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Cardio-respiratory health of women exposed to household air pollution in rural Nepal:

A propensity score matched cross-sectional comparative study among

traditional stove users and biogas users

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Preface

This thesis is subdivided into six chapters presented in order for their flow. In the first chapter, I provide an overview of the research topic focusing on the situation in Nepal, the rationale for this study and the specific aims and objectives. In the second chapter, I discuss the burden of household air pollution (HAP) in the global context and introduce major health effects of HAP including on lung function, chronic airway disease and cardiovascular health. I also discuss the global evidence base with respect to the suitability and effectiveness of interventions to reduce HAP and conclude with a review of exposure assessment methods used in HAP studies. In the third chapter, I describe the study design, data collection methods and the strategy for statistical analysis, including a detailed description of propensity score matching of households and women within households for specific outcome measures. Chapter 4 presents the results of the study, focusing on the matched analysis and highlighting differences with an unmatched sensitivity analysis, each with and without adjustment for potential confounders. Chapter 5 discusses the results of the current study and compares and contrasts the findings with related research findings in the field. Chapter 6 summarizes key findings and concludes with a review of their significance, limitations and suggestion for future research.

Abstract

Introduction: Globally, millions of deaths every year are attributed to household air pollution (HAP) caused by health-damaging pollutants produced while cooking in inefficient open firewood stoves under poorly ventilated conditions. These are mostly in low-and middle-income countries where cooking with solid fuel is nearly ubiquitous in rural areas. Women, by customary socio-cultural beliefs, spend significant amount of their time cooking and are disproportionately exposed to high levels of toxic pollutants like particulate matter, carbon monoxide and several other partially carcinogenic, organic and inorganic, compounds.

Strong evidence has consistently linked HAP to adverse health conditions like acute lower respiratory tract infection in children, and chronic obstructive pulmonary disease and lung cancer in adults. With better exposure response evidence and more diseases like ischemic heart disease and stroke now causally linked to HAP, it is identified as the second most important risk factor for females for global disease burden out of those examined by the Global Burden of Disease 2010 project. In South Asia, including Nepal, it is the leading risk factor for both sexes for disability adjusted life years lost.

Over recent years, global concerted efforts have been trying to address this problem through large scale initiatives to deliver improved firewood cookstoves to rural households who are inextricably trapped on the lowest rung of energy ladder. However, the nonlinear character of the exposure response analyses of health effects of HAP indicates the need to reduce HAP to a very low level so as to gain substantial health benefits. But, evidence is limited if the currently promoted cookstoves are reducing pollutant levels to the desired optimum so as to avoid health risks in a meaningful way. Therefore, a switch to clean fuels appears to be the only way to meet WHO Air Quality Guidelines.

In rural Nepal, around 0.3 million households have adopted biogas fuel plants which operate through anaerobic digestion of biodegradable human and animal waste to produce clean gaseous fuel. However, to date neither the impact of this program on pollutants nor its impact on health has been examined in Nepal or globally.

Materials and methods: This study was designed to explore if the adoption and sustained use of biogas by households impacts pollution levels and cardio-respiratory health of the cooks compared to households that have continued to use traditional firewood stoves.

Specifically, it was hypothesized that the sustained use of biogas for at least ten years would be associated with better lung function, reduced risk of airflow obstruction, lower systolic and diastolic blood pressure and a reduced risk of hypertension among adult female cooks.

Direct interviews regarding health and cooking practices and measurement of kitchen and ventilation parameters were conducted in 219 biogas- and 300 wood-using households from four rural villages located away from industrial and traffic related exhaust fumes. Outcome measures like 24 hour kitchen concentrations of carbon monoxide, forced expiratory volume in one second, airway obstruction as diagnosed by values below the lower limit of normal using Global Lung Initiative Equation 2012 and additionally by FEV1/FVC cut-off of 0.7 and high blood pressure as average readings more than 140/90 mmHg were defined *a priori* using standard guidelines. Data were analyzed using a combination of propensity score matching (PSM) of women and households and statistical regression modelling to account for confounding. An unmatched sensitivity analysis was carried out for each outcome.

Results: With the use of PSM and regression adjustment, results of this study show that sustained use of biogas is significantly associated with 77% lower 24 hour kitchen concentrations of carbon monoxide (20.1 ppm in firewood- vs. 4.6 ppm in biogas-using households). Biogas use was also significantly associated with 123 ml [95% confidence interval (CI), 11 ml to 236 ml] greater forced expiratory volume in one second (FEV1) after adjusting for smoking, kitchen and ventilation characteristics, and additional fuel use when compared to age, height and socio-economic score matched groups of firewood users. Similarly, the odds of developing airway obstruction (diagnosed by the lower limit of normal criteria using Global Lung Initiative equation-2012) among cooks using biogas was reduced by 65% [Odds ratio (OR) =0.35, 95% CI (0.16 to 0.46)].

After matching and adjustment for smoking, kitchen characteristics, ventilation and additional fuel use, the use of biogas was also associated with 9.8 mmHg lower systolic blood pressure [95% CI, -20.4 to 0.8] and 6.5 mmHg lower diastolic blood pressure (95% CI, -12.2 to -0.8) compared to firewood users among women > 50 years of age. In this age group, biogas use was also associated with 68% reduced odds [OR= 0.32 (95% CI, 0.14 to 0.71)] of developing hypertension. These effects, however, were not identified in younger women aged 30-50 years.

Conclusions: Findings from this study suggest that switching from traditional firewood to clean biogas fuel and its sustained use is likely to result in an overall health advantage likely achieved by the reduced concentrations of kitchen pollutants. However, owing to the cross sectional nature of this study, health improvements cannot be attributed to biogas use with certainty. Exposure-response analysis would have further strengthened our study; nevertheless, current findings suggest that household biogas plants could be an alternative energy source to improve the cardio-respiratory health of millions of cooks who are exposed to HAP globally.

Abbreviations

AEPC	Alternative Energy Promotion Centre
ALRI	Acute lower respiratory tract infection
ATS	American Thoracic Society
BP	Blood pressure
BSP	Biogas Support Program
CI	Confidence interval
CO	Carbon monoxide
CoHb	Carboxy-haemoglobin
COPD	Chronic obstructive pulmonary disease
CVD	Cardiovascular disease
DALYs	Disability adjusted life years
DBP	Diastolic blood pressure
DHS	Demographic and Health Survey
DOHS	Department of Health Services
ERS	European Respiratory Society
FEV1	Forced expiratory volume in one second
FVC	Forced vital capacity
GACC	Global Alliance for Clean Cookstoves
GBD	Global Burden of Disease
GLI	Global Lung Function Initiative
GOLD	Global Initiative for Chronic Obstructive Lung Disease
HAP	Household air pollution
HTN	Hypertension

ICS	Improved cooking stoves
IHD	Ischemic heart disease
IHME	Institute for Health Metrics and Evaluation
LBW	Low birth weight
LLN	Lower limit of normal
LPG	Liquefied petroleum gas
MEF2575	Mid forced expiratory flow rate
MoHP	Ministry of Health and Population
NLSS	Nepal Living Standard Survey
OR	Odds ratio
OxyHb	Oxy-haemoglobin
PEF	Peak expiratory flow rate
PM	Particulate matter
PM10	Particulate matter of less than 10 microns diameter
PM2.5	Particulate matter of less than 2.5 microns diameter
PS	Propensity score
PSM	Propensity score matching
RCT	Randomized controlled trial
SBP	Systolic blood pressure
SES	Socio-economic status
SHS	Second-hand smoke
SSE	Socio-economic status
VDC	Village Development Committee
WHO	World Health Organization
zFEV1	z score of forced expiratory volume in one second

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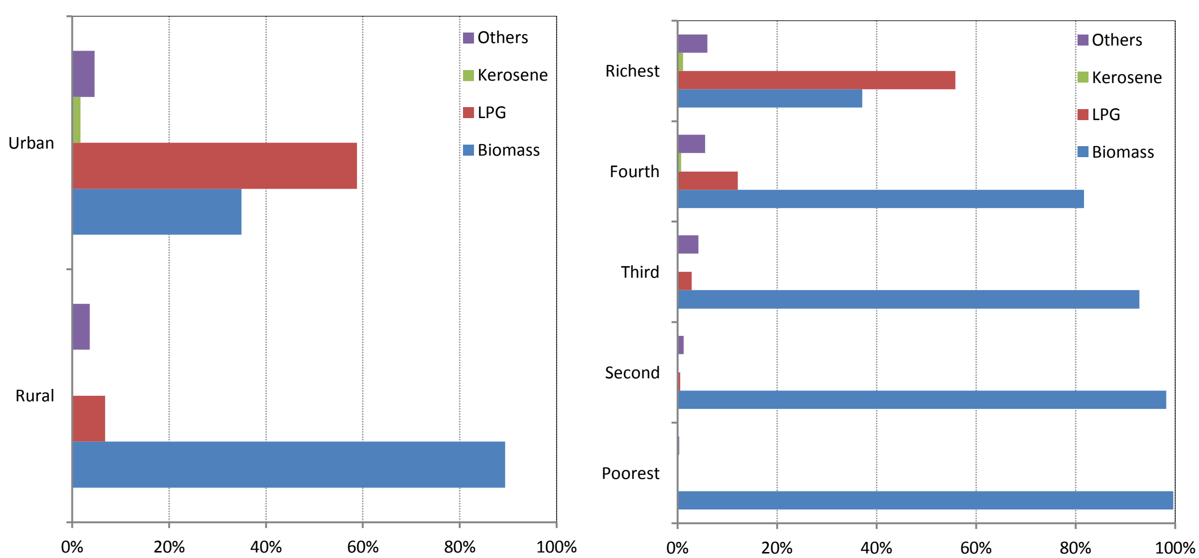
1 Introduction

1.1 Reliance on biomass fuels and household air pollution in Nepal

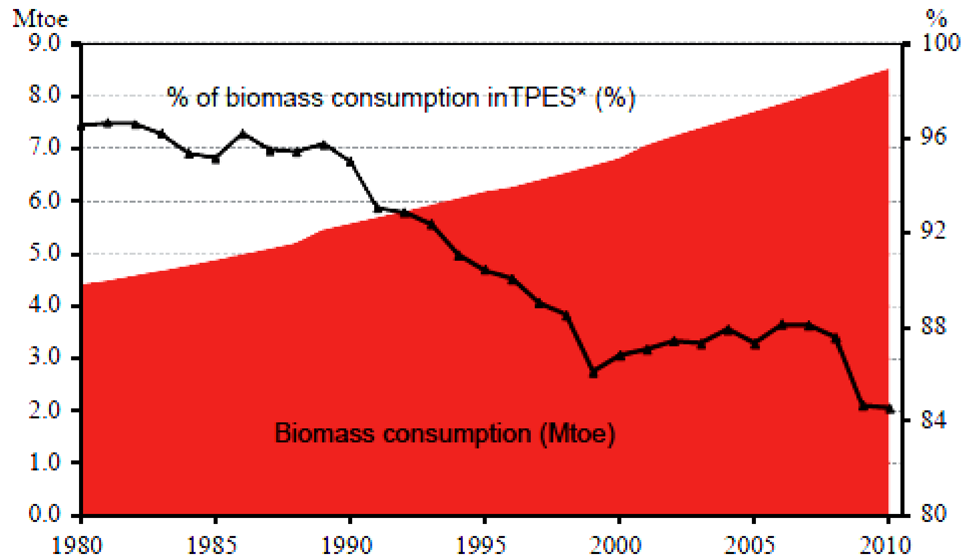
Nepal continues to suffer from one of the highest energy poverties in the world with the majority of its people deprived of even basic clean cooking fuel and access to modern energy options. Seventy five percent of its households are bound to using traditional biomass fuels (wood, dung and agricultural residues) for cooking, (CBS, 2012a) while sadly, only less than 2% of its feasible hydroelectricity potential has been exploited until now. (NEA, 2013) In the rural villages which constitute 83% of the population, the situation is worse and more than 85% of households are reliant on biomass fuels burnt invariably on inefficient open-fire stoves. The poorest quintile is so destitute that virtually all of them are on this lowest rung of the energy ladder (**Figure 1.1**). (CBS, 2011a)

Figure 1.1: Primary household fuel use in urban and rural Nepal and by wealth quintiles (CBS, 2011a, CBS, 2012a)



Around 90% of the total energy demand of the country is consumed at the household level (Parajuli, 2011), primarily for cooking human and animal feed or heating the house. This is mostly fulfilled by biomass, largely firewood. Although the proportion of biomass fuel consumption has seen a declining trend as shown in **Figure 1.2**, the absolute quantity of biomass use has been escalating over the last three decades. This is expected to rise further in the nearby future (Malla, 2013), particularly if other alternative and sustainable energy sources are not developed e.g. solar, wind, biogas and others.

