: The first stage of the field work was to identify a suitable slum location for the project. In order to do this, the following criteria were set: proximity to Dhaka city to ensure easy access, and reduce travel for field work (particularly important to reduce COVID risk); predominant use of biomass for cooking within the community; effective internal governance of the slum dwellers to ensure project security and potential for community ownership; and finally feasibility of PV installation. Considering these points, Bhashantek slum in the Mirpur area of Dhaka city was chosen. This slum has over 2200 households, of which 60 would be chosen for the pilot project.

Surveys and Workshops: The next step was to undertake an extensive household survey (see appendix 1) to understand cooking behaviors, socio-economic background, and health. This was implemented through field workers from SNV and UIU attending door-to-door and working with the lead-cook in the household to complete the questionnaire.

Following the household survey, a community workshop was held in the local school with the 60 households chosen to be part of the pilot. This was held over two days, with the 60 users split into five groups of twelve. Each group discussion was led by a trained female facilitator from SNV and note-taker from UIU, who used a workshop questionnaire (developed jointly by all project partners – see appendix 2) to undertake an open discussion. The facilitators asked about their preferred fuel type and the reason for the preference as well as the advantages, disadvantages, reliability, cost, availability, and social aspects of their preferred fuels. They were also asked about the respiratory issues caused by the smoke, as well as their initiatives to avoid smoke.

Cooking Diaries: Following the workshop, prior to the pre-pilot, cooking diaries (see appendix 3), were undertaken over the period of a month. This consisted of field workers going daily to assist in completing the diary documents in the first week, followed by regular visits the following week to ensure quality of data. The diaries were designed to understand what type of dish the users cook, what time they cook, with which fuel they cook, and finally with whom they cook.

E-cooker Training: We developed a safety manual (see appendix 4) for the safe and efficient use of induction cookers. SNV organized a four-day long group hands-on training period for the users and the local electricity suppliers to make them aware about the safe and efficient use of induction cookers & PV systems. The inauguration of the Solar PV plant and the distribution of electric cookers among the project beneficiaries took place in the presence of project partners, slum management committee, local electricity suppliers and the project beneficiaries. During the distribution, every beneficiary signed an acknowledgement paper. A Memorandum of Understanding (MoU) was also signed between Slum Management Committee and Local Electricity Suppliers Committee about the maintenance and management of the installed solar PV system and e-cookers at the project site. In the 1st day of training, SNV's energy specialist and solar PV installation engineer jointly conducted that training with local electricity suppliers. And the rest 3 days' users received the hands-on training on using induction cooker. The safety manual was distributed among all the users and local suppliers during the training.

Figure 2. Photos of community users undertaking e-cooker safety training and using their safety manual. image credits: University of Southampton

PV System

The project intended to implement electric cooking using the grid electricity with a solar PV installation to supplement the grid power. So far as the solar PV installation is concerned, there are two possible options:

i) Roof top solar for the individual households

ii) Central grid connected PV system.

The houses in the slum d very close to each other and most of the roofs were not strong enough to sustain the installation of the PV systems. Connecting PV systems to the individual grid connection of the households turned out to be more expensive compared to the central PV system. Moreover, the avoidance of an individual rooftop PV system makes maintenance more difficult. Considering all these factors, it was decided that a central PV system would be installed and connected to the internal line of the grid connection via grid tied inverters.

System sizing/design

It was estimated that the average power consumption during cooking would be around 800W. Corresponding to this value, the power requirement for ECs is approximately 36kW, considering a diversity factor of 0.8. The usual cooking hours are between 10am and 2pm and the corresponding energy consumption is 152 kWh. Considering a 50% energy supply from the solar PV, we designed a system to generate an average of 76 units of electricity per day. Dhaka has an average sunshine of 4.5kWh/m^2 per day and we expect to extract 75% of the solar power from the PV system. So, the expected output from the PV system is 3.38kWh per 1kWh peak of PV system. Accordingly, for an output of 76kWh, we need 76/3.38 = 22.5kWp of PV system. However, we faced difficulty obtaining a large enough free space inside the slum to install a 22.5kWp PV system and we finally compromised to install a 18.5kWp system. Three single phase grid tied inverters, each having a rated capacity of 5kW, were chosen to connect the PV array outputs to the grid line. It may be mentioned here that each of the 6kW inverters are capable of handling 20% higher PV power without getting damaged. As sunshine in Dhaka seldom produces 1000W/m^2, 5kW inverters should be enough to handle the PV power.

A single line diagram for the system is shown below.

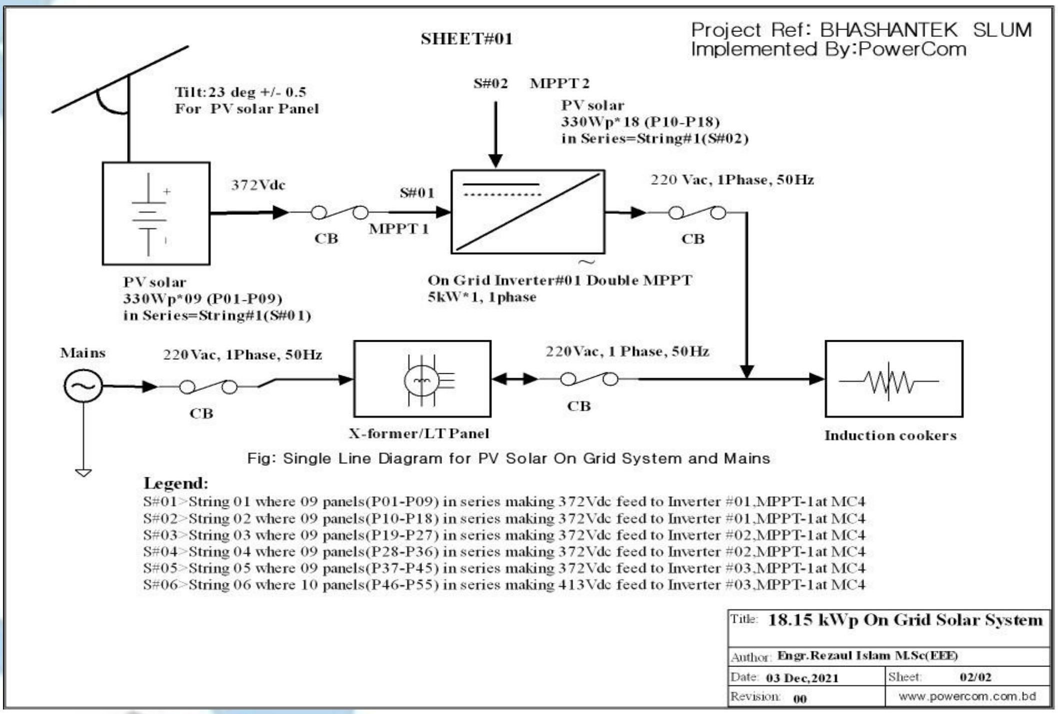


Figure 3. Single line diagram for the grid connected PV system.

While establishing the grid tied inverter it was observed that the grid voltage at the PV site was too low, around 160-170V, compared to the rated line voltage of 220/230V. The power connection from the main power line pole to the slum area is severely undersized that caused very high voltage drop. The grid tied inverters had a minimum operating voltage of 200V that makes them inoperative at such low voltages. So, the power line from the main pole of the grid connection (about 200m from the PV site) was replaced by a higher capacity line and the voltage improved to around 210V, which was an acceptable figure to connect the grid tied inverters.

The power distribution network inside the slum area was also undersized and there was a risk of accident or fire hazard. So, the electrical connections of all the 60 households in the project were upgraded. Each household was connected with a separate connection board with a plug point and an energy meter to measure the energy consumption from the cooking alone. This was necessary to obtain the cooking diary data.

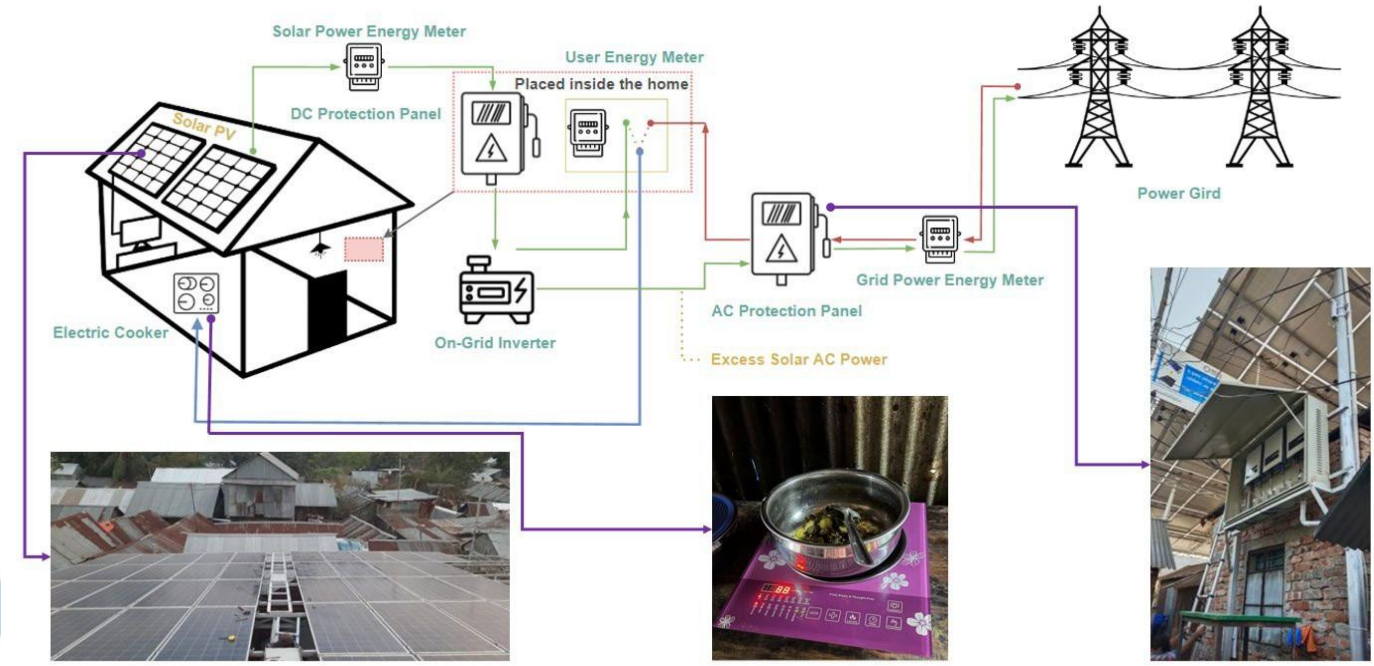


Figure 4. PV system network.

Air Quality Sensing

An innovative IoT network of smoke sensors was created to track the smoke pollution in the slums brought on by the use of biomass for cooking and identify its negative consequences. The electronic components utilised in the system on the transmission side (household) are presented in Appendix X.

- *Arduino Pro Mini:* Arduino is an open-source electronics platform based on easy-to-use hardware and software.
- *Smoke sensor:* The SDS011 is a high-resolution dust and particulate matter (PM) sensor that uses the principle of laser scattering for detecting particles between 0.3 to 10µm in the air and is designed and manufactured by Nova Fitness. This sensor is used to measure air quality and has been judged by the sensor community project as one of the best low-cost PM sensors for their project (Chen et al. *Sensors* 2022). It can return values of PM2.5 and PM10 through a UART (serial) connection. It is a reliable and precise sensor with a quick response time (10s) that was suitable to be used in the specific slum environment.
- *NodeMCU:* NodeMCU is a low-cost open source IoT platform. This was primarily selected to remotely transmit the smoke sensor data over internet by utilising the GSM-Modem to a real-time database for monitoring and analysing the incoming data.
- *LoRaTX – LoRaWAN:* LoRa (from "long range") is a physical proprietary radio communication technique. Together, LoRa and LoRaWAN define a Low Power, Wide Area (LPWA) networking protocol designed to wirelessly connect battery operated devices to the internet in regional, national or global networks, and targets key Internet of things (IoT) requirements such as bi-directional communication, end-to-end security, mobility and localisation services. The low power and low bit rate makes it an ideal transmitter for our purpose. The LoRaWAN data rate ranges from 0.3 $kbits^{-1}$ to 50 $kbits^{-1}$ per channel.
- *Power Adapter:* Two different power adapters were used i.e. 5V and 3.3V to step down the incoming 12V DC supply from the PV system to optimal values for the operation of the various components.
- *Ethernet Cable:* In order to efficiently manage the connection between the smoke sensor, which was placed closer to the stove, and the Arduino Pro Mini placed in a more secure place inside the household to avoid damage from environmental conditions, an Ethernet cable was an ideal choice. This consisted of eight wires bundled together, which is also the required number of connections between the two devices.
- *PCB*: A custom built printed circuit board was used instead of a breadboard as the basis of a more robust system and a GSM capable Internet Modem was used which was used by the NodeMCU to connect wirelessly.