Figure 1.2: Primary solid biomass consumption in Nepal. Note: TPES is total primary energy supply. Reprinted from Energy Policy, (Malla, 2013) with permissions from Elsevier



As a non-fossil renewable energy source biomass fuels are considered carbon-neutral and not inherently dirty. But, these fuels are often burnt in inefficient open stoves inside poorly ventilated houses where they undergo incomplete combustion and produce a complex mixture containing hundreds of pollutants, including fine particulate matter (PM), carbon monoxide (CO) and a broad range of partially carcinogenic compounds. (Rehfuess, 2006) These health-damaging pollutants are emitted at concentrations between those of active and passive smoking and spread in and around the home and the neighbourhood causing household air pollution (HAP). (Bonjour et al., 2013)

Several studies have reported household members chronically exposed to very high levels of HAP due to burning of biomass inside kitchens in rural Nepal. (Devakumar et al., 2014, Kurmi et al., 2013, Singh et al., 2012) These are well above the World Health Organization (WHO) air quality guidelines which recommend that the 24h average PM2.5 (PM of less than 2.5 microns aerodynamic diameter) exposure should not exceed 25µg/m^3 while the 24h CO exposure should be below 7mg/m^3 (~6.11ppm). (WHO, 2010) Women who largely for cultural reasons are responsible for cooking and spend most of their time indoors are disproportionately affected by this with peak respirable particulate levels at times reaching as much as 60 000 µg/m^3 inside the kitchen. (Devakumar et al., 2014) Besides the health damaging effects of smoke, women lose significant time in collecting firewood, which also exposes them to risks of injuries and violence. Spending many hours a day cooking on inefficient stoves, and having to scrub clean the cooking pots and clothes soiled with black soot adds to a reduced quality of life for the female population.

1.2 Health effects of household air pollution in Nepal

Household air pollution is a major cause of poor health in developing countries. These pollutants, even at a low concentration, can inflict health damage in multiple ways. (Smith et al., 2010) Strong evidence has consistently linked HAP to conditions like acute lower respiratory tract infections (ALRI) in children (Dherani et al., 2008) chronic obstructive pulmonary disease (COPD) (Kurmi et al., 2010) and lung cancer (Hosgood et al., 2011) among adults. Although two studies have linked HAP exposure to the risk of high blood pressure (McCracken et al., 2007, Baumgartner et al., 2011), evidence linking HAP to cardiovascular disease (CVD) is recent and is inferential and based on similar physical characteristics of the particulates from different sources ranging from ambient air pollution to active and passive smoking. (Smith et al., 2014) Additional evidence also supports an association of HAP and tuberculosis (Lin et al., 2007), cataract (Pokhrel et al., 2005), low birth weight (Pope et al., 2010), and risks of burns, scalds and injury and violence during fuel collection (Rehfuess, 2006).

Out of the several risk factors examined by the Global Burden of Disease study 2010, HAP accounts for the biggest share of the disease burden in Nepal with 19 500 deaths and around 7.5% of all disability-adjusted life years (DALYs) attributed to this risk factor. (IHME, 2013b) ALRI, 38% of which is attributed to HAP in the South-East Asian Region including Nepal (Niessen et al., 2009), is reported to be the leading cause of premature death (IHME, 2013a) especially among children under five years of age. In one of the rural Nepalese districts, where children are exposed to the effects of HAP from birth, HAP was estimated to cause around 50% of ALRI among children under five years of age. (Dhimal et al., 2010) In adults, HAP is mainly responsible for chronic lung diseases like COPD, lung cancer and cardiovascular disease. (Smith et al., 2014) In one of the earliest studies linking HAP exposure to poor health, Pandey reported 18-30% prevalence of chronic bronchitis among those exposed to biomass smoke in different villages of Nepal. (Pandey, 1984b) A recent study demonstrated a high percentage (27%) of airway obstruction among adults, who were all non-smokers, but showed long-term exposure to domestic biomass smoke and lived in traditional houses in one of the mountainous villages. (Mandolesi et al., 2011) The risk of airway obstruction, even in late-teenagers, was found to be twice as high in the Nepalese population exposed to biomass smoke compared to clean fuel users. (Kurmi et al., 2013) HAP contributes significantly to the Nepalese disease burden where more than a quarter of the country's population suffer from some sort of chronic cardiopulmonary disease and 13% have some respiratory disease alone. (CBS, 2011a). Studies conducted in Nepal have further identified HAP from biomass fuel combustion to be a risk factor for developing tuberculosis (Pokhrel et al., 2010) and cataract (Pokhrel et al., 2005). Although most of these health effects of HAP are due to chronic exposure, acute exposure in those with pre-existing airway disease may lead to impaired gas exchange and acute cardiopulmonary decompensation. (Kurmi et al., 2011)

1.3 Interventions to reduce household air pollution in Nepal

Global efforts have identified two main strategies to reduce HAP exposure: switching to clean fuels or using cleaner-burning, more efficient cookstoves. These strategies should be supported by improving the kitchen ventilation or changing the cooking behaviour. (Semple et al., 2014, Smith et al., 2010) In Nepal, programs at national and local level are in place promoting improved cooking stoves (ICS), smoke hoods, biogas, liquefied petroleum gas (LPG) and ethanol to combat HAP. A government body called Alternative Energy Promotion Centre (AEPC) has been acting as the focal point to promote alternative and renewable energy solutions including the dissemination of clean cooking options since 1996. (AEPC, 2103) On 20th January 2013, the government further announced an ambitious program of 'Clean Cooking Solutions for all by 2017'. (Rai, 2013)

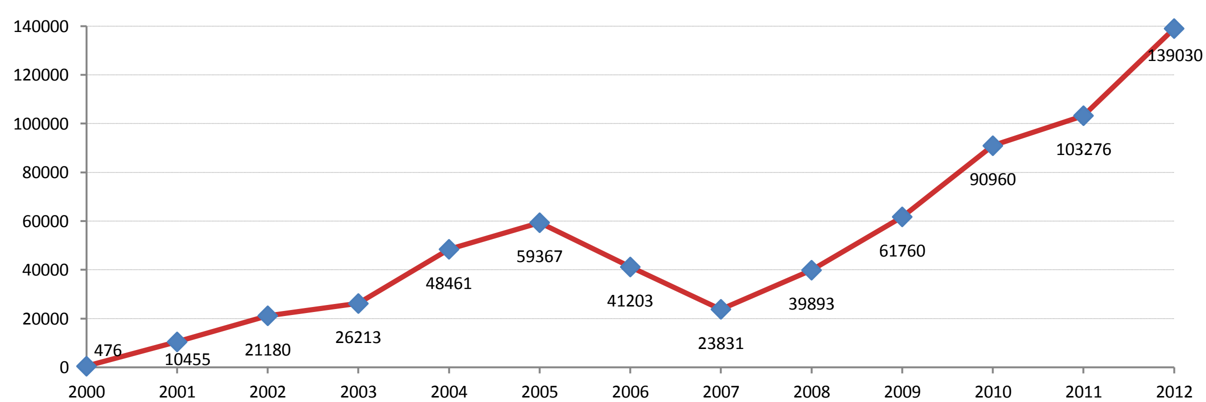
Subsequently, a Nepal Alliance for Clean Cookstoves, a public-private collaboration platform to coordinate the concerted efforts of all the partners to achieve this strategy has also been launched and is hosted by AEPC. (AEPC, 2013c) This alliance promotes all renewable clean cooking technologies, excluding fossil fuels like LPG and kerosene. Therefore, the current approach is twofold: to promote the use of different kinds of ICS, along with ventilation improvement through kitchen management strategies, among the poorest households, and to help with switching to clean fuels among better-off households who can afford it. But, when the choice of energy usage is also influenced by socio-cultural belief and not by socio-economic status alone, moving up the energy ladder is challenging. Indeed, it has been observed that people continue stacking multiple fuels and stove types in the process. This argues for further educational and awareness initiatives as well as policy and program incentives to promote the sustained use of cleaner fuels and stoves. (Rehfuess et al., 2014)

1.3.1 Improved cooking stove interventions in Nepal

The country saw the first ICS models distributed in the 1950s, but dissemination remained stagnant for many decades. Subsequent initiative from the Community Forest Development Program promoted prefabricated ceramic stoves and this was primarily driven to reduce firewood consumption and prevent deforestation. However, these stoves proved inappropriate as they often broke down during transport and as their free distribution did not impart any ownership to their users. Later, the 7th national government plan (1985-90) formally incorporated the need for wide dissemination of ICS in the country. Over the years, several cookstove designs have evolved under different programs of AEPC. The most commonly used are mud-brick types, which are simple, cheap and assembled using local resources. More heat-efficient metal stoves are also available but are more expensive limiting their installation to only around 10 000 households in the high hills. (AEPC, 2013b)

Around 715 000 households have installed mud type ICS, with or without chimney, throughout the country and their installation has seen a rising trend over the last decade as shown in **Figure 1.3.** However, the current trend cannot meet the national target to provide clean cooking solutions for all by 2017, so installation of ICS would have to skyrocket in the coming years or other clean cooking solutions would also need to be promoted aggressively. Moreover, many households adopting these ICS continue burning biomass fuels simultaneously in traditional stoves to meet different cooking needs like preparing animal feed or boiling water and brewing alcohol.

Figure 1.3: Installations per year of improved cooking stoves in Nepal. (Source: AEPC)



Although the installation of ICS has been increasing, only a few studies have studied the effectiveness of these interventions in terms of reductions in HAP and their performance over a long time. A before-and-after intervention design with improved mud brick cook stoves in Nepal found more than 60% reductions in PM2.5 and CO concentrations but the lower limits were still higher than the WHO cut-offs. (Singh et al., 2012) Metal smoke hoods, promoted by Practical Action Nepal, were reported to reduce concentrations of kitchen pollutants by 82% and firewood consumption by 30%. (Practical Action, 2013) Besides the reduction in firewood consumption, these ICS have shown to significantly decrease the time spent on cooking and promote better health of the cooks and families. However, a lot of these ICS in Nepal, if used and maintained properly, are only capable to reduce a part of immediate personal exposure or they vent some smoke to the near outdoors and contribute to poor outdoor air quality of the neighbourhood. This limited effectiveness of ICS in Nepal is also mirrored by the global evidence base which paints a difficult picture (refer to section 2.8).

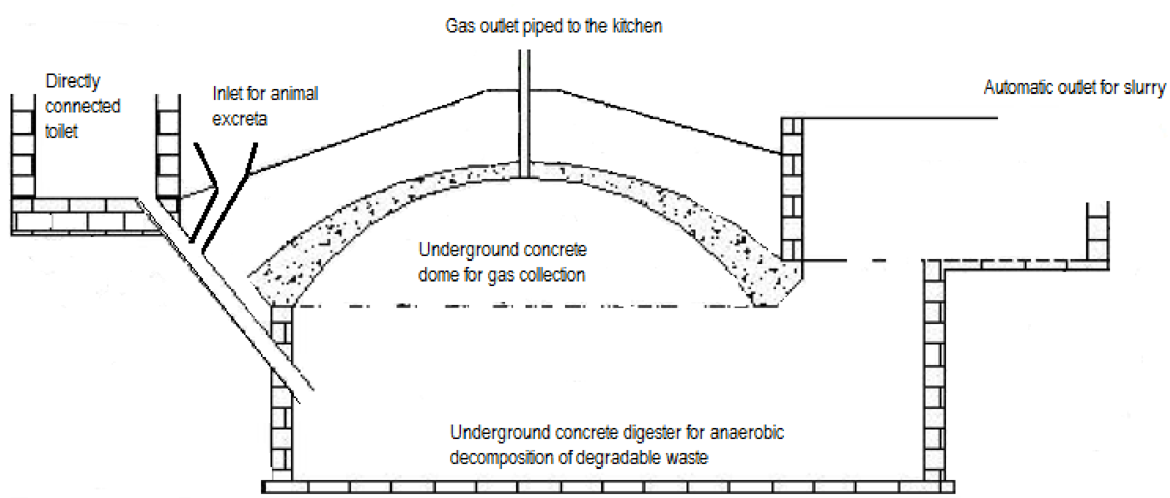
1.3.2 Cleaner fuel interventions in Nepal

Since the effectiveness of currently available ICS in reducing HAP exposure is limited, a switch to clean fuels up to the next rung of the energy ladder appears to be the only way to meet WHO Air Quality Guideline limits. Also, in terms of providing cooking fuels, the eventual goal of any country should be to provide its people with clean cooking energies without any pollution hazard and resultant damage to health. This is ideally achieved by electrification (with electricity not only used for lighting but also for cooking) but due to significant infrastructure development needs and the large costs to households, electrification is unrealistic in countries like Nepal, at least in the near future. Thus, feasible clean cooking renewable options currently promoted in Nepal are biogas, wind power, solar cookers and community electrification through micro hydropower. As of the most recent census, roughly 1.28 million households use some kind of clean fuel like biogas, LPG and electricity. (CBS, 2012a) However, switching to these clean fuels remains a farfetched goal for the poorest households. Among the rural households, who depend on subsistence farming and animal rearing, the potential for household biogas development which operates through degradable animal and plant waste remains extensive and this is being materialized by the Biogas Support Program of Nepal (BSP).

1.3.3 Household biogas interventions in Nepal

Biogas is a unique biomass-based gaseous fuel produced through anaerobic digestion by methanogenic bacteria. Organic human and animal wastes are decomposed inside locally made underground digesters as shown in **Figure 1.4**, under anaerobic conditions generating biogas, composed primarily of methane. (Dhingra et al., 2011) Methane, thus produced in the digester is piped to the kitchen for cooking or heating where it burns with a smokeless clear blue flame and is considered non-toxic. While biogas plants primarily rely on cattle dung as the raw material, human excreta from the toilet can also be channelled into the digester; in this way, an important aspect of sanitation is also addressed. In a study by Smith et al. (2000b) in India, biogas was strikingly superior among all the tested stove-fuel combinations: the carbon monoxide (CO) emission factor for biogas was lower than for LPG, and so were the corrected total suspended particles. Biogas is therefore attractive because of its potential for multiple health benefits and in terms of being both a renewable and carbon-neutral fuel.

Figure 1.4: Schematic of household biogas digester. (Adapted from AEPC report and modified for simplicity)



One of the schools in Kathmandu valley introduced the first biogas digester of the country in 1955. 20 years later - in 1975/76 - the Department of Agriculture launched the first household biogas promotion program. (NBPA, 2014) Subsequent contributions from the United Mission to Nepal, Gober Gas Company (GGC) and the Agricultural Development Bank Nepal sustained the fledgling biogas programme through technology development, promotion and subsidy schemes. (NBPA, 2014) After various research and development activities, the GGC2047 model, the popular fixed dome digester, was approved in 1992.

The same year, with support from the Netherlands Development Organisation, the Biogas Support Programme of Nepal was established. (BSP-Nepal, 2012)

The BSP was established to promote the large-scale use of biogas as a substitute for biomass fuels and kerosene used for cooking and lighting in rural Nepalese households. (BSP-Nepal, 2012) From 1997, the German and Nepali governments through the AEPC also started supporting the BSP with technical and financial support. Since its inception the BSP has been committed to developing and disseminating biogas plants as mainstream renewable energy solutions in rural Nepal; the program is now greatly expanded to all 75 districts covering 2800 village development committees. (BSP-Nepal, 2012) It has been an exemplary public-private partnership and is an international household energy project co-funded with carbon credits under the Clean Development Mechanism. Around 300 000 plants have been installed all over the country and the trend has been increasing. (AEPC, 2013a) With the subsidy from the government and the microfinance loan, more than 15,000 new plants are being installed annually. (BSP-Nepal, 2012)

There are no clear-cut studies reporting the factors that determine the adoption of biogas plant among the households in Nepal, although a global systematic review has recently been published (Puzzolo et al., 2013). However, the Biogas User's Survey of Nepal designed for other purposes concluded that the shortage of firewood was the prime reason for adoption and use of biogas. The time saved during cooking and cleaning utensils, and the increased price of the conventional modern energy sources, such as LPG, are some of the other reasons cited for the installation and use of biogas for the majority of households. On the other hand, a high upfront investment deters households from adoption although subsidy and micro finance schemes help to reduce this challenge. (Alternative Energy Promotion Centre, 2010)

1.4 Rationale for the study

Although there has been wide adoption of biogas plants throughout the country for more than two decades, only the social, environmental and economic impacts of the program have been evaluated until now. To date, no studies in Nepal or elsewhere have assessed whether there is an actual reduction in the concentrations of health-relevant pollutants when switching from biomass to biogas use. Health impact assessments have been restricted to self-reported respiratory symptoms but any measurable health changes have not been quantified until now to the best of our knowledge. (Semple et al., 2014) Therefore, the likely exposure reductions and associated health benefits when switching to biogas can only be estimated through comparisons with the impacts of switching to ICS. The high-quality '*plancha*' stove, an improved woodstove with a chimney, used in the seminal RESPIRE trial in Guatemala, the first cookstove randomized trial, achieved reductions in personal exposure to CO by 50% in infants (Smith et al., 2010) and it was associated with an 18% reduction in the relative risk of physician-diagnosed pneumonia. (Smith et al., 2011) However, in adult female cooks, a 60% reduction in personal CO exposure and 90% reduction in kitchen CO exposure was not associated with significant gains in lung functions after 1.5 years of follow-up. (Smith-Sivertsen et al., 2009) This suggests that the chronic effect of HAP exposure on lung function may not revert immediately, but that it could rather take as long as a decade to detect an unequivocal effect on the prevalence of obstructive airway disease, as also advocated by a previous retrospective cohort study that used chimney stoves in China. (Chapman et al., 2005)

1.5 Aims and objectives

The main aim of this study is thus to quantify the concentrations of CO and PM2.5 in households that primarily use biogas for cooking and to analyze their association with respiratory function, prevalence of obstructive airway disease, cardiovascular and respiratory symptoms compared to those households that primarily use firewood for cooking. We also aim to explore if there are differences in blood pressure, resting heart rate and blood oxygen saturation following the adoption and sustained use of biogas plants for at least 10 years. In this way, we aim to evaluate the health impacts of the BSP in terms of reductions in key health-relevant pollutants and in terms of cardiopulmonary health benefit.

Specifically we will address the following research questions:

Main questions:

- Does the installation and sustained use of household biogas plants result in reduced kitchen concentrations of PM2.5 and CO?
- Does the installation and sustained use of household biogas plants for ten years result in improved cardiopulmonary function among women?
- Can kitchen concentrations of PM2.5 and CO be linked to cardiopulmonary function among women?

Sub-questions:

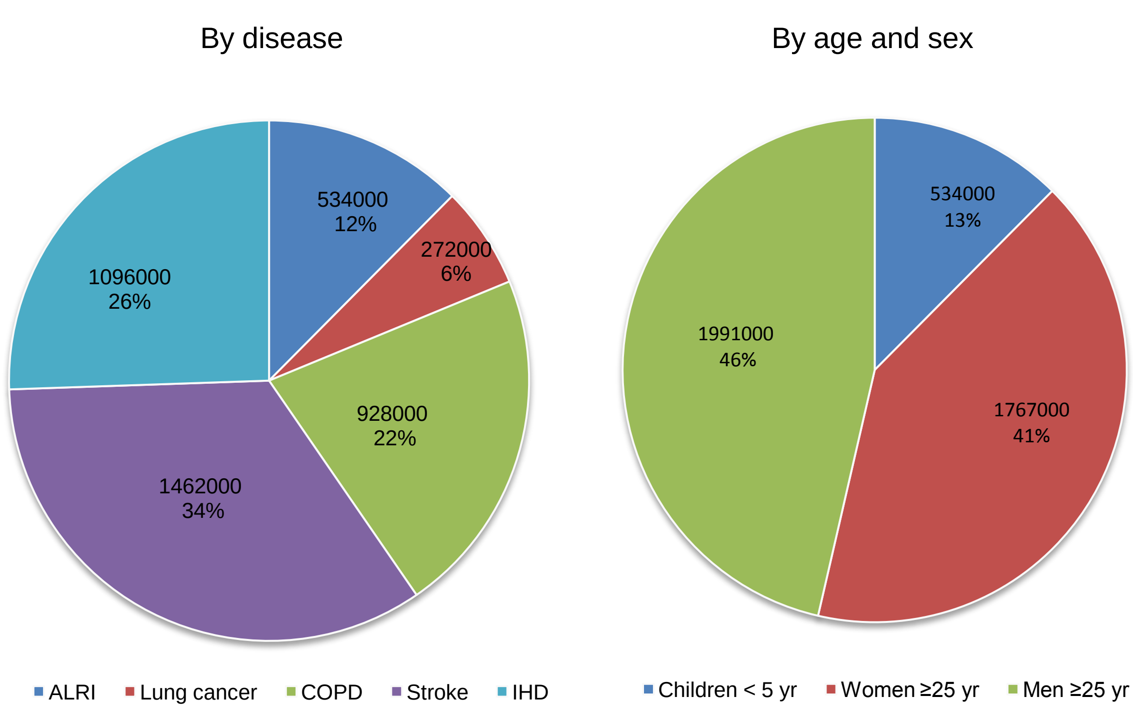
- To what extent has the BSP had an impact on the prevalence of respiratory symptoms among women?
- What are the factors determining household adoption of biogas plants?

2 Literature review

2.1 Global burden of household air pollution

Although the world has seen a decreasing trend, from 62% in 1980 to 41% in 2010, of proportion of people cooking with solid fuels (biomass and coal) over the past three decades, the absolute number has remained stable at around 2.8 billion due to population growth. (Bonjour et al., 2013) On the contrary, deaths attributed to household air pollution has more than doubled from 2 million in 2004 (attributed to solid fuel use) to 4.3 million in 2012. However, this massive increase is due to the change in the methodology adopted in the risk assessment and the inclusion of additional health outcomes in the recent estimates.(WHO, 2009, WHO, 2014) **Figure 2.1** displays the deaths attributable to HAP in 2012 by disease, and age and sex. Almost all of these deaths were in low- and middle-income countries where more than 90% of people in the rural areas cook with solid fuels in unvented stoves. The poorest are the ones who are hardest hit by this burden as poverty is inextricably linked to the vicious cycle of reliance on solid fuel use and restricted economic development. (Bruce et al., 2006).