Working Principle:

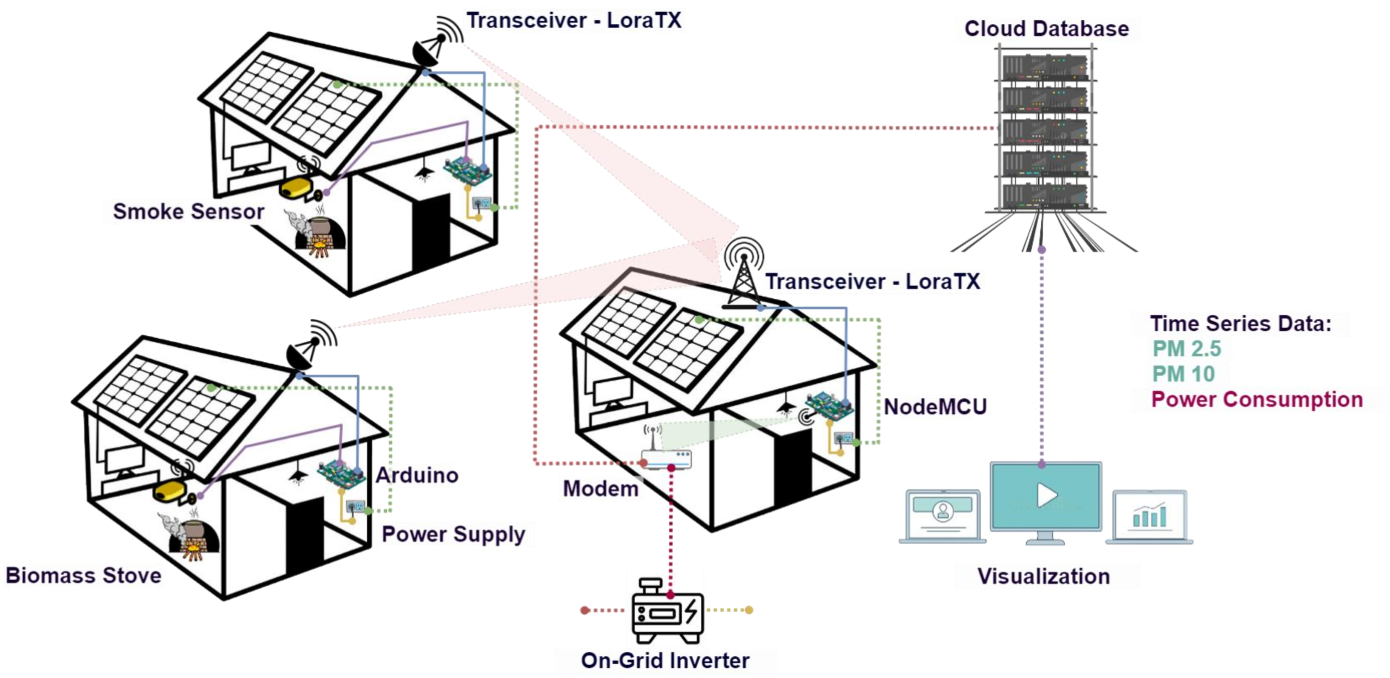


Figure 5. System layout for IoT Network of air quality sensors

The IoT system is currently setup in eight households, where four sensors are used for biomass particle size measurement and the other four for induction cookers users. The central node consisting of the NodeMCU and the modem are located centrally to all the smoke sensors for efficient data communication between the receiving and the transmitting devices. The measurement routine starts from the receiving end i.e. the NodeMCU. The node is programmed to ping each Arduino individually. All the Arduinos are given a specific label/tag. The NodeMCU using the two transmitting and receiving Lora devices first pings the Arduino of the first sensor (S1) asking it for the measurements from the smoke sensor. The Arduino then commands the smoke sensor to measure the particle size and concentration and transmits back the data to the NodeMCU. Hereafter, the NodeMCU then using the wireless connection with the GSM capable modem uploads the data to the online database on InfluxDB. This repeats in a loop until the data is gather from all the sensors from S1 – S8 and then restarts the routine from S1.

Challenges and Recommendations:

a) Some of the components were not readily attainable in the principal country of the project or were extremely expensive. Therefore, as a cost-effective measure it was decided to transport these components from the UK, after specifying the contents as a list until a much later date than intended.

b) Lack of expertise locally on IoT systems companies, (particularly as regards building such systems), which resulted in poor staffing.

c) Initially the system was designed to hear all the sensors as the data was received simultaneously. However, this did not work in the long run as there a lot of data was missed. This occurred mostly due to the tin housing of the community which lead to major distortion. A new/current running program was developed to counter this issue.

d) The NodeMCU has a limited cache memory which would get filled after a couple of cycles of data collection from the sensors resulting in the NodeMCU to stop uploading the data to the database. To overcome this an additional Arduino is used and is programmed to reset the memory after ever five cycles leading to continuous data flow.

e) Initially the system was designed on a breadboard. However, due to the environmental conditions such as the oncoming monsoon season this was deemed to be unreliable as contact with water would be detrimental to the circuitry of the system. Therefore, a custom-built PCB was designed and housed in a secure container to prevent any contact with water as well as dirt from the surroundings.

f) The transmission of the data from the sensors to the NodeMCU would drop out due to unknown reasons. Further analysis of the system revealed that the antenna height required was higher than initially anticipated. Therefore, the height of the antennae was increased from 10ft to 15ft.

g) There are frequent power cuts during which time the system does not work. Battery back-ups are recommended going forward.

h) The system cannot be controlled or debugged remotely. Therefore, a plausible upgrade would involve using a RasberryPi instead of the current NodeMCU based microcontroller. Although comparatively this is an expensive option, it provides complete control of the system and much more functionality. For example, in absence on-field personnel to check on the system operation and causing minor delays, this can be done remotely. Rather than updating the programming of the microcontrollers in person, which requires a lot of communication with the on-field contributors, it can be done remotely by experts at the UoS resulting in enhanced network performance.

Main Research Finding and Lessons Learned

Household Survey

Bhashantek is a low-income community with some 2200 households, from which our sample of 60 households was identified. Access to electricity is controlled by a slum management committee consisting of male community elders often associated with the ruling political party, with elected members of the committee managing designated blocks of the slum. Most of the families living within these blocks have done so for some 20-30 years, having an average family size of four members living in informal or slum dwellings with minimal assets (TV, bed wardrobe etc.) and limited WASH facilities. Housing is cramped and as such cooking activities impinge directly on others. Typically there is no ventilation available for in-door cooking. Many of the men and women within the community work as rickshaw pullers, hawkers, maids, or are full time supporting their family in the home. All the households are connected to the informal grid electricity line with gas mains connection being unavailable. The most common fuel sources for cooking are wood, electricity and LPG gas in cylinder form. The main food cooked in the informal settlement is rice, lentil, fish/chicken curry and vegetables and these form the majority of meals eaten by the families. The average household will cook once or twice a day with peak cooking times being between 8am to 10am and 4pm to 6pm. The use of firewood for cooking in the community has some direct impacts on health, particularly for the women whose task it is to prepare food. People report headaches, cough, burns and eye irritation. There is also a risk of electric shocks when cooking by electric due to poor and exposed wiring associated with coil-based heater stove.

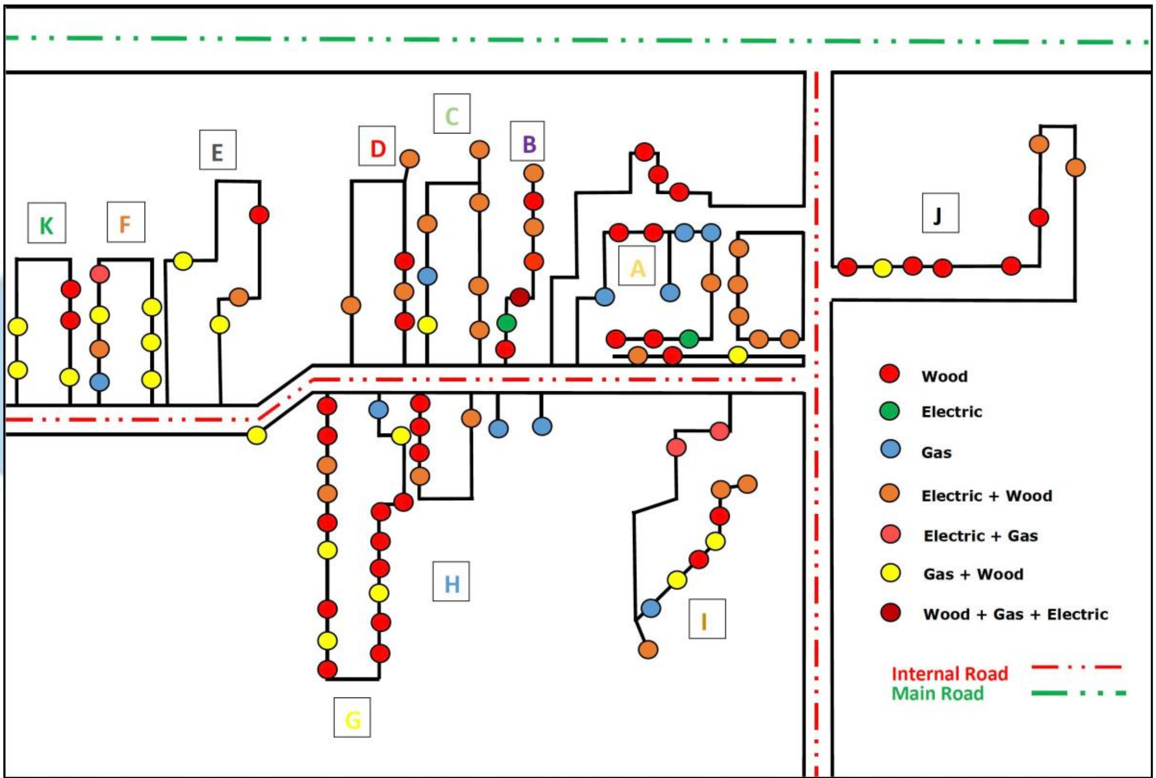


Figure 6. The household distribution of fuel use for cooking. Each point represents a household, and the key identifies the dominant fuel uses. There is a substantive mix of fuel use, with many houses using more than one source one regular basis. However, wood is almost universally used across the study site.

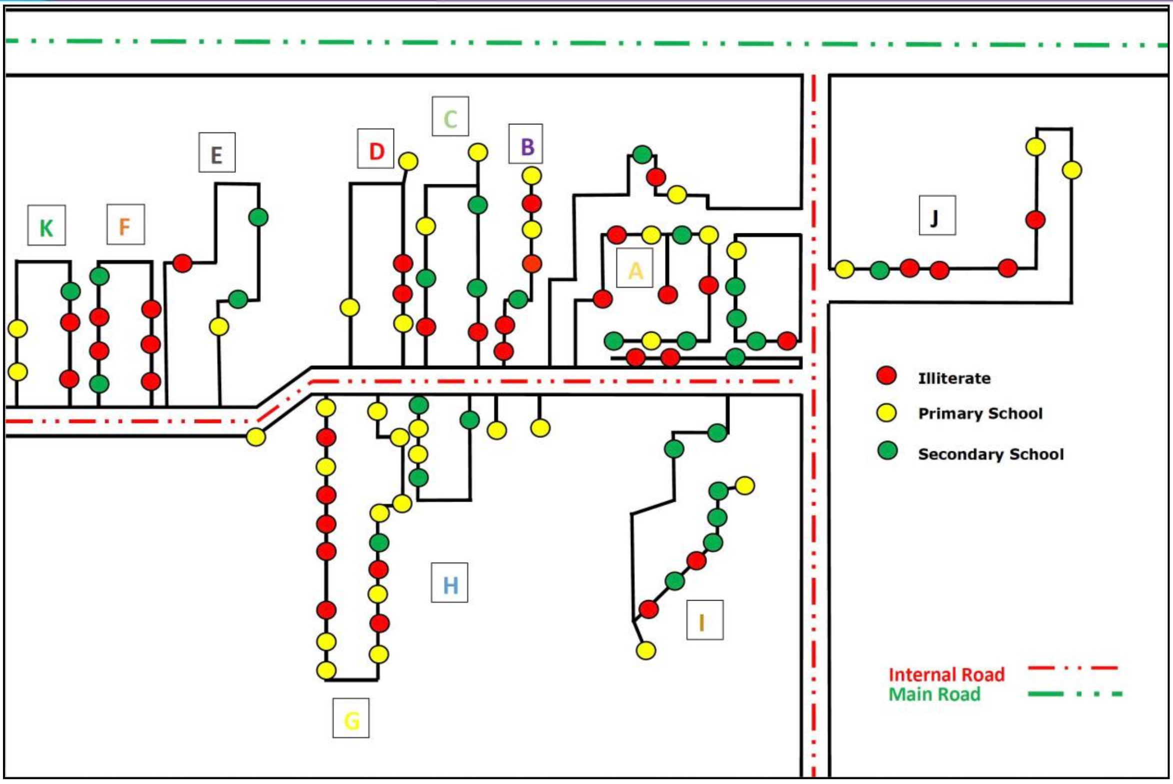


Figure 7. Distribution of education level shows no spatial pattern, with levels of education ranging from illiteracy to some degree of secondary education. This does not appear to be an influencing factor on the selection of wood as a fuel or indeed any other fuel source.