Figure 2.1: Deaths attributable to household air pollution in 2012, source: WHO (2014)



With better exposure response evidence and more diseases now causally linked to HAP, it is identified as the second most important risk factor for females for global disease burden out of those examined by the Global Burden of Disease (GBD) 2010 project. In South Asia, including Nepal, it is the leading risk factor for both sexes. (Lim et al., 2012) Women and girls receive the highest exposure to HAP as they spend significant times cooking for their family. However, because of higher rates of background diseases in men, mostly due to high smoking prevalence among them, absolute number of deaths attributed to HAP is more in case of men than women although women are more susceptible and are exposed to higher risks.

2.2 Concentrations of household air pollutants and its exposure

As briefly introduced in **section 1.1**, burning of solid fuels in open fires and unvented stoves produces several harmful pollutants, including different sizes of particulate matter, carbon monoxide, sulphur oxides, nitrogen dioxides, aldehydes, benzene, polyaromatic compounds, heavy metals like arsenic and fluorine (in case of coal burning) and free radicals. (Smith, 1987, Naeher et al., 2007, WHO, 2006) All of these have health damaging potential including the polyaromatic compounds which are mutagenic or carcinogenic. (Wornat et al., 2001). Other ill effects are mediated through inflammation, immune suppression, mucociliary dysfunction, and severe irritation. (Naeher et al., 2007) Children and women from the poorest rural areas are exposed to very high levels of such harmful pollutants daily. A large household survey in India measured 163 $\mu g/m^3$ of daily PM2.5 in living areas and 609 $\mu g/m^3$ in the kitchen. National averages extrapolated from these household figures were 113 $\mu g/m^3$ in the living area and 450 $\mu g/m^3$ in the kitchen. (Balakrishnan et al., 2013) Based on the same survey, women were estimated to be exposed to 337 $\mu g/m^3$, children (under the age of five years) to 285 $\mu g/m^3$ and men to 204 $\mu g/m^3$ of PM2.5 daily. (Smith et al., 2014) These concentrations are at least hundred folds higher than the WHO air quality guidelines (24 hour PM2.5 of 25 $\mu g/m^3$ and annual mean of 10 $\mu g/m^3$) and still far beyond the WHO interim target I (24 hour PM2.5 of 75 $\mu g/m^3$ and annual mean of 35 $\mu g/m^3$). (WHO, 2010) Several other studies have measured HAP exposures in households and other microenvironments globally and these are essentially in the ranges reported in India or higher with age, gender, and socioeconomic differences influencing the exposure.

2.3 Health damaging potential of household air pollution

2.3.1 Particulate matter

Particles are the most health-damaging component of solid-fuel smoke. (Smith, 1987) They are a complex mixture of microscopic solid and liquid particles-both organic and inorganic and primarily composed of, but not limited to, sulphate, nitrates, ammonia, black carbon, metals, soil, dust particles and water. They are of different sizes and their ability to damage health depends on the sizes that one is exposed to. Besides the size, several other factors including the number of particles, solubility and composition of particles (either hygroscopic or hydrophobic), surface area of particles and even the breathing rate, physical activity and lung volume and lung morphology of an individual influence the deposition of particles inside the lungs. (Carvalho et al., 2011, van Rijt et al., 2014, Londahl et al., 2012) Particulate matters of or less than 10 microns (PM10) in diameter are essentially the ones that are inhalable and travel deep into the lungs, those larger than 10 microns are deposited in the oropharyngeal region. Fine particles which are below 2.5 microns in diameter can travel to the bloodstream and cause systemic inflammatory oxidative stress. This oxidative stress remains central to the patho-physiology of adverse respiratory and cardiovascular health. (Brook et al., 2010) Exposures to PM have shown the potential to impair alveolar macrophage immune response thereby increasing susceptibility to pulmonary infections. (Sawyer et al., 2010, Pope III and Dockery, 2006)

The large Framingham offspring cohort study demonstrated 20 ml lower lung function after previous-day exposure to a “moderate” range of ambient PM2.5 classified as per the U.S. Environmental Protection Agency (EPA) index. (Rice et al., 2013) Acute exposures to PM are associated with aggravation of heart and lung diseases, e.g. COPD exacerbations (Ling and van Eeden, 2009), oxygen de-saturation and cardiac decompensation (Kurmi et al., 2011). All of these acute events have the potential to cause premature deaths. Long term chronic PM2.5 exposure contributes to the development of chronic diseases like COPD (Ling and van Eeden, 2009) and can reduce life expectancy (Brook et al., 2010). Additionally, it is reported that long term exposure to PM2.5, from ambient sources, was associated with an increased incidence of acute myocardial infarction. (Madrigano et al., 2013)

2.3.2 Carbon monoxide

Carbon monoxide (CO) is produced in abundance during incomplete combustion of solid fuels. It is a colourless and odourless toxic gas easily absorbed into circulation through pulmonary bed after inhalation. (Raub, 1999) It has a strong affinity to haemoglobin, more than 200 times that of oxygen, so that oxygen cannot compete to bind with haemoglobin. This impairs oxygen transport and delivery and leads to tissue and cellular hypoxia. (Ernst and Zibrak, 1998, Prockop and Chichkova, 2007) Health damaging effects, mostly to the brain and heart, are mediated by tissue hypoxia or direct cyto-toxicity. (Somogyi et al., 1981)

Although symptoms are non specific, headache is the most common one observed with both acute and chronic exposure. Other associated symptoms could be nausea, vomiting, dizziness, confusion, shortness of breath, visual changes, and loss of consciousness or death. Those with pre-existing conditions, especially of heart and lung, might manifest these symptoms even at mild levels of CO. (Prockop and Chichkova, 2007) Acute exposure to very high levels can be lethal. In developing countries including Nepal, burning of inefficient heating devices inside closed rooms during winter has resulted in accidental deaths when CO levels accumulate to a very high level thereby asphyxiating persons to sudden unconsciousness and death.

Chronic exposure to CO can cause neurobehavioral abnormalities, cognitive deficits and impaired short term memory. Of special importance in this regard is the effect on the developing foetus when the pregnant mother is exposed to chronic levels of CO. As CO has the potential to cross the placenta, it can accumulate and cause tissue hypoxia in the foetus which can lead to low birth weight, pre- and post- natal deaths, developmental disorders, and chronic cerebral conditions. This also exposes mothers to complications during delivery. (Raub et al., 2000)

2.4 An overview of health effects of household air pollution

As briefly discussed in **section 1.2,** several studies have identified household air pollution from solid fuel use as an important modifiable risk factor for acute and chronic health conditions in both children and adults. With firm evidence available, the latest WHO burden estimates for HAP incorporated diseases like ALRI under the age of five years, and COPD, lung cancer, ischemic heart disease (IHD), and stroke in adults.

2.4.1 Effects on foetus and children

Studies have established associations between household air pollution and pregnancy outcomes like still birth (Lakshmi et al., 2013, Pope et al., 2010) and low birth weight (Pope et al., 2010, Epstein et al., 2013, Boy et al., 2002) The systematic review by Pope et al found a 95.6 g (95% CI: 68.5 to 124.7) reduced mean birth weight associated with HAP exposure. (Pope et al., 2010) Although these associations are yet to be causally proven through longitudinal studies, the evidence is consistent across a broad range of settings and the mechanism cited is biologically plausible given that such effect is seen with active or passive smoking, which have characteristics similar to those of smoke from solid fuel use, except for nicotine. The carboxy-haemoglobin levels in cooks exposed to HAP are also comparable to those seen among active or passive smokers thereby further strengthening this link. (Behera et al., 1988)

Infants and young children who receive significant exposure to HAP while spending time with their mothers are at increased risks of ALRI. Studies conducted in different settings have consistently confirmed this link. (Dherani et al., 2008, Smith et al., 2011, Ezzati and Kammen, 2001) Considering that children are exposed to 285 $\mu g/m^3$ of daily PM2.5 based on Indian household survey estimates, the risk of ALRI in children <5 year ranged from 2 to 3.8 folds. (Smith et al., 2014) Although the mechanism by which HAP causes ALRI is not fully understood, it is hypothesized that immature lungs and an immature immune system during early childhood are particularly vulnerable to inflammatory insults induced by different HAP components leading to increased ALRI susceptibility. (Mishra, 2003, Smith et al., 2000a). Those who survive episodes of ALRI in early childhood are likely to have unhealthy lungs and impaired lung functions during adulthood (Lopez Bernal et al., 2013) making them susceptible to COPD when they continue being exposed to HAP.

Further explorations are needed however to sort out the conflicting association of HAP exposure and asthma in children in the context of studies identifying associations for (Wong et al., 2013, Trevor et al., 2014) and against (Po et al., 2011) it. The same holds true for the association of HAP with anaemia and stunting in children. (Mishra and Retherford, 2007, Samet and Tielsch, 2007, Machisa et al., 2013)

2.4.2 Effects on adults

In adults HAP is associated with various health risks as summarized in **Table 2.1**. These are based on systematic reviews and meta-analysis, as well as integrated response analysis conducted as part of the comparative risk assessment for the GBD 2010. (Smith et al., 2014, Lim et al., 2012).

Table 2.1: Summary of odds ratio of diseases associated with HAP based on systematic reviews, meta analysis and integrated exposure response function

Disease	Odds ratio with 95% confidence interval	
	Women > 15 year	Men > 15 year
COPD	2.30 (1.73 - 2.06)	1.90 (1.15 - 3.13)
Lung cancer- coal	1.98 (1.16 - 3.36)	1.31 (1.05 - 1.76)
Lung cancer- biomass	1.81 (1.07 - 3.06)	1.26 (1.04 - 1.52)
IHD	(1.4 - 2.2)	(1.4 - 2.2)
Stroke	(1.4 - 2.4)	(1.3 -2.4)
Cataracts	2.47 (1.63 - 3.73)	NA

Adapted from Smith et al. (2014)

The remainder of this literature review is focused on lung functions, particularly airflow obstruction and cardiovascular diseases among adult women as they are directly related to the research questions being addressed through this dissertation.

2.5 Measuring respiratory health and lung indices

HAP inflicts severe damage on the respiratory health of cooks as shown in **Table 2.1**.To understand how HAP affects lung function and thereby leads to airway limitation and COPD, one has to understand the basics of different lung indices, predicted lung values for the general population and how COPD is diagnosed in modern practice. Thus a few introductory basics of spirometry and different lung indices are presented first, followed by the choice of reference equation to calculate the predicted values of lung indices and concluding with diagnosis criteria of COPD.

2.5.1 Overview of spirometry and important lung indices

Spirometry, a procedure which measures the flow and volume of air in the lungs, is one of the first line investigations for any respiratory complaints. It is used to facilitate a diagnosis, to assess the severity of a disease, to monitor its progress and prognosis or to follow the efficacy of a treatment. (Miller et al., 2005) It is also used to identify airway disease at an early stage as a screening tool. The concept of measuring lung volumes dates back to as early as the second century. (Kiraly, 2005) However, only after Hutchinson introduced his water spirometer in 1846, its clinical use started albeit measuring only one of the lung parameters- the vital capacity. (Hutchinson, 1846). A century later, seminal works from Tiffeneau and Pinelli helped transform lung function measurements to its present day form with forced expiratory volume in one second (FEV1) and other important lung indices added. (Yernault, 1997)

Measurement of lung indices through spirometry is dependent on the participant's cooperation, and respiratory societies have released strict guidelines on how spirometric tests should be performed and interpreted. (Miller et al., 2005, Pellegrino et al., 2005) With proper instruction and demonstration of the procedure, as young as five year old children can be encouraged to perform lung function testing through spirometry (Eigen et al., 2001), although it is demanding to perform such tests with very young and very old age groups.

Incorrect measurement of age and height can introduce significant biases in the predicted values of lung indices, so these should be recorded very precisely, documenting exact date of birth and measuring the standing height up to the nearest millimetres. (Quanjer et al., 2012a) It is equally important to explain the procedure and answer the questions and allow the participants to try and familiarise themselves with the procedure. Finally, participants are encouraged to blow into the spirometer as hard and as fast as possible immediately, without a pause, after a maximum inspiration, and to completely empty their lungs. (Miller et al., 2005) During the blow, participants are asked to look straight forward without bending. Applying a nose clip is not absolutely mandatory but its use prevents participants from inhaling or exhaling through the nose.

Introduction to different lung indices (FEV1, FVC, MEF $_{2575\%}$)

FEV1 or the forced expiratory volume in one second is the volume of air exhaled from lungs in the first second of a forced expiration started from the level of full inspiration. (Miller et al., 2005) This is usually expressed in litres. This is the most commonly used lung index to diagnose airway obstruction.

FVC or the forced vital capacity is the volume of air exhaled from lungs with a maximally forced effort started from the level of full inspiration. (Miller et al., 2005) This is also expressed in litres and is also referred to as forced expiratory vital capacity.

The Z score of FEV1 or FVC is useful in making comparisons between two FEV1 values or z scores of FEV1, as lung indices are highly dependent on age, sex, height and ethnicity of a person.

$MEF_{2575\%}$ or mid forced expiratory flow between 25% and 75% is the average expiratory flow rate during the middle half of expiratory vital capacity. (Miller et al., 2005) It is also known as maximum mid-expiratory flow and is expressed in litres per second. Mathematically, this is:

$$MEF_{2575\%} = \tfrac{1}{2}\,FVC/\Delta t$$, where Δt is the time required to expire the middle half of FVC

So, this index is highly dependent on reliable measurement of FVC.

The largest values of FEV1 and FVC are taken from acceptable curves (those having good starts, without artefacts and with satisfactory exhalation) obtained from repeated blows during spirometry, even if they are not from the same curve. $MEF_{2575\%}$ is taken from the curve that has the largest sum of FEV1 and FVC.

Criteria for an effective and acceptable blow

Automated spirometer displays quality control messages as shown in **Table 2.2** that guides one to easily instruct participants on how and what to improve in the subsequent blows. It also provides information on overall quality of the procedure. Grades D and F are not acceptable and it is rarely helpful to record more than eight blows in an attempt to obtain an acceptable blow.

Table 2.2: Automated quality control checks, messages and grading of blows during spirometry

Manoeuvre acceptability	
Message displayed	**Criterion**
Don't hesitate	If the back extrapolated volume (BEV) > 150 mL
Blast out faster	If the time to peak expiratory flow (PEF) > 120 ms
Blow out longer	If the change in exhaled volume during the last 0.5 s > 100 mL, and forced expiratory time < 2 s
Blast out harder	PEF values do not match within 1.0 L/s,
Deeper breath	Forced vital capacity (FVC) values do not match within 150 mL
	Only one error message is displayed (in the order of priority listed above)
Good test session	After 2 acceptable manoeuvres that match
Quality control grades	
A	At least two acceptable manoeuvres with the largest two FEV1 values matching within 100 mL
B	At least two acceptable manoeuvres with FEV1 values matching between 101 and 150 mL
C	At least two acceptable manoeuvres with FEV1 values matching between 151 and 200 mL
D	Only one acceptable manoeuvre, or more than one, but the FEV1 values match > 200 mL (with no interpretation)
F	No acceptable manoeuvres (with no interpretation)
	Adapted from Ferguson et al. (2000) and (http://www.spirxpert.com/performing7.htm#top)

2.5.2 Importance of a reference equation and its choice

Interpretation of the values obtained after spirometry depends on the choice of a reference equation for comparison. As a person’s lung indices measured and documented at a prior healthy state are usually not available, it is difficult to ascertain if a person’s current lung measurement is within a normal range. So, to overcome this challenge, one has to compare the results to a predicted value obtained from a healthy subject of similar age, height, gender and ethnicity and who does not smoke. Such predicted values could be based on parsimonious regression models derived using high quality spirometry data obtained from representative sample of the population to which the prediction is to be applied.

More than 300 reference equations have been published for lung functions and many unpublished ones are available in spirometer. (Stanojevic et al., 2013) However, a reference equation should be chosen that does not need extrapolation of age ranges, and that considers suitable ethnic group. (Stanojevic et al., 2013, Swanney and Miller, 2013) Recently, the Global Lung Function Initiative (GLI), a special task force of the European Respiratory Society, developed all age range reference equations, the “GLI 2012” equations, that are valid across wide age ranges (3-95 years) globally and that incorporate multiple ethnic groups, based on spirometry records from around 0.1 million healthy non smokers collated from 70 centres of 33 different countries. (Quanjer et al., 2012b) Major respiratory societies have already endorsed the GLI 2012 equations.

Although several ethnic groups are included in the GLI 2012 equations, these are still not comprehensive. (Stanojevic et al., 2013) However, for the time being for ethnic groups like Nepalese, for whom a reference equation does not exist, a composite equation averaging the equations for the rest of the ethnic groups is likely to facilitate spirometry interpretation until remaining global ethnic groups are also incorporated. (Quanjer et al., 2012b) This reference equation takes the form of: “

$$\log(FEV1)= a + b.\log(height)+ c.\log(Age)+ age\text{-}spline + d.group$$

The predicted value is: $e^{a}.H^{b}.A^{c}.e^{d.group}.e^{spline}$

a is the intercept, H is height (cm), b the exponent for height, A is age (years) and c the exponent for age, and spline the contribution from the age spline, group is Caucasian, African American, South or North East Asian, and takes the value of 1 for the appropriate group and 0 for other groups”.(Quanjer et al., 2012b)

2.5.3 Diagnosis of airflow obstruction: LLN or GOLD cut-off?

Airflow limitation as evidenced by reduced FEV1/FVC is a hallmark of obstructive lung disease. (Hogg, 2004) The Global Initiative for Chronic Obstructive Lung Disease (GOLD) recommends confirming the diagnosis of COPD by documenting airflow obstruction by spirometry in adults with chronic cough or sputum production with exposure to tobacco smoking or smoke from indoor cooking. (GOLD, 2014) An objectively measured post bronchodilator FEV1/FVC < 0.70 confirms airflow obstruction/limitation (AO) and the diagnosis of COPD can be made in cases with such risks. (GOLD, 2014)

However, there is a controversy on whether such an absolute cut-off, as advocated by GOLD, should be used in the diagnosis of AO. (Csikesz and Gartman, 2014) The simplicity of one cut-off without the need of a reference equation has been argued as the basis for adopting this straightforward arbitrary value. On the contrary, many studies, reviews and editorials have argued against such practice which is susceptible to age-related bias because of the inherent dependency of FEV1/FVC to age-related changes in lung function thereby leading to over-diagnosis of AO in elderly and under-diagnosis in younger age groups. (Quanjer et al., 2010, Culver, 2006, American Thoracic Society, 1991, Roberts et al., 2006, Hansen et al., 2007, Enright and Ruppel, 2009) All these studies advocated for the use of the lower limit of normal of FEV1/FVC as the diagnosis criterion for AO/COPD. It is important to note however that regardless of the diagnosis criteria used, clinical context cannot be ignored.(Csikesz and Gartman, 2014)

2.6 Effects of HAP on COPD

Many studies have evaluated the effects of HAP on respiratory health, especially COPD. (Lin et al., 2008, Liu et al., 2007, Kurmi et al., 2010) Although, cigarette smoking has always been the most important risk factor for COPD, exposure to solid fuel smoke has now been estimated to be more important than tobacco smoking given that nearly 3 billion people are exposed to HAP compared to just over a billion smokers. (Salvi and Barnes, 2009, Salvi and Barnes, 2010). This is further strengthened by data from prevalence studies from around the world which show that a quarter to as close as a half of all the COPD patients are found to have never smoked in their life. (Regional COPD Working Group, 2003, Ehrlich et al., 2004, Zhou et al., 2009, Salvi and Barnes, 2009) In any case, there is little doubt that the effect of smoking and HAP exposure is additive and that they are the prime etiological factors for COPD pathogenesis.

GOLD defines COPD as

> "*a common preventable and treatable disease, characterized by persistent airflow limitation that is usually progressive and associated with an enhanced chronic inflammatory response in the airways and the lung to noxious particles or gases." (GOLD, 2014)*

Although the manifestations of COPD are heterogeneous, chronic cough, sputum and dyspnoea are usually universal. Other associated symptoms could be wheezing and chest tightness. It is noteworthy that symptoms experienced by COPD patients are often not correlated with spirometry-based objective measurement of lung function or even computer tomography-based changes in the lungs. (Agusti et al., 2010)

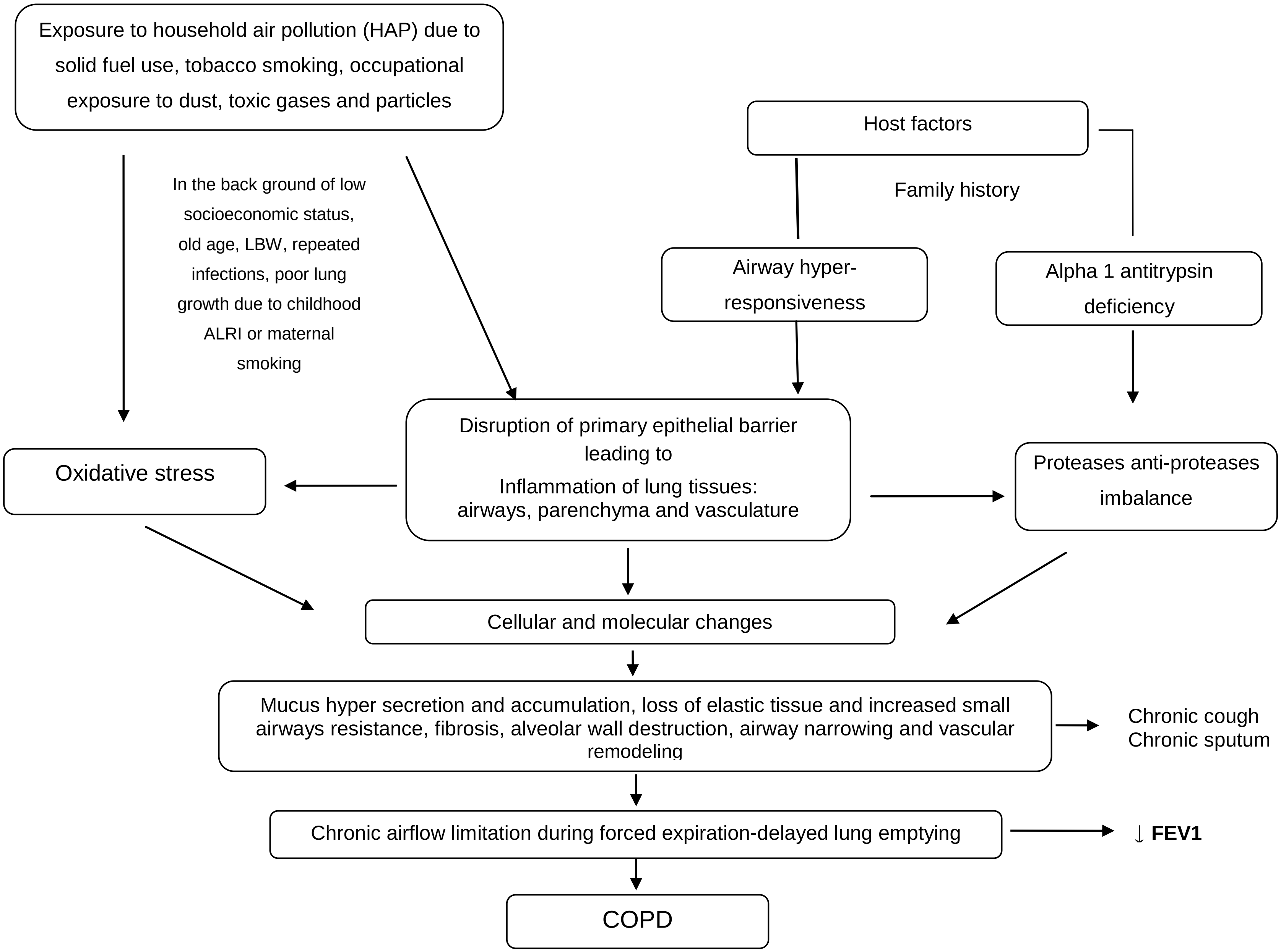
The firm belief until very recently was that nothing except for smoking cessation would alter the natural course of COPD. (Decramer and Cooper, 2010, Fletcher and Peto, 1977) This assertion deterred the development of early diagnosis and treatment initiation strategies for COPD patients. However, recent studies pointed out that a majority of patients with objective COPD are not aware of the presence of the disease. A large representative household survey from the UK reported a high prevalence of undiagnosed COPD. This survey reported 13% prevalence of spirometry diagnosed COPD among the participants but the majority (80%) of them denied any prior awareness. (Shahab et al., 2006) In this backdrop it is plausible to argue for attempts to make early diagnosis and initiate interventions aiming to avoid tobacco smoking or exposure to solid fuel smoke. It should be noted, however, that a lot of factors come into play in such interventions and attempts should be linked to a cost effectiveness analysis.