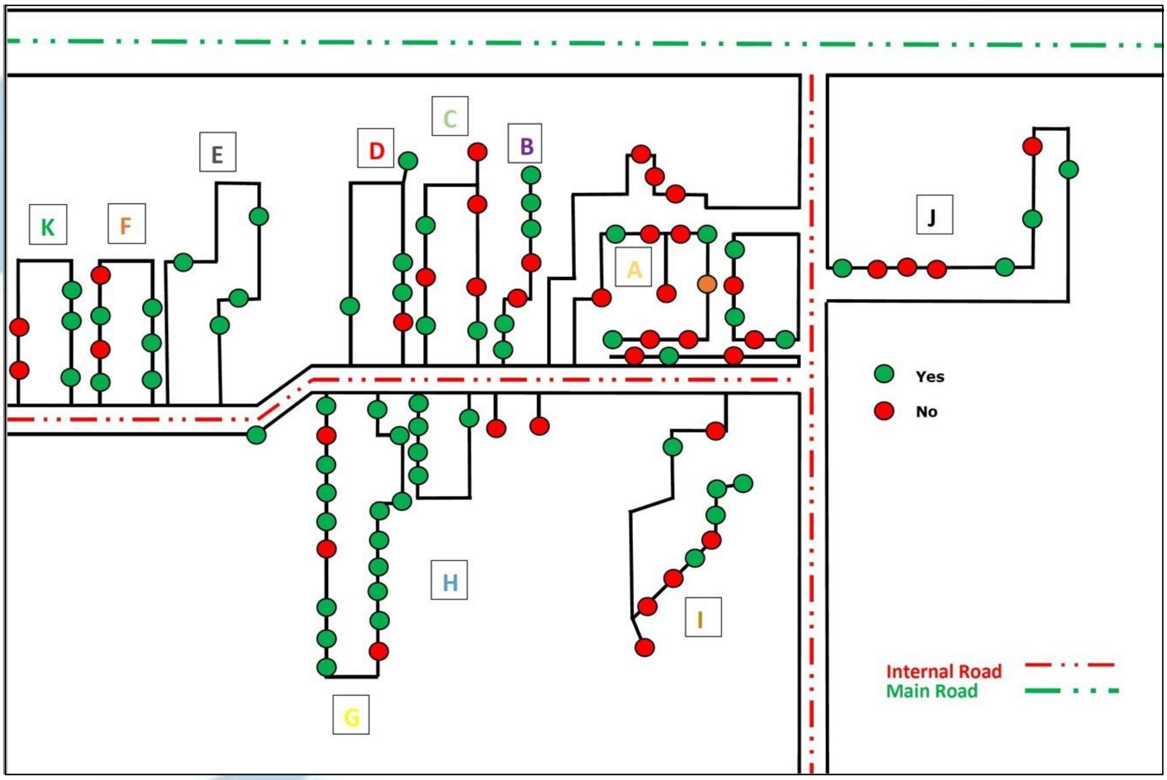


Figure 8. Distribution of those reporting ill-health associated with cooking. Clearly there is a majority reporting issues of ill health that can, at least in the first order, be partially linked to wood use. However, there are exceptions where wood users report no illness. This may reflect the cooking conditions (outdoors/indoors), ventilation or not attributing health issues to cooking.

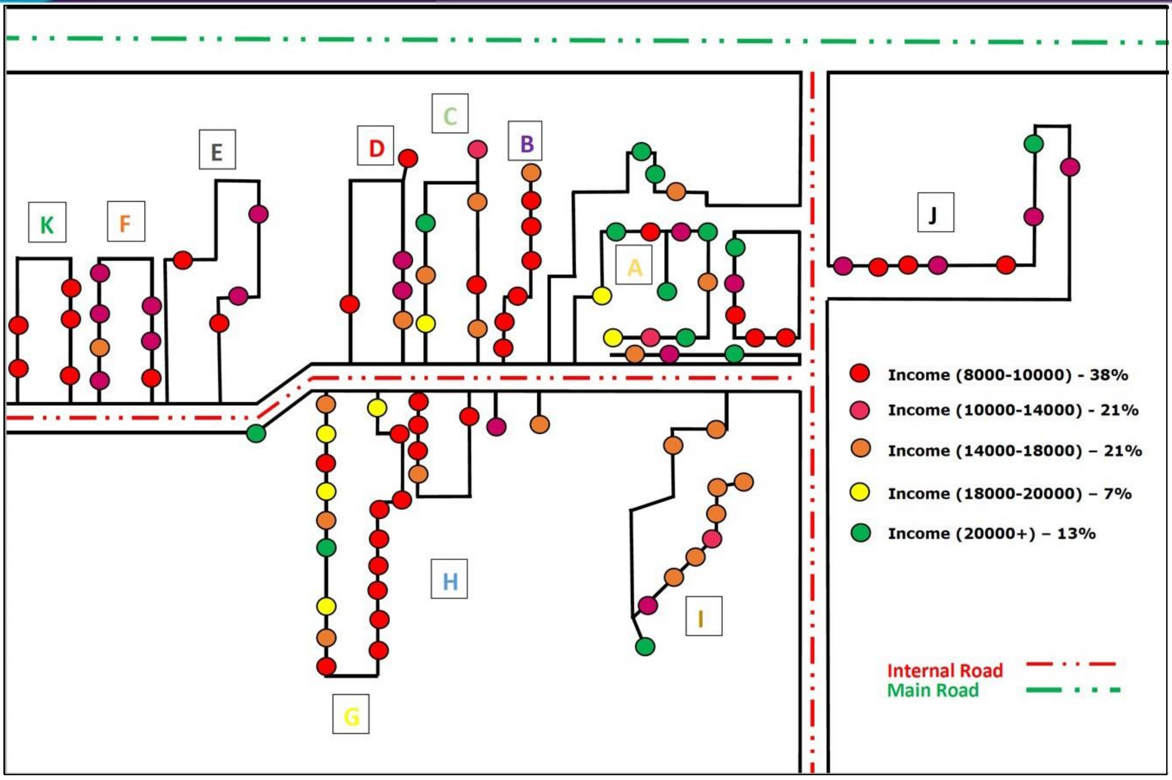


Figure 9. Distribution of monthly income. Whilst there are too few households to make any statistically sound comments here, as a pilot study there is a potential association between the use of wood and poorer sectors of the community, the corollary of that being that wealthier members of the committee tend to use gas, for example.

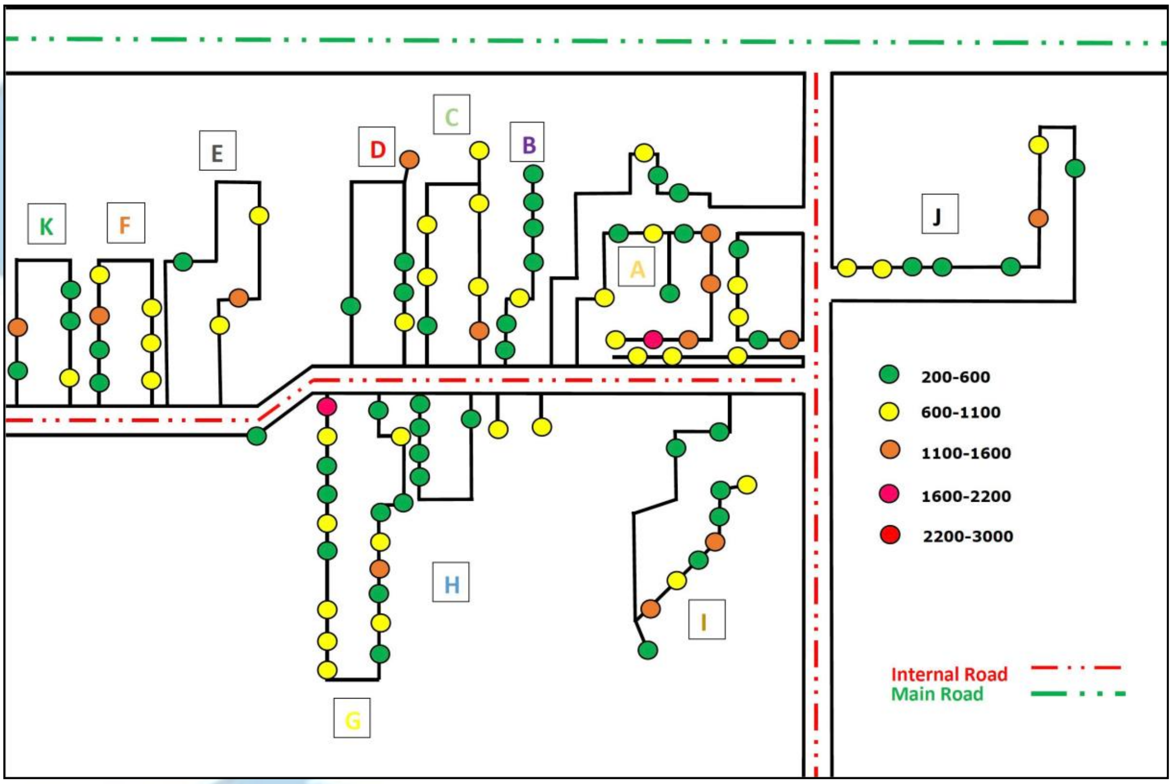


Figure 10. Distribution of expenditure on fuel. Distribution of monthly income. While there are too few households to make any statistically sound comments here, as a pilot study there is a potential association between the use of wood and fuel expenditure based on the cheaper cost of wood. The corollary of that being wealthier members of the committee tending to use more expensive gas for example.

1st Community Workshop

Through an open discussion with the 60 community users, a causal loop diagram (see figure 11) was designed to capture some of the key points identified by the community, and how they impacted each other. Some key findings include:

- Most of the slum members are using wood as their primary or secondary fuel. However, sometimes they use LPG or electric stoves as well. People often revert to the wood stove in case of a shortage of their reserved gas or load shedding.
- People prefer to use wood when cooking for ceremonial purposes.
- Some of the people of the slum associate respiratory health issues with cooking fuel, while some do not. Some further suggest that they are effectively used to the smoke.
- Most people are interested in switching to the e-cooker. The potential cost-effectiveness and longevity of the system are the most desirable features for them.
- In the community, there are a number of recognised health issues associated with the use of wood including respiratory problems, eye and skin issues as well as a particular recognition of the impact on children.
- Secondary smoke is identified as a social issue potentially generating conflict between neighbors.
- Despite being comparable with or more expensive than electric cooking (Grid) wood is often preferred as it is reliable, available and can be purchased daily - unlike electrical supply.
- Wood is seen to produce better tasting food and be more flexible in terms of what foods can be cooked.
- Gas prices are high and rising, making this fuel source of limited availability. There is also a real fear of explosions associated with the canister.

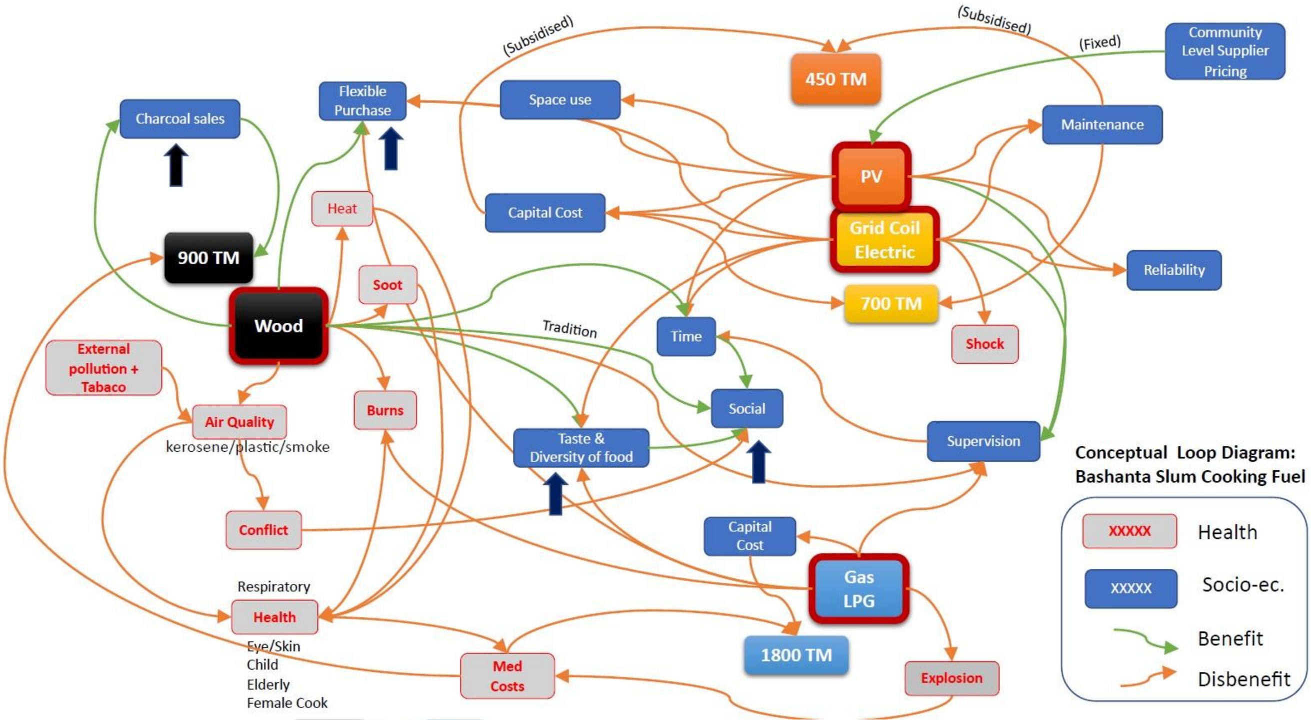


Figure 11. Causal loop diagram capturing some of the key points identified by communities. The red lines show negative association in the direction of the arrow. For example, LPG Gas has a negative association with taste of food. A green line shows a positive association. Key findings are identified above.