2.6.1 Pathogenesis of COPD in the context of HAP

Figure 2.2 shows the mechanism of how different factors come into play in the pathogenesis of COPD, primarily driven by inflammation of the lung tissues-involving airways, parenchyma and vasculature, thereby activating cellular and molecular changes (resulting from innate and adaptive immune responses) leading to the destruction of alveolar wall, airway narrowing and airflow limitation.

Alveolar macrophages, which are an important part of the innate human immunity, regularly clear inhaled foreign particles deposited in the airways by phagocytosis and transport. (Kulkarni et al., 2005) However, regular and chronic exposure to smoke and toxic irritants directly invades and disrupts the physical epithelial barrier that separates other lung tissue from alveolar airspaces. Disruption of this barrier initiates an inflammatory response. (Hogg, 2004) Macrophages, eosinophils, neutrophils thereby act to phagocytose the invading particles. On subsequent attacks, the cellular and humoral immune systems are activated and initiate a series of cellular and molecular changes thereby leading to accumulation of inflammatory mucous exudates in the lumen. Alveolar walls are then infiltrated by inflammatory immune cells. This is now coupled with airway and vascular remodelling that leads to the thickening of airway walls, loss of elastic recoil and increased small airway resistance which are characteristic features leading to chronic airflow limitation. (Hogg, 2004, Hogg et al., 1968, Hogg et al., 2004, Yanai et al., 1992)

Figure 2.2: Pathogenesis of COPD



2.7 Effects of HAP on cardiovascular health

According to the most recent WHO data, 60% of all deaths attributed to HAP were caused by either ischemic heart disease (IHD) or stroke in 2012 (**Figure 2.1**). IHD and stroke are a part of the broad cardiovascular disease complex which includes all conditions affecting the heart and blood vessels.

Ischemic heart disease is caused by decreased blood supply to heart muscles owing to the narrowing of coronary arteries that supply it. This is essentially due to development of atherosclerotic plaques in the intimae of blood vessel thus narrowing the vessel calibre. These plaques are rich in cholesterol deposits, collagen and other smooth muscle cells. When the plaque grows significantly to occlude the vessel, it impedes blood supply to heart muscles thereby causing ischemic symptoms only during exertion in the early stages. These plaques favour the build-up of thrombus around them and at times may completely block the vessel supplying the heart thereby causing acute myocardial ischemia/infarction. At other times a blood clot may break from a thrombus and embolise to distant vessels supplying the heart muscles, again leading to ischemia or infarction depending on the extent of blockage and muscle injury.

Stroke can be ischemic or hemorrhagic, with the ischemic type being the most common. A thrombus, atherosclerotic plaques, or an embolus can directly occlude or induce spasm of the cerebral artery and any of its branches thereby causing ischemia of the associated vascular territory distal to the occlusion site. Brain cells, primarily neurons, in the blood-deprived territory are susceptible to irreversible death if the occlusion is complete without any collateral blood supply and sustained for a longer duration. Hemorrhagic strokes on the other hand are due to rupture of weakened blood vessels in the brain-mainly due to rupture of the aneurysm.

2.7.1 Pathogenesis of IHD and stroke in the context of HAP

Evidence linking HAP to cardiovascular disease (CVD) is recent, indeed there are no epidemiological studies that directly examine how HAP exposure increases the risk of IHD or stroke, although two studies have linked HAP exposure to the risk of high blood pressure (McCracken et al., 2007, Baumgartner et al., 2011), which is a leading risk factor for global disease burden. (Lim et al., 2012). Instead, the recent burden of disease estimates provided by the Global Burden of Disease 2010 project (Lim et al., 2012) and WHO (2014) are based on a novel integrated exposure-response analysis across multiple sources of particulate matter air pollution, ranging from active and passive smoking via HAP to ambient air pollution. (Burnett et al., 2014) PM2.5 from ambient air pollution and active or passive smoking is a well-recognized risk factor for CVD mainly mediated through continued oxidative stress and systemic inflammation. (Brook et al., 2004, Brook et al., 2010) They are associated with increased hospitalization (Schwartz and Morris, 1995, Lin and Kuo, 2013) and mortality (Beelen et al., 2014, Zhou et al., 2014).

The likely effect of HAP on IHD and stroke is inferential and is based on the knowledge that particulates from ambient sources and smoking and HAP share similar physical characteristics. This is further strengthened by the fact that PM levels from HAP are located in between the levels seen in active smoking and passive smoking or ambient air pollution. (Smith et al., 2014) Additionally, for both IHD and stroke high blood pressure is one of the major modifiable risk factors (Poulter, 2003) and controlling high blood pressure together with other risk factors is the main way to prevent IHD and stroke.

Studies from Guatemala and China have linked HAP to increased blood pressure among adult cooks. (McCracken et al., 2007, Baumgartner et al., 2011) The study from China documented more than 4 mmHg rise in systolic blood pressure (SBP) and 1.8 mmHg rise in diastolic blood pressure (DBP) with each one log unit increase PM2.5 mass among women beyond their fifth decade of life. (Baumgartner et al., 2011) Studies have now started looking at direct outcome measures of IHD rather than the intermediate outcome – hypertension. A recent study from Pakistan demonstrated nearly fivefold increased risk of suffering from acute coronary syndromes (myocardial ischemia and unstable angina) among women who were current users of solid fuel compared to those who were natural gas users for cooking. (Fatmi et al., 2014) Similarly, another study from China found household solid fuel use associated with 2.6 (95% CI of Odds ratio: 1.5-4.3) times the risk for self reported ischemic heart disease after adjusting for potential confounders. They also reported a 1.87 times (95% CI of Odds ratio: 1.03 to 3.38) higher risk of stroke among those using solid fuel for longer duration-categorized as those in the highest tertile versus those in the lowest tertile of the duration of solid fuel use for heating and cooking. (Lee et al., 2012)

HAP exposure causes systemic inflammation and oxidative stress which mediates high blood pressure. High blood pressure is a major risk factor for atherosclerosis at all ages. (Fausto et al., 2004) HAP has also been found to increase the tendency for coagulation and platelet activation thus further favouring atherosclerosis. More than 90% patients with IHD have atherosclerosis of one or more of the coronary arteries. (Fausto et al., 2004)

2.8 Evidence of effectiveness of HAP interventions

With the advent of the Global Alliance for Clean Cookstoves (GACC), there has been a massive rise in the momentum to disseminate cleaner-burning stoves in the last few years. The GACC has been working to meet its interim target of 100 million homes adopting clean and efficient stoves by 2020 with the ultimate goal of universal adoption. (GACC, 2014) Many partners have been involved in delivering this target, and several cookstoves are being tested in the market and communities. Some of these are driven by locally formed national alliances e.g. the Nepal Alliance for Clean Cookstoves.

However, evidence as such if these stoves are reducing HAP exposure to the desired level is limited. Several studies have tested different improved cookstove designs before and after their installation. Many of them performed well in that they achieved reductions in PM or CO levels after the installation of the stoves. But, these levels were still much higher than the WHO guideline limits. Although the mean or median levels are statistically reduced, many studies document high variability and overlapping concentrations before and after the stove use.

A forthcoming systematic review of the effectiveness of different stove and cleaner fuel solutions, conducted in the context of new WHO guidelines on indoor air quality, paints a difficult picture: None of the ICS models currently promoted around the world and evaluated through PM or CO measurements in the field meet the WHO guideline for PM2.5 or its interim target (Rehfuess et al., personal communication). On the other hand, the nonlinear character of the integrated exposure response analyses has a huge implication on the exposure reduction we have to aim for so as to gain substantial health benefits. Smith et al. (2014) indicates such level of exposure reduction is difficult to achieve with currently available cookstove technologies that still burn solid fuels, and also is unlikely to be achieved by switching to fuels that are at the highest rung of energy ladder-electricity and gas due to the fuel stacking phenomenon.

The limited effectiveness of these improved technologies mirrored by the global evidence base brings us to a difficult situation to trying to address the HAP burden experienced by almost half of humanity, where adoption of new technology is already multifactorial-influenced by factor that spans poverty to sensitive socio-cultural beliefs.

3 Methodology

3.1 Study design

This is a propensity score matched cross sectional study to compare the concentrations and effects of household air pollution among women who primarily use traditional woodstoves versus those who primarily use biogas fuel for cooking. We tried to explore if the adoption and sustained use of biogas plants for at least 10 years, has had any measurable pollution and health benefits to its users compared to those who have continued to use traditional woodstoves.

We specifically assessed the impact of sustained biogas fuel use on the concentrations of particulate matter (PM) and carbon monoxide (CO), cardio-respiratory health outcomes- mainly lung indices, blood pressure, heart rate, oxygen saturation and self-reported cardiovascular symptoms for adult female cooks of rural Nepal.

3.2 Study duration

All recruitments and measurements were done during the summer months, 20 March - 12 May, 2012 and 18 April - 10 May, 2013 to rule out any seasonal variation. Both air pollution measurements and health assessments were intended to be undertaken in every household.