In addition to the open discussion with the community workshop users, a pre-pilot workshop was also undertaken with the slum management group. It was established that the monthly electricity bill for the users should be 450 BDT – this would act as an incentive for the local electricity suppliers to engage in the project. This will cover their grid costs and time for regular cleaning. Additionally, the slum leaders agreed to take responsibility for the system post project implementation, with the local electricity supplier agreeing to take responsibility for maintenance services to beneficiaries.

First Cooking Diaries

To better understand the slum inhabitants' cooking habits, cooking diaries were kept for one month. The factors examined included time of cooking, location, the type of cooking activity, the size of the household, and the equipment used. The day was separated into four sessions - morning, afternoon, evening, and night - for better analysis. The distribution of the household size, time, location, and method are presented in Figure 12. In the morning session, most of the cooking was done between 5:00 and 7:00, with a monotonic decline continuing until 11:00. Similarly, much of the afternoon's cooking was completed early between 11:00 and 13:00. A tiny percentage of households also prepared lunch during the final morning session between 9:00 and 11:00. If a meal was prepared for the evening session it was always prepared between 17:00 – 19:00. Finally, the dinner was consistently prepared between 19:00 and 21:00. On average, 80% of the cooking was done inside. Throughout the day, there was a discernible change from inside to outside as lunch was being prepared. In terms of cooking methods, both heaters and wood stoves contributed about 40% each of the total during the morning and afternoon sessions. At night a shift from wood stoves to heaters is noticeable, whereas the evening witnessed a modest dominance of the wood stove over the heater. During the remaining 20% of the time, a gas stove was used for cooking. Given that families typically consist of 2 - 4 adults and 1 - 2 children, approximately 60% of meals were cooked for 2 - 4 adults and 80% for 1 - 2 children. The number of persons for whom the food was prepared sometimes increased as a result of extended visits. Figure 13 illustrates the different kinds of food that were cooked, further sub-categorised based on cooking activity such as frying, making a curry or boiling. Several combinations of meals were prepared throughout the day, for example, vegetables alongside fish. In the morning session, boiling was the dominant activity for dishes like khichdi and egg alongside preparing lentil curries. Lentil curries were the most consistently prepared food, comprising 30% of the time during each session. From Figure 13 it can be observed that frying was prominent during the afternoon session for dishes like vegetables and fishes. Vegetables, rice and potato, and fish were amongst the most prepared meals during the afternoon session, comprising about 40% to 45%. During the evening session, either boiled or lentil curries were the preferred meals, made about 60% of the time. The most prominent meals prepared during the night were either boiled or fried egg alongside vegetables, contributing to about 30 – 35%. However, about 60% of the times food was reheated for dinner.

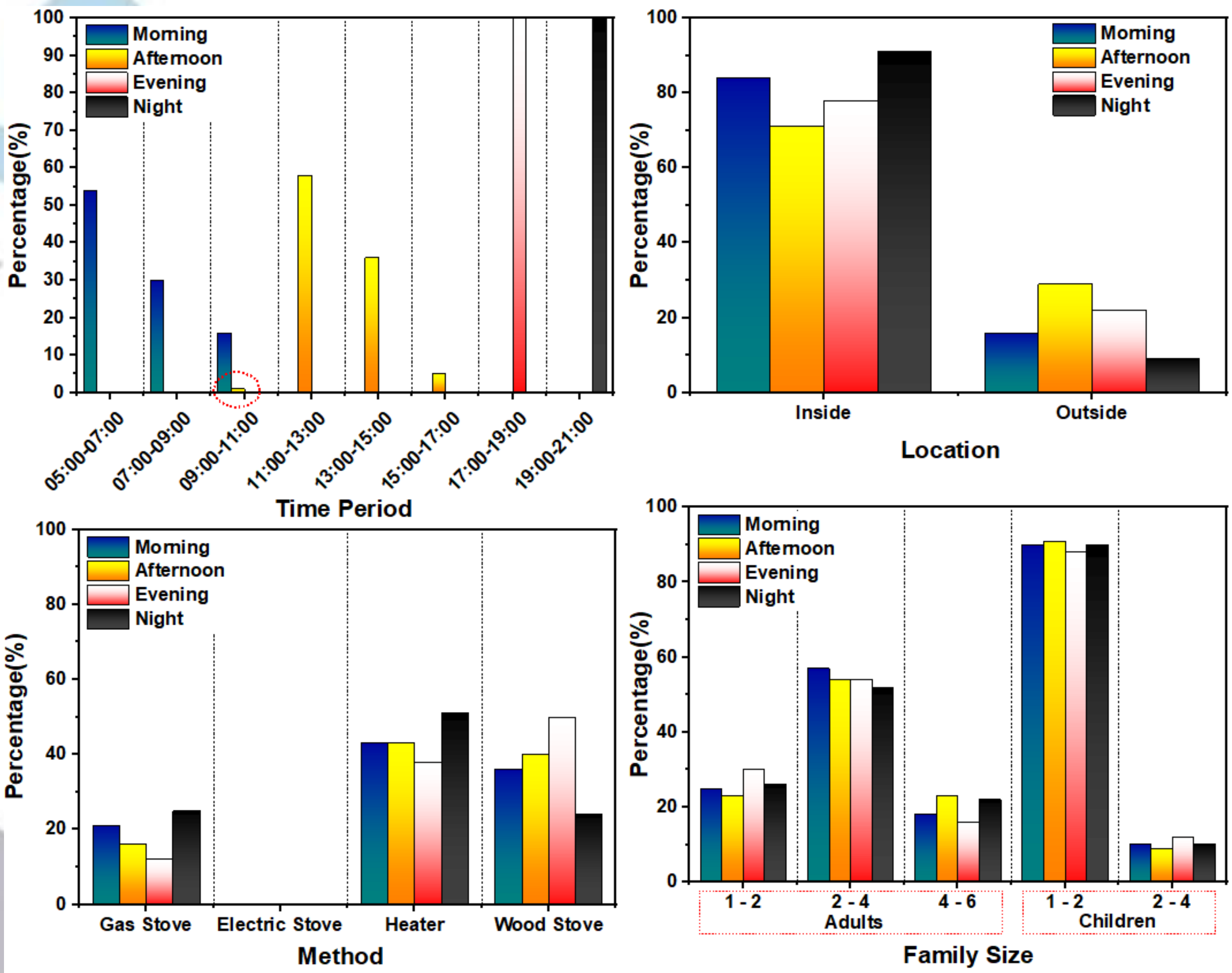


Figure 12. Clockwise from left A) Proportion of total households (N= 60) cooking at different times of day. There are 3 clear peaks in cooking with substantial activity between 19:00 and 21:00 ours. B) Cooking at all times occurs mainly inside (Noting this is a 1-month survey during the month of April in Bangladesh). C) Plot showing daily use of different modes of cooking. D) Plot showing a disproportionate increase in cooking activity associated with child presence in the household.

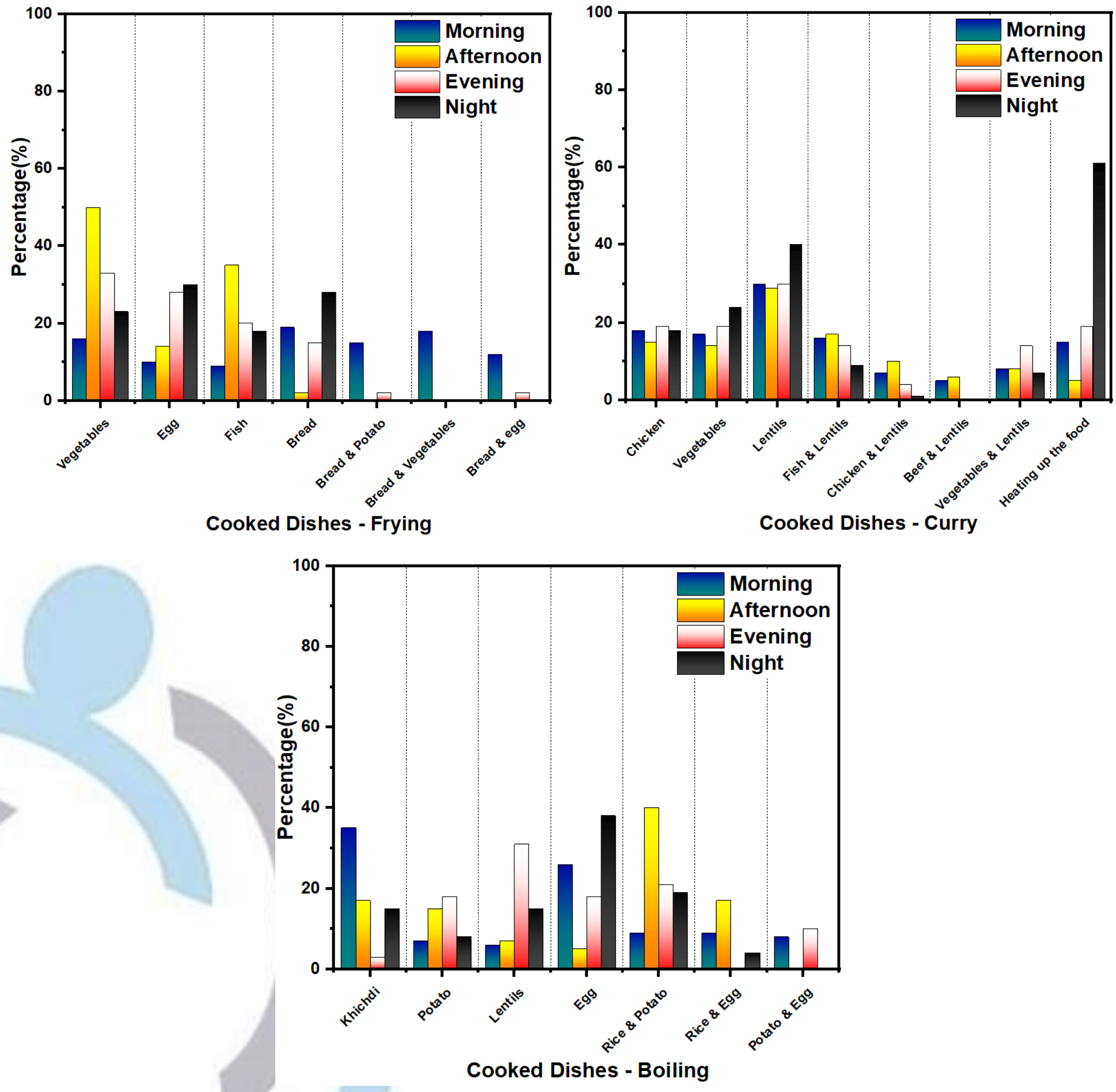


Figure 13. Clockwise from left: A) Proportion of user cooking different dishes that involve frying throughout different time of the day B) Cooking full curries C) Boiling different dishes.

Final Workshop and Cooking Diaries

Once the project had been finalised and the community of users had had six weeks of exposure to the new induction cookers, a repeat of the pre-implementation workshop was conducted, ostensibly to understand how impressions and perceptions might have modified and to consider the benefits and barriers of the use of induction cooking. The figure below identifies the distribution of those that remained interested in a continued use of induction cookers, those that remained unsure and those that rejected their use.