3.3 Study site

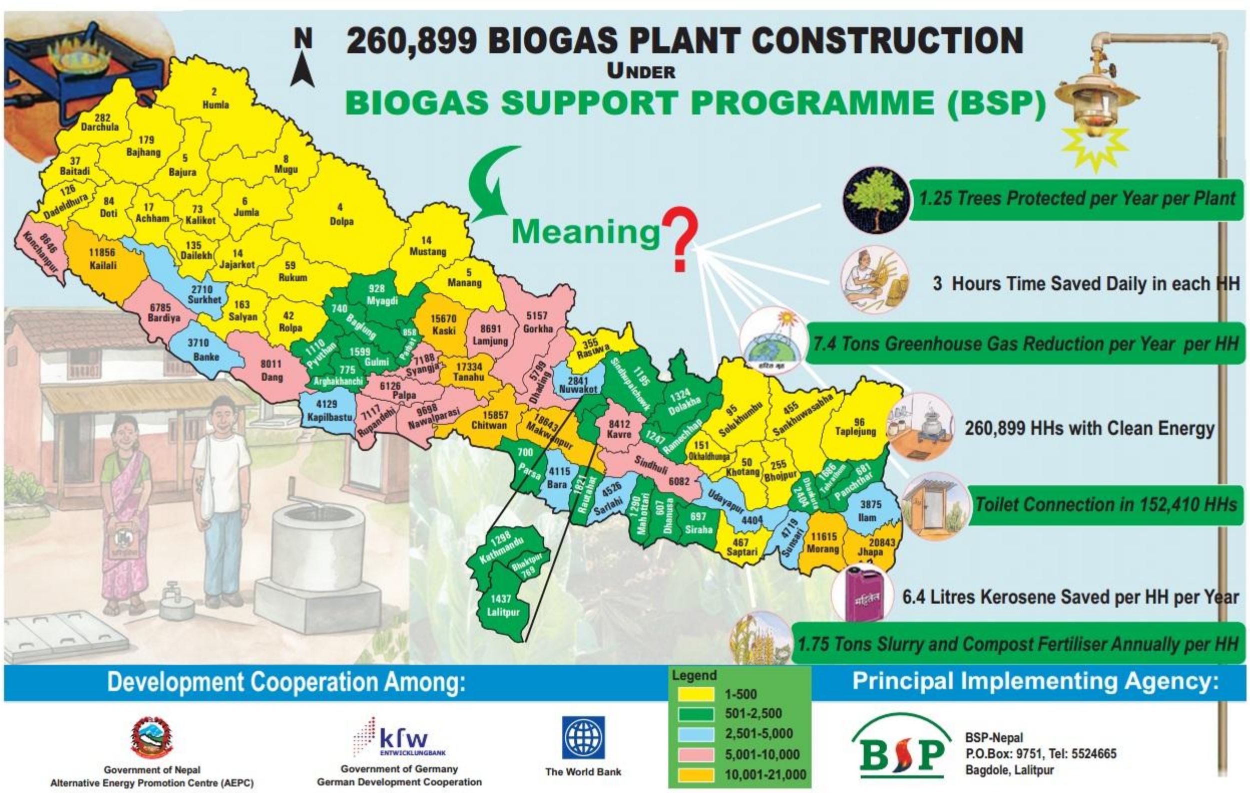
Nepal is landlocked between India to the east, south and west and China to the north. With a total land area of 147 181 square kilometres, the country is divided into three ecological zones: mountains (above 4877 meters), hills (610 meters to 4876 meters) and *terai* or plains (less than 610 meters). For administrative purposes, it is subdivided into five development regions, 14 zones, and 75 districts. Districts are further divided into 3,915 smaller rural units called village development committees (VDCs) and 58 urban municipalities. (CBS, 2012b) Each VDC comprises 9 wards.

Of the 5.4 million households and 26.5 million total population of the country, nearly 50% live in the southern plains, 43% in the mid hills and the remaining 7% in the northern mountains. There is high cultural diversity with 125 caste/ethnic groups speaking 123 different languages. 83% of the population still lives in remote rural areas with more than three quarters of households involved in subsistence farming. (CBS, 2012a) Remittance remains the foremost source of income for more than half of the country's households where a quarter of the population lives below the national poverty line. (CBS, 2011b). With energy access linked to poverty, 78% of the household still use traditional biomass fuel (wood, cow dung, leaves and agricultural residues) for cooking and related chores. (CBS, 2011a)

3.3.1 Selection of district

BSP as discussed under **section 1.3.3** is a nation-wide programme to promote the use of household biogas plants through a subsidy mechanism. According to data from BSP, there are 19 districts with more than 5000 biogas plants installed, 20 districts with 1000-5000 plants and 36 districts with less than 1000 plants. **Figure 3.1** shows the distribution of biogas plants in Nepal. (BSP-Nepal, 2012)

Figure 3.1: Distribution of biogas plants in Nepal



Source: BSP Year Book 2011/12

For practical reasons and to ensure timely, high-quality data collection, we limited our sampling frame to only those 19 districts with high density of biogas adoption. Next, we assessed the road network density of these 19 districts from the data obtained from the Department of Roads and the District Profile of Nepal 2007 (Intensive Study Research Centre, 2007) as shown in **Table 3.1**. So as to minimize the effect of outdoor air pollution due to vehicular emissions (Kan et al., 2007) as well as industrial emissions that are commonly seen when road access is better, we purposively selected Gorkha district as our study site because it had the lowest road density network. We also presumed that with access to better road and transport services people would have access to multiple energy solutions and would have adopted several fuel combinations making it difficult to identifying a pure sample of wood only and biogas only users in the study. Gorkha also ranked 40th in the Human Development Index and 32nd in the Overall Composite Index (Intensive Study Research Centre, 2007) out of the 75 districts of Nepal and may therefore share characteristics of both extremes.

Table 3.1: Comparison of districts with the highest adoption of biogas according to road density and other characteristics

Districts	Geography	Households	HDI ranking	Composite index ranking	% of households using solid fuel	Road density (km/sq km area)
Gorkha	Hills	66506	40	32	81.6	0.03763
Sindhuli	Hills	57581	34	49	90.0	0.03842
Lamjung	Hills	42079	20	22	82.9	0.06393
Nawalparasi	Terai	128793	25	37	85.5	0.11579
Dhading	Hills	73851	55	44	93.3	0.13130
Makwanpur	Hills	86127	31	26	54.6	0.13563
Kailali	Terai	142480	46	40	84.3	0.14230
Kanchanpur	Terai	82152	39	35	84.2	0.14548
Bardiya	Terai	83176	50	34	91.0	0.15013
Dang	Terai	116415	57	21	68.4	0.17962
Syangjha	Hills	68881	7	9	72.2	0.18079
Kaski	Hills	125673	3	6	48.1	0.20672
Palpa	Hills	59291	23	8	63.8	0.21700
Rupandehi	Terai	163916	5	13	44.8	0.22047
Tanahu	Hills	78309	9	16	66.7	0.26112
Kavre	Hills	80720	6	15	72.2	0.29462
Chitwan	Terai	132462	12	2	48.3	0.35904
Morang	Terai	213997	8	11	80.8	0.37101
Jhapa	Terai	184552	18	3	71.9	0.37136

Compiled using data from the District Profile of Nepal (2007)

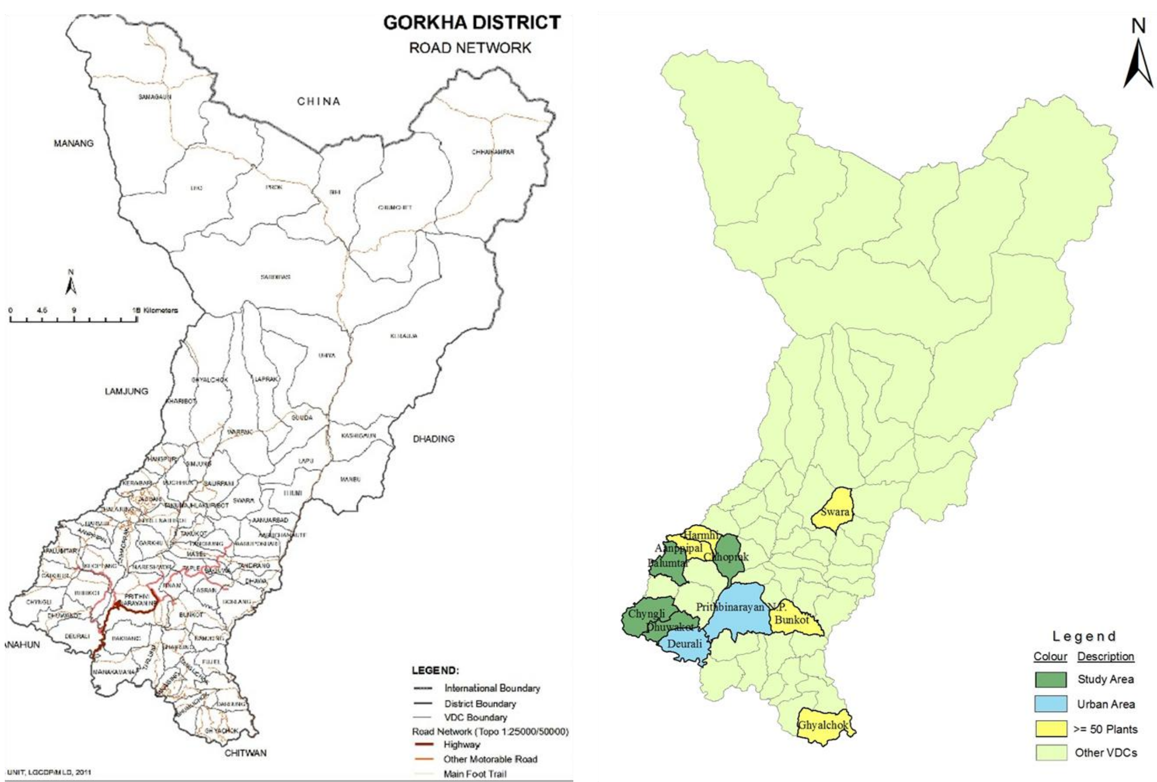
3.3.2 Selection of villages

Having selected Gorkha district, the same principle was applied to purposively select VDCs, however, only focusing on those VDCs where 50 or more households owned biogas plants for at least a decade. The number of biogas plants installed ten or more years ago in different villages of Gorkha district is shown in **Table 3.2**. After excluding one of the relatively urban VDCs, Deurali, with access to a black topped highway, the remaining top four VDCs with highest biogas adoption were selected for household recruitment as shown in **Figure 3.2**.

Table 3.2: Villages ordered according to the number of biogas plants installed ten or more years ago

Villages	No of biogas plants*	Road type	Outcome
Deurali	196	Black topped highway	Not selected
Palungtar	154	Gravel and earthen road	Selected
Dhuwakot	125	Gravel and earthen road	Selected
Chyangli	123	Gravel and earthen road	Selected
Chhoprak	92	Gravel and earthen road	Selected
*Compiled using unpublished data from BSP. * Installed 10 or more years ago*			

Figure 3.2: Map of Gorkha district showing its road network to the left and showing villages selected for this study to the right



Gorkha is located 140 km west of Kathmandu with the altitude ranging from 228m to 8156m (Mount Manasalu). The population of the district is 0.27 million and 97% of them reside below 2500m. All the selected villages were below 1000m elevation from sea level thus ruling out any effects of high altitude on cardio-respiratory functions as well as impaired functionality of biogas at cold temperatures.

The selected villages, home to agricultural indigenous populations, were visited in person to obtain firsthand information regarding fuel use, functionality of the biogas plants, willingness to participate in the study, accessibility, security situation and logistic issues including electricity supply for the research devices. In each village, unofficial meetings were held with local leaders, school teachers, and VDC representatives to get to know the village in detail.

Households used a combination of fuels: wood, biogas, LPG, charcoal and small amounts of crop residues depending on season. Those villagers cooking with wood fuel collected it in the community forest. Temperature in the district ranged from as low as 2.3°C to 33.2°C. (Intensive Study Research Centre, 2007) Cold season night time temperatures never fall below freezing so families did not use space heating even if they could afford to.