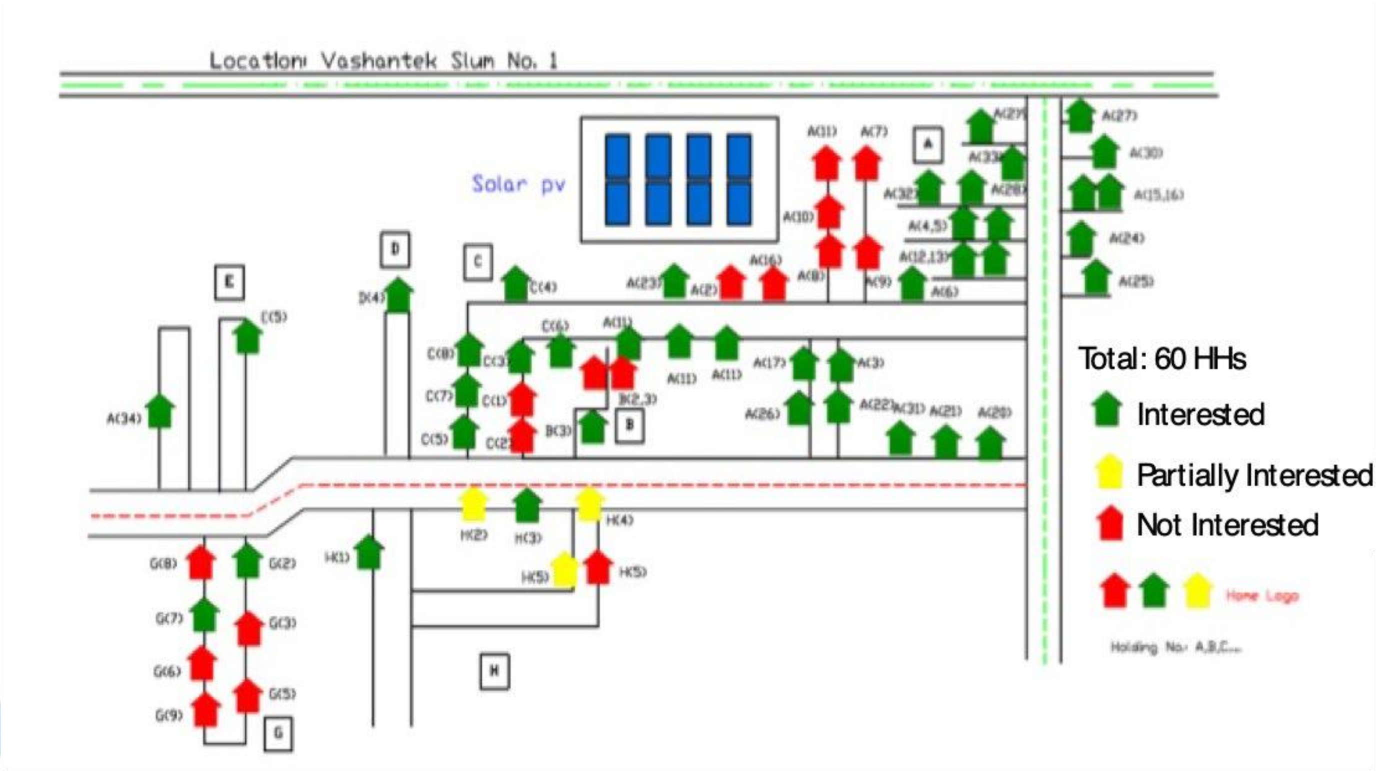


Figure 14. Spatial map of induction users at end of project. There is some clustering of no interest possibly linked to i) Peer influence extending from a few users ii) There may be some association with those that report low health impacts. There would need to be greater numbers to explore this further

One of the key findings from the second workshop was the identification of detailed perceptions of the different fuel sources in the community, with the inclusion of induction cooking. The following tables provide an outline of these finding and complement the findings of the cooking diaries.

Fuel: Wood	
Positive +	**Negative +**
Availability: -Readily available -Can be bought in small affordable units	**Health Impacts:** - Respiratory/Eye/Burns - Particularly women and children - Overheating in summer - Fire Hazard
Reliability: Not susceptible to load shedding	**Social Conflict:** Smoke can enter neighbour's space
Usability: Can be used with all cooking utensils	**Finance:** Rising costs
Acceptability: Believed to make food taste better	
Warmth: Heating in winter	

Finance: Can be bought daily and therefore offers flexibility, also charcoal can be sold	
Formal: Bought legally from shop	

Table 2. Community perspectives on the use of firewood as a cooking material. There are substantial benefits to the use of wood that should be considered when planning a replacement. This includes the ability to pay in small amounts, such as a few days or even one day at a time by the poorest in the community. The key issue with wood is of course the substantial health impacts for both user and those that in close proximity to the user.

Fuel: Gas	
Positive +	**Negative +**
Availability: Readily available	**Health Impacts:** Potential for explosion
Reliability: Not susceptible to load shedding	**Social Conflict:** Gas canister shared between neighbours, and conflict can occur on usage
Usability: Can be used with all cooking utensils	**Finance:** Rising costs
Acceptability: Believed to make food taste better	
Health: Low PM emissions from cook stove	
Formal: Bought legally from shop	

Table 3. Community perspectives on the use of gas as a cooking material. l Gas is both clean and not susceptible to load shedding, but it is very expensive and causes concern in the community over the potential for explosions.

Fuel: Coil Heater	
Positive +	**Negative +**
Availability: Readily available	**Reliability:** -Susceptible to load shedding -breakages common
Finance: Low capital outlay	**Informal:** electricity through informal grid connection
Usability: Can be used with all cooking utensils	**Usability:** Low volume of food capacity
Health: negligible PM emissions from cook stove	**Health:** Electric shock

Table 4. Community perspectives on the use of coils as a cooking device. Electrical heater is both dangerous and susceptible to load sharing. However, they are considered to be quick and relatively clean.

Fuel: Induction Cooking	
Positive +	**Negative +**
Availability: Market available	**Finance:** High capital Outlay
Health: negligible PM emissions from cook stove	**Informal:** electricity through informal grid connection
Usability: -Can cook very quickly when used at high power -Can focus on the other productive activities, as cook stove is safer to use around children	**Usability:** -Cannot be used with all cooking utensils -Susceptible to load shedding -Limited cooking heat at low power -Food can taste worse

Table 5. Community perspectives on the use of induction cooking as a cooking device. Induction cookers are seen as quick, efficient and, once mastered, highly flexible. However, they are expensive and susceptible to load shedding.

At the end of the project, around 75% of the targeted beneficiaries (N= 60 all Female) are using induction cookers for the majority if not all of their daily cooking (Figure 15). However, 25% are not using induction cookers at all due to the issues of food taste, capital cost and, in a small number of participants, moving away from the area. It is found that most of the users are satisfied with the service of induction cooker as it is easier to operate, saves time, very handy and there is no fear of electric shocks. By using induction cookers people are now getting more time to do other tasks. As induction cookers are smoke and dirt-free, their clothes are not getting dirty from cooking activities. During the early phases of the introduction of induction cookers many users felt that they needed to keep multiple systems of cooking available as they were unclear on how to use induction cooking for all their needs, especially frying. This resulted in some dropouts from the program. However, with time users ascertained how to increase the energy output of the devices and thus for the remaining users this latter point appears to have been resolved by the end of the food diary data collection (1 month). Additionally, many community members were concerned about the price of an additional frying pan which is necessary if the induction cooker is to be used for frying, which which accounts for some of the dropouts.

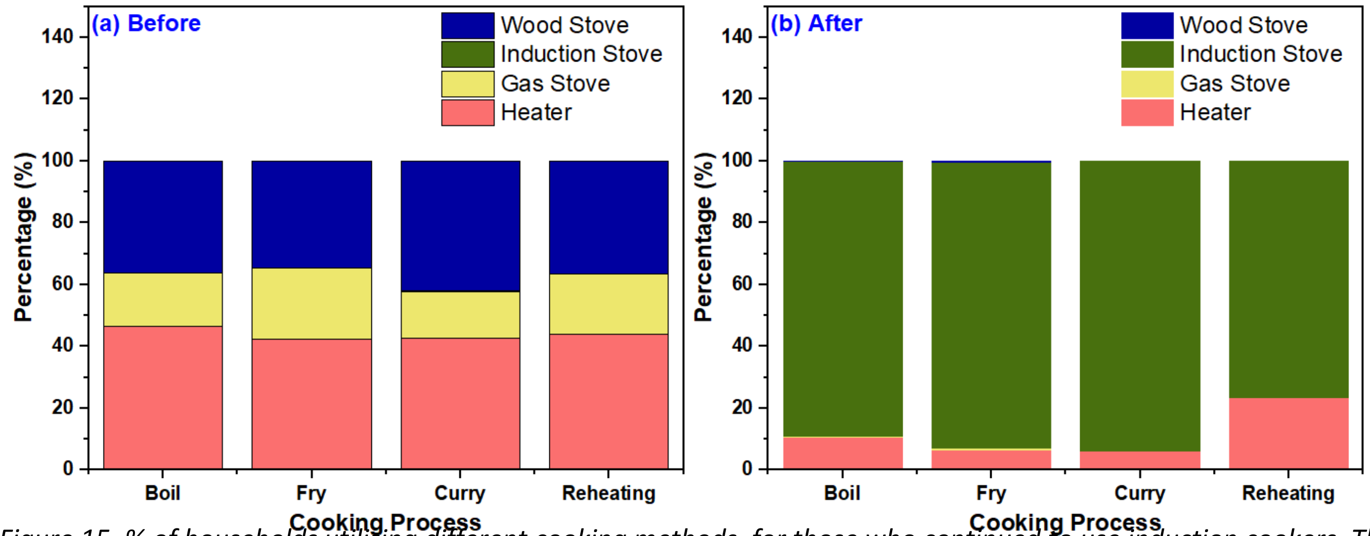


Figure 15. % of households utilising different cooking methods, for those who continued to use induction cookers. The plots show a substantial conversion to induction cooking across all cooking methods. Before has an N value of 60 and after N value of 47.

One of the stated intentions of the project is to understand something of the barriers to uptake of induction cooking from the perspective of the users. First and foremost, among these has been the ability or willingness to pay for the additional cooking utensils needed to use the induction cooker for the purpose of frying food. This point has been raised on multiple occasions in both the food diaries and in association with the community workshops. However, an initial analysis of the socio-economic survey outputs against those that remain and cease using induction cookers show that there are perhaps some additional factors that influence dropout rates. Figure 15 provides a plot of the proportion of dominant cooking types in those that remain using induction cooking (in) and those that chose to stop using it (out). The number of houses involved is 60 with a N value of 31 (in) and 17 (out). As such these can only be interpreted as the initial results of a pilot or scoping study. There is a clear need to extend these numbers. There is a clear shift in the ratio between wood users and electric coil users with a higher proportion of coil users, or indeed a lower proportion of wood users among those that leave.

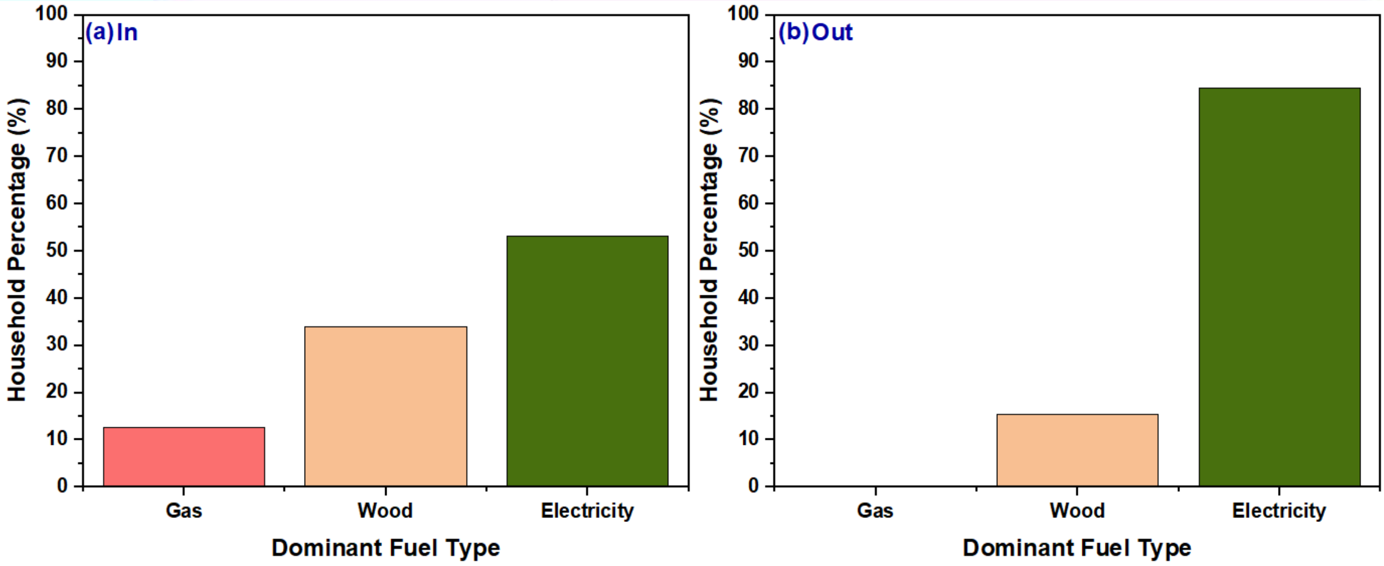


Figure 16. The proportion of users of different fuels that both remained (in, N=47) and stopped using (out N=13) the induction cookers. There is a clear shift in the ratio between wood and electric coil users in favor of coil users in those who dropped out. This can be seen as the result of both the proportional desire to remain using the induction cookers by wood users combined with a relative increase in heating coil users stopping using induction cookers.

An initial interpretation of this finding, based upon workshop findings and analysis of cooking device costs is that:

1) Wood users have more to gain from remaining in the process, with induction cooking substantially reducing issues of air quality and danger from burns. As such wood users are incentivised to remain using the induction cookers.
2) In the early stages of the process many users felt that induction cookers were not sufficient to cover all cooking requirements and thus alternative devices needed to be maintained. For wood and gas users this meant reverting to these methods when required. Indeed, one of the attractions of wood to the poorest sections of the community is the possibility to purchase small, quantities of wood for daily use. As such, when accounting for the flat rate charge of the induction cooker this added an occasional additional cost burden to the user. However, a heating coil is also charged at a flat rate regardless of its use and consequently users who might wish to maintain both will effectively be charged at the full rate twice over. This highlights issues with the payment method (flat rate) imposed on electrical cooking devices by the management committee, something which reduces flexibility in cooking methods. This issue was anticipated to decline as users became more familiar with the full capabilities of induction cooking and felt able to relinquish the coil.
3) If coil users were inclined to keep both systems of cooking (both coil and induction), then one reported issue was the requirement for payment to be made to two differing suppliers.

Likewise, Figure 17 goes on to provide a plot of the proportion (%) of households that both remained and dropped out from use of induction cookers, against their socio-economic categories. The plot demonstrates, perhaps counter intuitively, that there is a somewhat higher proportion of those leaving the use of induction cookers (out) who are in the less poor category than the poorest category itself. Once again this is thought to reflect the proportional increased loss of heating coil users who opted out earlier in the process. The coil users can be identified from the socio-economic survey as being broadly less poor than the wood users, as we might expect.

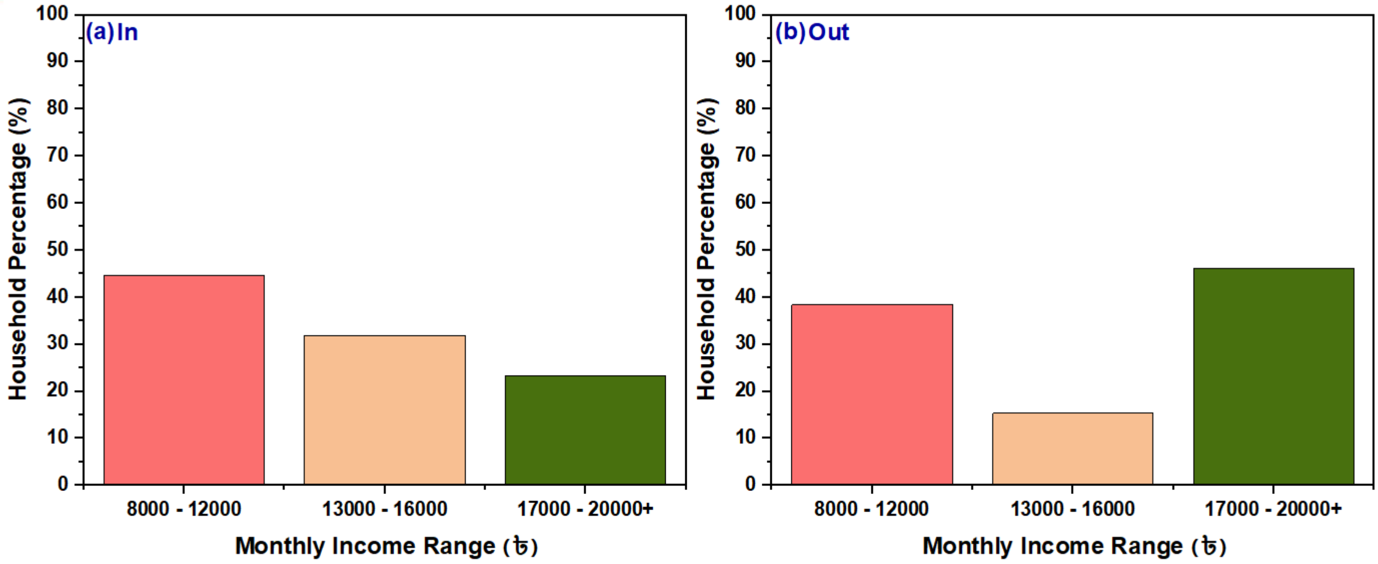


Figure 17. Monthly income range for those that remained using the induction cooker (in N= 47) and those that stop utilising the induction cooker (out N= 13). This has been interpreted as being linked to the loss of coil users and higher proportional retention of wood users (see Figure 16).

A critical factor in the assessment of any technological uptake is the potential for raising awareness and building an effective knowledge base in target users. The proportion of users who remained using the induction cookers and those that stopped using is represented by educational level in Figure 18. There is a small but clear shift toward illiterate users leaving the process. This may suggest that those who could not read were in some way disadvantaged in the process of building user confidence in the use of induction cooking. Indeed, part of that process was based upon the use of written materials (supported by workshops and verbal support) and this may account for the difference.

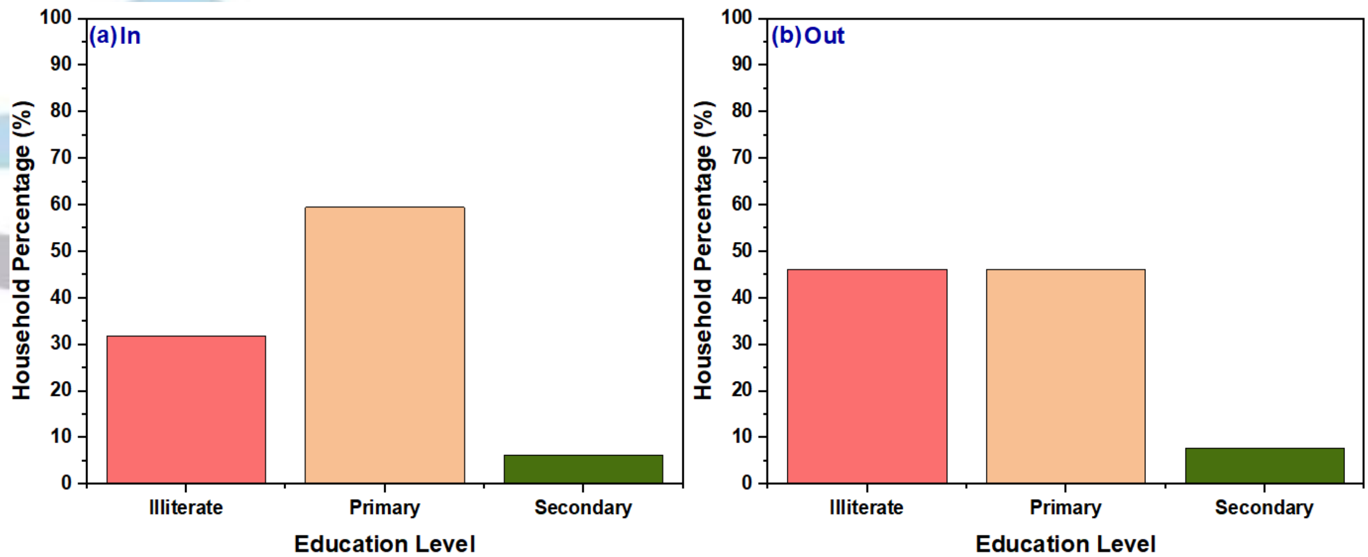


Figure 18. Identification of the educational status ratios of those who choice to remain using the induction cooker and those that choose not to do so. It inferred that those who are unable to read are placed at a disadvantage and as such are more likely to withdraw from the process.

Clearly these results cannot be considered statistically significant in anyway. However, they do offer initial hypotheses that might be tested in a broader household survey across larger numbers or with follow-up individual semi-structured interviews.

Energy monitoring

Energy monitors were placed within the PV system, grid connection and with each e-cooker. This helped establish energy consumption from electric cooking, power generated from PV system, and finally the grid usage. The data was collected form 1st of April until the 31st of July. Typically, according to weather data these months have the highest level of irradiance and therefore the highest power generation output. With a daily average of 53 KWh a total of 6352 KWh was generated over the duration. On average, 1590 KWh was generated in the month of April from the PV system. The average user consumption during this month was approximately 1.36 KWh with a daily maximum of 5.62 KWh. Approximate daily energy consumption was around 58 KWh. Therefore, in the presence of energy storage, only 5 KWh would be required via the grid, saving about 92% of the cost incurred to the government due to informal tapping of the electrical grid. Out of all the users, wood users on average used induction cookers the most. This change was anticipated because induction cooking is uncomfortable owing to the significant health risk and exposure to smoke. Due to the potential of shock and sparks, coil heater users had the second-highest average consumption. However, compared to wood and coil heaters, since gas stoves emit comparatively less smoke and do not pose a substantial health risk the transition was less noticeable. The data obtained from the energy monitors is presented below in Tables 6 and 7. A comparison of energy consumption based on predominant fuel use prior to induction cookers indicates that wood users utilised induction cooking up to 70% more than that of coil heater and gas users.

Total	6352	KWh
Daily Average	53	KWh

Table 6. PV Generation (18.5KWp System): Data for 1st April to 31st July

Dominant Fuel Type Pre-Pilot	Daily Average (KWh)	Daily Max (KWh)
All Users (100%)	2.30	5.62
Wood (47%)	2.97	5.2
Coil (47%)	1.75	5.62
Gas (6%)	1.29	1.3

Table 7. Demand load of induction cookers in month of April

Financial Mechanisms

During the community workshops, estimations of monthly costs for electric, gas based and wood-based cooking were identified. The rates were:

Type	Cost
Electric	৳ 700 pm
Gas	৳ 1800 pm
Wood	৳ 700 pm

Table 8. Monthly average expenditure on cooking fuel

The price of ৳ 450 pm is set as the PV cost to be reflective of the assumed price point that could be achieved in a large PV slum-based system. This is being paid by the 60 HH users to the local community suppliers within the slum management group.

Equipment	Cost
Induction Cooker	3000 – 4000 ৳
Induction Pan	1000 ৳
Coil Heater	100 – 200 ৳
Coil Heater Pan	200 ৳

Table 9. Current market capital costs of e-cooking between coils and induction cookstoves

An induction cooking set is around ten times more expensive than a coil heater set. With the lower cost of PV, even with the coil heater it would take about a year for it to break and become economically viable. This is a long process and is not the best option because most slum dwellers are low-income with less ability to cover the high initial investment. Furthermore, lack of formal electricity supply has led to mixed electricity suppliers in some households and the suppliers refuse to cut the electric heater line. Therefore, users would need to pay both electric heater and induction cooker bills which is not affordable for the users. As a result, in such a scenario it is difficult for solar to compete against electric coil heaters. However, several households have demonstrated a strong interest in the long-term advantages. Five households have purchased and are already utilising their own induction cooking pans in addition to the pan supplied as part of the pilot. Nevertheless, with awareness, well layout initiative and a subsidy to help cover the initial cost a transition to solar power and induction cooking is possible. This is further aided by the fact that the current gird power supply cost at 13 ৳ per KWh is approximately three times as that of a large scale optimized solar PV system at 4 – 5 ৳ per KWh.

Respiratory Health

Based on a combination of responses from the household survey, the workshop discussions, as well as the air quality sensing monitoring, some aspects of users' respiratory health in regard to clean cooking can be discussed. Almost two thirds of the questionnaire respondents had experienced problems with cooking, the major effects being related to respiratory tract irritation and eye irritation. Certainly, coughing, breathing issues, and eye irritation are commonly reported effects of exposure to air pollution. Most respondents believed that cooking with smoke causes the reported symptoms, and a sizeable minority reported cough and breathing problems. In terms of affecting health, it's clear that respondents understood effects on the respiratory system and eye symptoms, along with headaches, mirroring the reports of these symptoms earlier.

The pre-pilot workshop showed similar results and displayed a greater range of health concerns associated with cooking over wood rather than gas and electric coil. Notably, the risks associated with these latter two were more about the safety of the devices themselves, rather than the concerns regarding wood stoves, which related to the symptoms of exposure from wood smoke, so it is clearly appreciated that (1) emissions from wood burning are driving those effects, but (2) there are concerns regarding use of other cooking methods which need to be addressed. There were also reports that children suffer most from these effects, although groups also generally reported increased effects in the elderly. This mirrors much of the research, which generally shows that effects of air pollution are greatest amongst the young and the old. It is worth considering, however, that the reported increased suffering of children and the elderly might be down to increased susceptibility, increased exposure, or a combination of the two. A noteworthy response from questions about other forms of exposure was that where (male) members of the household smoke, they were reported as leaving the house to do so. This might imply an understanding that a build-up of pollutants indoors is to be avoided, and also further implies that there might be a desire to reduce emissions from cooking indoors where possible (assuming that it is not feasible to simply move the cooking apparatus outside). A range of airway/lung diseases were reported, although it is not clear the extent to which these might result from cookstove exposures. However, the literature strongly suggests that such diseases can be exacerbated by exposure to air pollution, and therefore exposure mitigation may be especially important for such individuals. Furthermore, there are clearly associated financial costs of treating these conditions, and therefore if management was aided by reduced exposure to indoor emissions, there may be a financial benefit through reduced need for such medication.

Focusing on the sensor data (Figure 19 and 20), it is clear that there is a much greater concentration spike for wood than induction (PM2.5 peaks around 1000 $\mu g/m^3$, vs around 210 $\mu g/m^3$ for wood and induction, respectively). There is clearly some increase for induction – this might simply relate to steam or the cooking method itself (cooking at temperature will itself generate PM, whatever the source of the heat and additionally increase the humidity leading to overestimation of the PM2.5 – Bhadura et al. *Journal of Sensors 2018*. If we assume that the induction use represents the emissions from the food, then cooking with wood might increase PM2.5 emissions by around 900$\mu g/m^3$ (this likely comes mainly from the wood itself, although a portion might also come from the food if cooking with wood results in differential emissions, e.g. because it provides more heat). Another thing to bear in mind here is the decay rate of the spike – looking at sensor 5 (bottom right), from the peak of 1000 $\mu g/m^3$ at around 8am, it takes around 2h to for this to return to baseline. It is harder to make out peaks with the induction users, but clearly when you turn an induction hob off, the source of heat is gone, whereas the same is not true when you have finishing cooking on wood (unless you douse the flames with water). So not only does the fuel source provide a greater level of PM2.5 emissions, but these may be expected to persist for a lot longer after cooking is finished.

Clearly, 24h average exposures to PM2.5 are greater for wood cooking than induction cooking. The fact that differences of ~2-5 fold can be induced by relatively short-lived activities underlines the difference in PM2.5 emissions from the two respective sources. It should be noted that the WHO has recently revised its guideline PM2.5 average down to 5ug/m3, and certainly there is evidence for health effects of exposure to PM below even the lowest concentration on the induction graphs. The emphasis here however remains the significant difference in the peaks and the average values between wood-based and induction-based cooking.

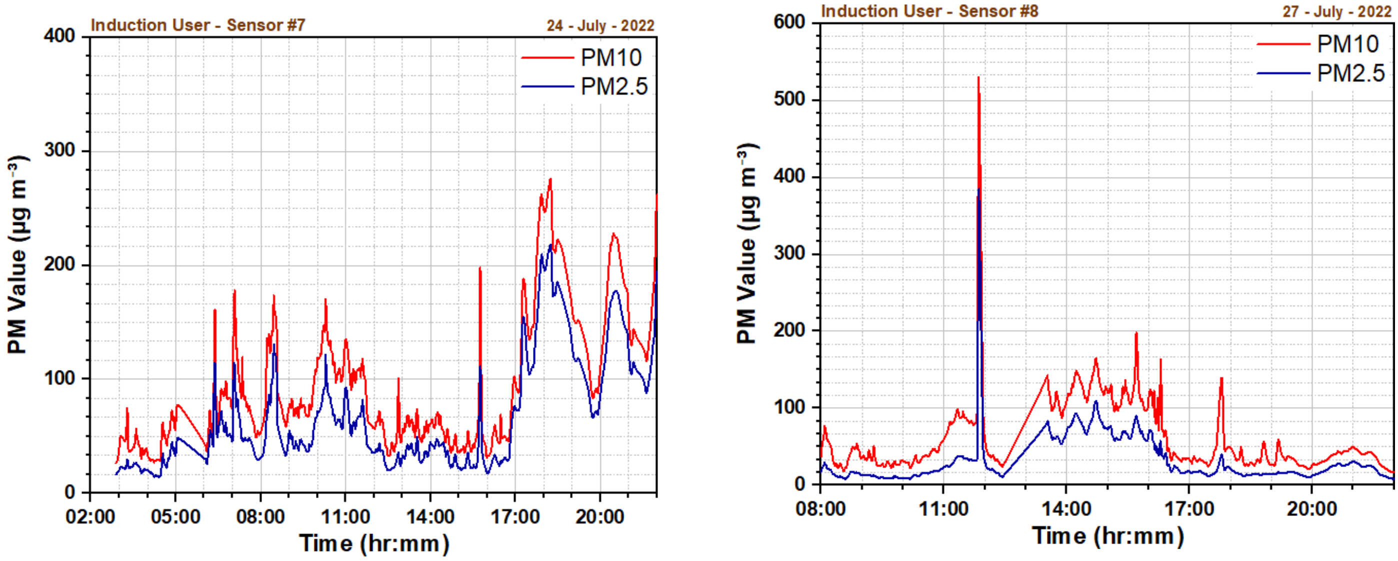


Figure 19. PM2.5 measurements over a 24 hour period for two different HHS with induction-based cook stoves.

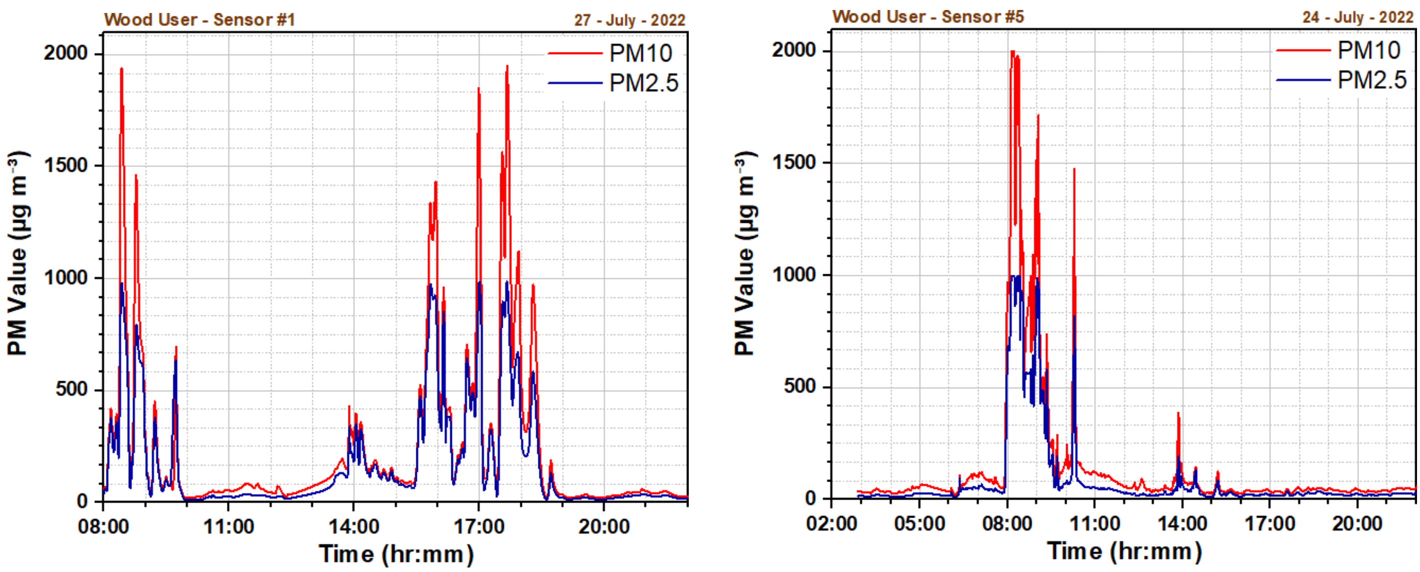


Figure 20. PM2.5 measurements over a 24 hour period for two different HHS with wood-based cook stoves.

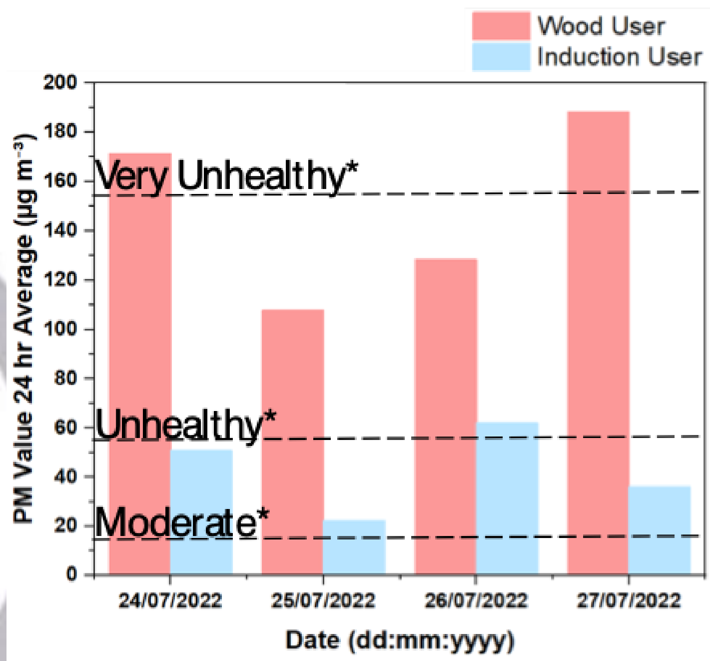


Figure 21. Air Quality index difference between wood-based cooking and induction cooking. It shows a shift from very unhealthy exposure to moderate, which is the baseline for Dhaka. Here, very unhealthy refers to mass concentration above 155 µg/m^3, unhealthy: 55 < x <155µg/m^3 and moderate is the background yearly average mass concentration.

Scaling up electric cooking

Community perspective: HH surveys, and workshops with HHS, the Slum Management group, and stakeholders, it is likely that electric cooking is likely to occur. With gas prices rising in the country, a desire to move away from biomass is clear. Challenges of scaling up electric cooking are:

- An unwillingness to change cooking habits.
- The unaffordable price of e-cooker.
- Load shedding frequency.
- Community conflicts.

Stakeholder perspective: SREDA will be key to scale up electric cooking, as they are leading both the clean cooking and renewable energy policy changes within Bangladesh. Action points to scale up electric cooking in Bangladesh include:

- An analysis of research findings and identification of prospects and barriers.
- The strengthening and mobilization of SREDA through knowledge sharing and dissemination.
- The Slum Management Committee can also be a key stakeholder if the project is to be scaled up in other zones of Bhashantek low-income community.
- Behavior change counselling sessions for educating beneficiaries for raising awareness towards modern cooking systems.

Social inclusion

The Bhashantek slum is home to a diverse but universally community who are living in poor conditions. There is indeed some differentiation in the level of poverty but those living in this slum setting can all rightfully be considered vulnerable. However, the small differences in income do allow for a range of fuel sources to be utilised with an associated variance in risk of the prevailing health issues associated with burning wood for cooking. The poorest in the community almost exclusively utilise wood, with the relatively better off utilising gas or electric in their fuel stacking. As such the focus on the substitution of wood fuel with induction cookers addresses the most vulnerable within the community. Furthermore, the work conducted in Bhashantek is almost exclusively aimed at women, who can be identified as a vulnerable group within the community in their own right, as evidenced by their lack of representation in both community leadership and income generation.

Gender Context: Potential gendered impacts of uptake

The study is centered almost exclusively upon girls and women and their role in the choice, utilisation and perceptions of cooking fuel types in the selected case study slum. Most of the cooking activity is conducted by women and girls and as such the focus of the workshop activity has fallen exclusively upon women. It should be noted that gender refers to the role of both men and women and indeed some of the comments recorded on behalf of women relating to the men of their family. However, this focus on women is simply because it is women who are the most substantially impacted by those choices.

Whilst we often refer to women in the role of cooking it should be noted that girls from the age of 14 can be expected to contribute or lead the household cooking. Indeed, young girls will be in positions of support with their mother from very young ages. Figure 22 demonstrates the age range of women and girls who participated in the introduction of induction cookers. This ranges from as young as 14 to 69. The graph actually shows that of those who started using induction cookers it was disproportionately the younger women and girls who ceased to use them. This is perhaps best explained by the fact that it is coil users who predominantly leave the use of induction cookers (see key results) and that these users are known to be younger and indeed less poor as they are of prime working age and able to afford heating coils.

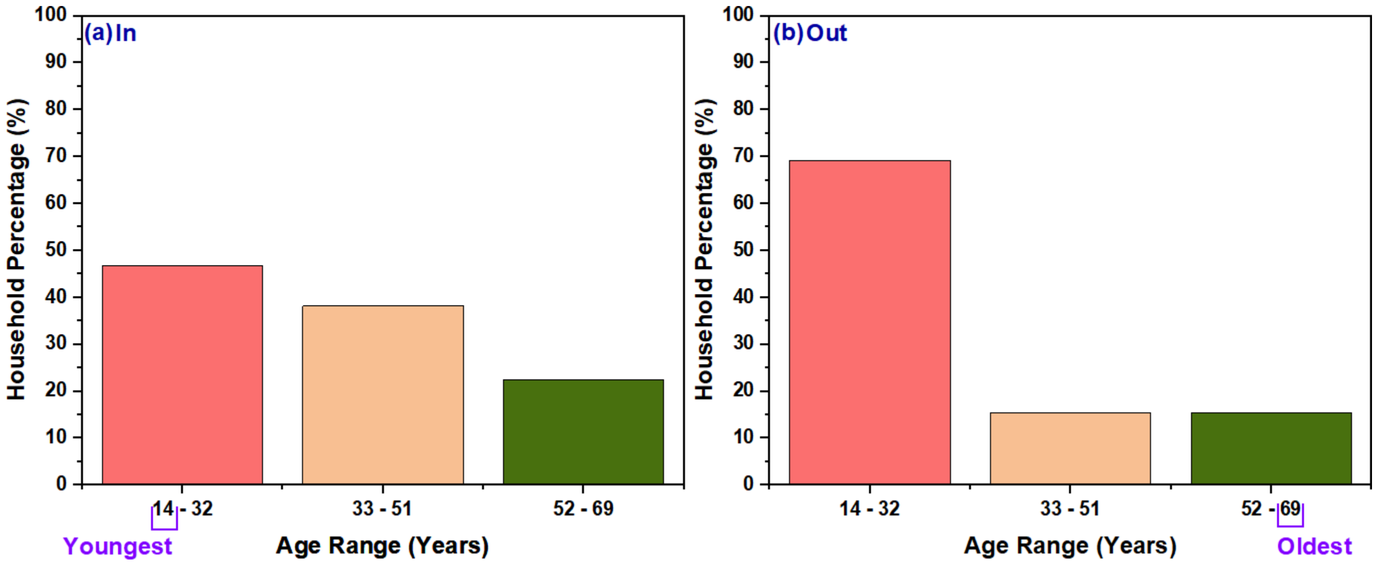


Figure 22. Age range of girls and women that remain using induction cookers (in) and those that opted to leave (out). The greater proportion of younger girls and women leaving is thought to be associated with more coil users leaving and this group tending to be younger.

Community workshops allow for the identification of an individual's comments (anonymised) to be examined in terms of how they relate to gender and gendered issues. These are:

- The occurrence of the negative health impacts identified in the workshop, such as respiratory issues, burns, eye/skin irritation, which are predominantly visited upon women, girls and young children. This is the key issue in regard to women's experience of cooking, particularly when cooking indoors and with wood. Women and girls who assist their elders have little or no option but to be exposed to the smoke associated with cooking. The preponderance of comments raised in the workshops regarding wood relate to the health impacts.
- Women are required to organise and access cooking fuel as well as feed and support their family and as such none of those surveyed questioned this arrangement. It was simply accepted that this is a role for women in the household.
- One key issue raised was in regard to time taken for cooking depending upon the method used. Electrical cooking devices including induction cooking offer not only a healthier approach but saved time. When asked about what women and girls might do with that time they identified opportunities to i) socialise, ii) do sewing (to make additional money), iii) conduct housework, and iv) care for and educate children.
- Associated socializing whilst cooking. It should be noted that whilst cooking activities place a burden almost exclusively on women there is also opportunity for social interaction that is valued by many women. Higher safety regulations and safer environment allows women to communicate more often whilst cooking as compared to when cooking utilizing firewood-based stoves. The opportunity for exchange of information associated with a shared activity can be fundamental in developing social bonds, joint learning and developing joint approaches to problem solving.
- Women have the sole responsibility for children which places a great deal of responsibility on them as protectors, educators and providers of food and support. Cooking and its outputs are both practical requirements but also clear demonstrations of care and support for children. Access, utility and affordability of cooking approaches, without compromising the health of those cooking and the children in their care, is a fundamental component of the lives of these women as evidenced by the frequency that children get mentioned in the community workshops.
- There is a recognition that some men spent their days in crowded, polluted and dangerous workshop or

factory settings that are considered akin to those issues experienced by women cooking in poor conditions.

- The women in community workshops identified smoke from cooking as a cause of conflict and social friction with neighbours. Again, this is a burden solely carried by women and can undermine social coherence and cooperation in such a close-knit community.

Conclusion

The project consisted of three phases: a pre-pilot, pilot and post-pilot. The pre-pilot consisted of identifying the appropriate slum for the research, based on a number of criteria such as proximity to Dhaka city, a predominant usage of biomass for cooking and an effective system of internal governance within the slum to ensure security for the project and potential for community ownership, as well as feasibility of PV installation. As a result of these considerations, Bhashantek slum in the Mirpur area was selected. Following this, an extensive household survey was undertaken to gain a better understanding of cooking behaviours, socio-economic background and the health of those concerned. This was followed by a community workshop involving the 60 households chosen for the pilot, the purpose of which was to gain insight into preferences for fuel types used for cooking as well as health-related issues caused by these fuels. Then, over the period of a month, cooking diaries were compiled, the purpose of which was to gain understanding of the types of dishes cooked by participants, the times cooking took place, the fuel used and with whom such cooking was undertaken. A safety manual for the use of induction cookers was provided, along with a four-day training period to enable users to learn how to use these cookers safely and effectively. The solar PV plant was inaugurated, and the e-cookers were distributed.

During the actual pilot period itself, users had six weeks exposure to the new e-cookers. User experiences were recorded in a second set of cooking diaries. From a technical point of view, PV generation and e-cooker load were both monitored as was air quality sensing. During the post-pilot period, a second community workshop was held in order to ascertain how impressions and perceptions of e-cookers had altered and consider the benefits and barriers to their use.

The slum its very densely populated and 95% of households have been present there since 1974. Most properties are tin-shed and lack clean cooking facilities, relying instead on wood burners and electric coil heaters. Most households comprised two to four adults and two children. During cooking, many people report headaches, coughs, problems with eyes as well as the ever-present risk of electric shocks. On average, two meals were prepared daily with cooking times generally falling between 05.00 and 07.00 for breakfast, 11.00 and 13.00 for lunch and 19.00 and 21.00 for dinner. In some houses, an extra meal was prepared between 17.00 and 19.00. The general pattern of cooking indicated boiled food was prepared for breakfast, fried food for lunch and reheated food for dinner. The most frequently prepared dishes were rice lentils, fish or chicken curry and vegetables. Wood was the preferred type of fuel use because it was thought to improve the taste of the dishes prepared and it is regarded as a convenient, readily available, reliable, affordable and diverse form of fuel. However, there are a number of negative effects associated with it such as respiratory issues, threat of fire, overheating during summer and social tension provoked by smoke invading neighbouring spaces. Similar findings were reported for gas although this was considered more expensive and due to the risk of explosion, was less popular. Coil heaters provide a popular alternative because they are initially less expensive, healthier (due to lack of smoke emissions) and versatile (due to their ability to cook all dishes). However, because of their reliance on electricity, they are vulnerable to load shedding and blackouts and can only cook a relatively small amount of food at a time and, because of their open design, are more prone to sparks and electric shock.

Around 75% (N:60) of targeted beneficiaries are using induction cookers. The remaining 25% do not due to issues of inferior food tase, capital cost and, in a small number of cases, participants moving away from the area. In comparison to other means of cooking, induction cooking requires a significant capital outlay and is sensitive to load shedding. In terms of health, however, it is the superior option since it emits no smoke and poses no health risks from fire or electric shock.

There was a distinct shift in the proportion of wood users taking up induction cooking as opposed to electric coil users, with a higher proportion of coil users amongst those who left. In terms of socio-economic circumstances contrary to initial expectations, individuals leaving the usage of induction cookers were more likely to be in the less-poor category rather than the poorest. This is thought to represent that fact that coils are charge at a flat rate by the community management as were induction cookers. Thus, where households did not feel comfortable yet in relying wholly on induction and wanted to keep a backup, this became particularly expensive. This was not such an issue for wood users. There was also a slight but noticeable trend away from the process by less educated consumers. This could indicate that those who cannot read were disadvantaged in the process.

Average daily energy use was roughly 58 KWh, the majority of which was supplied by the PV system and only the excess 5 KWh supplied by the grid, saving the government approximately 92% of the cost incurred due to informal grid tapping. Induction cookers were used the most by those who were previously wood users. This shift was expected as wood cooking has a number of unpleasant side effects, particularly in regard to health. An induction cooker set is roughly ten times more expensive than a coil cooking set. Due to the large initial investment, as well as the requirement of maintaining two connections in certain houses, solar energy powered induction cooking has key economic barriers in the short term. However, at 13 ৳ per KWh the current grid power supply cost is roughly three times that of a large scale optimal solar PV system at 4 – 5 ৳ for the levelized cost of electricity, making it a lucrative alternative.

The following table summarizes the key focal points:

Table 10. Summary of key focal points from the project including barriers, positives, and discussion points going forward.

Barriers	Positives +	Going Forward
PV systems • Lack of policy and infrastructure for formal PV installation in informal settlement • Local electric supply line upgrade • Lack of storage to support load shedding **Induction cooking** • Upfront Cost – cooker and additional pans • Susceptible to Load shedding • Competing with Coil (double connection) • Lack of awareness • Taste Fixed rate charging of electricity based on appliance, and is not dependent on fuel consumption	**PV Systems** • Legal electricity supply • Provide grid reinforcement for low voltage issues • Reduce overall cost of e-cooking than pure grid connection • Prevent overloading of local grid when cooking • Promote renewable energy and future RE hubs for local consumption **Induction Cooking** • Air Quality Index – shift from unhealthy to moderate • Noticeable throughout community, leads to increased engagement! • At high power – able to cook quickly and variety of foods • Reduced cooking time for users (women), increased productivity • Safe	**Policy –** • legal/formal utility connections? • Encouraging market growth of e-cookers through subsidy or tax **National Campaigning** Awareness of health benefits of e-cooking **Training on e-cooking** Distribution of cookbooks and training sessions **Prefeasibility** Survey community to understand current social context and fuel diversity (transfer barrier)

Future Work

Future work will focus on knowledge-sharing and dissemination with clear pathways to implementation through policy stakeholder uptake. This will involve further funding proposals.

The results of this project will be useful for vulnerable communities across the country. People who are unaware of the negative impacts of traditional cooking approaches will shift towards an energy-efficient cooking approach. Policy influencers will also get an insight on how the National Action Plan for Clean Cooking (NAPCC) can be catered towards marginalised communities who are mostly affected by energy security and associated respiratory problems from cooking activities.

Next Steps:

a) Further Funding:
   - Application to UK Aid/UKRI funding for development of a full mini-grid for induction cooking
   - Longer term approach to global climate funds for larger substantial applications for PV in urban slums
   - Utilising current site for longer term study in habits and behaviour

b) Transferability
   The issues of slum energy supply and its current association with health and environmental issues is well established in all growing Asian cities. Mumbai, Kolkata, Kathmandu, Karachi, to name but a few, are cities where many of the lessons learned from such work, particularly in association with high levels of migration, high density living and substantive poverty and vulnerability, would be readily transferable.

c) Socio-Economic areas for research:
   - Informal settlements are dominated by community management groups which charge monthly flat rates for electrical cooking devices, irrespective of their usage. This tends to preclude the poorest community members who often are not financially stable enough to be able to fund a monthly bill, preferring instead to pay for wood on a daily basis. This is compounded by the fact that women who do the cooking do not usually have access to money yet are responsible for all duties related to feeding the family. We want to research how financial payment schemes, subsidies and business models can be developed that might simulate this flexibility in electrical cooking and encourage adoption in the poorest sectors.
   - How can financial payment schemes, subsidies and business models be developed that might simulate the flexibility provided by electric cooking and thus encourage its adoption?
   - Gender is a critical issue with induction cooking offering. Associated areas of importance include i) substantive reduction in smoke inhalation for exposed women, young girls assisting in cooking, young children and expectant mothers; ii) real reduction in fire and burn hazard and iii) the time required for utilisation by women in other productive activities such as education, small scale business activities, WASH and childcare. This might include:
     - Development of women-lead cooperatives and CBO to raise awareness and effectively utilise and maximise the benefits of induction cooking. Building community champions.
     - There are currently 60 households, so expansion in baseline numbers of women is a priority.
     - Longitudinal studies. How will the uptake, awareness and utilisation vary with tie and socio-cultural context. What are the gendered impacts of the uptake over time?
     - It was noted that illiteracy might have had an impact on the take up of induction cooking. This needs to be explored further to see if better modes of training, raising of awareness and capacity-building can be identified that do not disadvantage those women that have not been given the opportunity to learn to read.

- Consideration of the socio-economic impact of induction cookers on women. Induction cookers also free up time for other productive activities such as WASH, childcare, education and small-scale business activities.

- The development of women-lead cooperatives and CBO to support the raising of awareness as well as to effectively utilise and maximise the benefits of induction cooking. How will uptake, awareness and utilisation vary with technology and socio-cultural context? What are the gendered impacts of uptake over time?

- During the project, it was noted that illiteracy might have impacted the uptake of induction cooking. Will better modes of training, raising of awareness and capacity building positively impact those who have not had the opportunity to learn to read.

d) Technical areas for research:

- What are the technical challenges in upscaling PV to support stabilisation of grid network on larger scales? This will involve dedicated support staff and an appropriate business model.
- What would be the impact of improved and more-relevant policies as well as formal utility connections?
- The development of an extensive IoT network.

e) Health areas for research

- What are the patterns of respiratory exposure for differing groups associated with cooking in informal settlements? There needs to be a specific focus on exposed women, young girls assisting in cooking, young children and expectant mothers, birth outcomes each of which is linked to specific respiratory vulnerabilities. This is particularly true of young children and expectant mothers where early exposure leads to disproportionally high negative medical impacts.