3.4 Study population

This study targeted all the households from the selected villages who had either primarily used biogas fuel for at least the last 10 years or traditional firewood stoves for coking for lifelong. As biogas plants rely on manure from adult cattle, only those households which owned at least one adult cattle were studied. Further, we investigated only adult female cooks of 30 years or more from the above mentioned households to study our health outcomes.

3.5 Sample size

As there were no studies assessing the impact of biogas on respiratory health at the time of study design, we made an assumption that the differences in our primary outcome would be at least equivalent to what has been observed with improved cookstove interventions. Therefore we used the estimated population mean FEV1 based on studies from Guatemala, Mexico and Nepal that assessed the impact of different ICS compared to those using traditional firewood to calculate our desired sample size. The RESPIRE trial in Guatemala was powered to detect 90ml difference in FEV1 at 80% power with mean FEV1 of 2700ml and standard deviation of 350ml. (Smith-Sivertsen et al., 2009) A trial from Mexico was designed to detect a 3% difference in FEV1 between women exposed to HAP and non-exposed women with a power of 90%. (Romieu et al., 2009) Another study from Nepal reported a mean FEV1 of 2.69±0.36 litres among women using ICS compared to 2.61±0.46 litres for those using traditional woodstove, although the difference was not statistically significant. (Joshi et al., 2011)

Using the FEV1 values obtained from the above studies, we needed 146 women in each group to detect a 115 ml difference in FEV1 between women cooking on biogas and women cooking on traditional woodstove, with 80% power at a two-sided significance level of 5% Considering that only 80% of the women would be able to undertake spirometry successfully, we estimated that we would need to recruit 183 women in each group.

Table 3.3: Sample size calculation using estimates from comparable studies

Endpoints	Mean in biogas users	Standard deviation	Difference	Power	Each arm (n)
FEV1 (ml)	2700	350	100	80%	193
FEV1 (ml)	2700	350	115	80%	146
FEV1 (ml)	2700	350	135	80%	86
COPD rate	15%	-	15%	80%	121

As shown in **Table 3.3**, with 146 women in each group this study was also sufficiently powered to detect a potential difference in COPD prevalence of 15% among biogas and 30% among woodstove users. Of note, as we intended to conduct matched and unmatched analyses, the sample size calculation at this stage however did not account for the matched nature of the study and was thus conservative, i.e. it was likely to underestimate the true power of the paired analysis of the primary outcome.

3.6 Selection of households

Once the VDCs were selected, we conducted a pilot study in Palungtar, one of the selected VDCs, and identified some discrepancies between the addresses of biogas users provided by the BSP and the observed actual addresses. This could be due to the restructuring of the wards inside the villages and renaming of the wards. Also, there were additional households who had installed biogas plants for 10 or more years ago but were not listed in the BSP list. Moreover, the hilly terrain of the villages which were only accessible by foot made it impractical to conduct a rapid census as a basis for estimating a reliable sampling frame for biogas as well as firewood users. Consequently, random sampling became an unfeasible choice and we decided to adopt a structured sampling mechanism as detailed below.

The Government of Nepal, according to the Local Self-Governance Act 2055, specifies a designated centre in a convenient place within each of the VDCs in Nepal. (Government of Nepal, 2000) All the village-level offices are located in this centre. In the selected four VDCs, we thus set up our research base at the centre and from there we undertook 'complete enumeration' of the households within a radius of two hours of walking distance. Door to door visit of the potential households were done and only those households and cooks meeting the inclusion criteria as described in **section 3.7** were recruited. VDC-based recruitment is shown in **Table 3.4**.

Table 3.4: VDC wise recruitment of households among biogas and firewood users

VDCs	Number of households*	Total biogas users	Biogas users (10 years or more)	Recruited biogas users	Recruited wood users
Palungtar	2108	404	154	57	69
Dhuwakot	1110	231	125	49	38
Chyangli	1532	332	123	62	50
Chhoprak	1531	240	92	51	143

**Number of households as of Nepal Population and Housing Census 2011*

3.7 Household and participant recruitment

All the recruitments were done by the PhD candidate visiting each household in turn. At several stages of the study three medical doctors and two other medical and a public health student who had prior training and experience on community based research and interview techniques assisted the PhD candidate.

The inclusion and exclusion criteria were staged at household and individual level:

Inclusion criteria:

- Households having used biogas as their primary/main cooking fuel for at least the last 10 years
- Households having used traditional biomass fuel as their primary/main cooking fuel lifelong
- Household owning at least one adult cattle
- Main cook living in the same household for at least the last ten years
- Female cook aged 30 years or more

Exclusion criteria:

- Non functional biogas plants for 12 months or more in the last 10 years
- Women showing a current sign of infection with fever >38^{0}C or suffering from tuberculosis to rule out the possibility of spread of infection
- Women suffering from severe scoliosis or having a known neuromuscular disorder, myasthenia gravis or a scar from severe and extensive burns of the chest to rule out any unwanted effect on lung function
- If the cook said she is pregnant
- If the cook was unwilling to participate in the study

3.8 Ethical considerations

The protocol of this study was reviewed and approved by the Ethical Review Board of the Nepal Health Research Council (Kathmandu, Nepal) and Oxford Tropical Research Ethics Committee (University of Oxford, UK) prior to any contact with the study participants. The LMU Ethical Commission (Munich, Germany) granted an ethical waiver for the study after having reviewed the two granted ethical clearances.

In all of the villages, the project was explained to the VDC representatives, local leaders and school teachers. Potential study participants were briefed about the study and the consent form read to them in Nepali. A written informed consent was mandatory and those able to sign had their signatures on the informed consent form. For those unable to sign, the study administrator signed it on their behalf indicating that it had been read to them and that they had agreed to participate voluntarily and could withdraw from the study at any time.

Participants were required to undergo non-invasive spirometry test. Mandatory individual single-use mouthpieces were used to prevent any risk of cross-infection while performing such test. Participants were provided with a report of their lung function and blood pressure for free. If the investigator physician found any symptoms and signs of disease and conditions requiring medical attention, participants were advised to visit the nearby health facility. However, they did not receive any financial assistance for doing so.

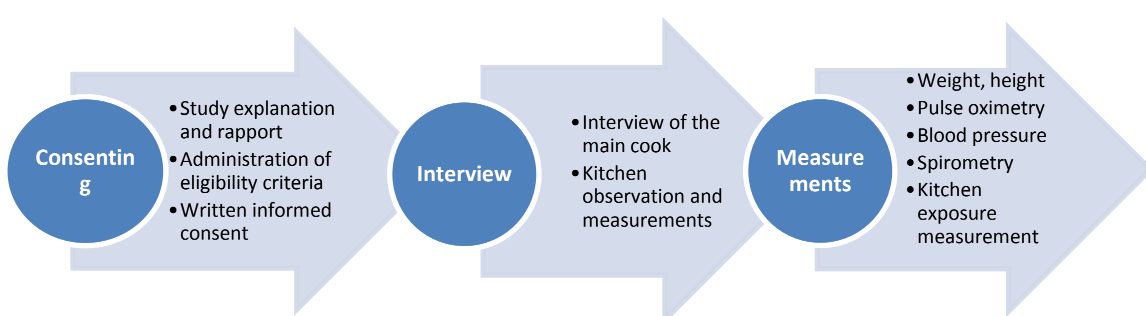
The risk of invasion of privacy was minimized through the use of identification numbers and confidentiality was maintained throughout the study. Data sets were anonymised and stored in password-protected computers only accessible by the study team.

The study sponsors had no role in the design, data collection, data analysis or interpretation and writing of this dissertation and any manuscripts produced.

3.9 Data collection overview

Figure 3.3 shows an overview of the whole data collection process and flow of activities. The questionnaires used were constructed using selected questions from various resources so that cross study comparisons could be done. Questionnaires were framed to administer the eligibility criteria, to identify the households and the cook, to find out the reasons for adoption and non adoption of biogas plants. Standard respiratory health questionnaires and additional cardiovascular questionnaires were framed. For housing and kitchen characteristics, cooking practices and exposure assessment, we referred to the questionnaires used by the University of California, Berkeley (Indoor Air Pollution Team, 2006) and Practical Action Nepal (Bates, 2007b). Additional health end points were documented using appropriate record forms.

Figure 3.3: Flow of activities during data collection



All the questionnaires were developed in English and administered to the participants solely by the PhD candidate in Nepali. The drafted questionnaires were pretested to make sure that they were clear and could be understood by the respondents. Based on the pretesting, the socio-demographic, kitchen and cooking practice questionnaires were refined.

3.9.1 Socio-demographic questionnaire/household questionnaire

These questions were broadly of four categories: eligibility questions, identification of the household and the cook, characteristics of the main cook, ownership of durable assets and housing characteristics. Questions were framed to identify the eligible household and eligible women. Details to identify the household like name of the village, ward number, name of the household head were included. Other questions identified the cooks with their age, smoking status and education attained. We also referred to the questionnaire used by the Demographic and Health Surveys that are used to assess the household wealth index. (ICF International, 2011) These were reviewed and adapted to suit our need in the context of the villages that were selected for the study. An observation checklist was developed to collect the information on the materials used for the roof, floor and wall of the dwelling.

3.9.2 Reasons for biogas adoption

To better understand why some households chose to adopt biogas plants and why others did not, we developed a set of closed and open-ended questions. These questions were asked to enquire about the reasons for installing or not installing the biogas plants and if there were any factors that would facilitate adoption. Respondents could give multiple answers including an open comment.

3.9.3 Kitchen characteristics and cooking practices

A standard questionnaire adapted from the questionnaires used by Practical Action Nepal, and the University of California, Berkeley on household air quality monitoring was used for this study. (Indoor Air Pollution Team, 2005, Bates, 2007b) We collected details on kitchen type, stove type, stove location, eaves spaces, number of windows and doors. We asked detailed questions on the main fuel and additional fuels used for different cooking activities in different seasons. We also enquired about the source of the fuel used and if it was collected or bought. We checked if there were any smoke venting mechanisms in the kitchen, such as smoke hoods or chimneys.

3.9.4 Health questionnaire

We adapted the health symptoms questionnaires used in prior HAP studies done by Practical Action Nepal (Bates, 2007a) and additionally the Modified British Medical Research Council Questionnaire for Assessing the Severity of Breathlessness (Fletcher, 1960, Smith K et al., 2000). These respiratory health questionnaires assessed symptoms like cough, sputum production, exacerbations of COPD and breathlessness. Cardiovascular questions on chest pain, palpitations and night time cough were also used. Questions were also developed to document the severity of headache and the number of times the cooks were visiting the health facilities for check up.

3.9.5 Weight and height measurement

Body weight was measured in kilograms using a CAMRY weighing scale (Camry Inc, China) and recorded on a paper form as well as within the spirometer. The scale was placed on a hard, level surface and the participants were asked to stand still on it in light clothing, without shoes. Before each measurement the scale was standardized and set to zero.

Standing height without any shoes was recorded on a paper form and within the spirometer. Participants were asked to stand straight with their head positioned such that the person is looking straight ahead with knees straightened and their feet and heels together. Participants stood against a wall and their height was marked which was later measured using a non-stretchable measuring tape.

3.9.6 Cardiovascular health assessment

Cardiovascular health was assessed by measuring the heart rate, percentage saturation of oxygen in the blood, and resting brachial blood pressure.

3.9.6.1 Pulse oximetry

Blood concentrations of oxygen (O_2) and resting heart rate were measured using a non-invasive method known as oximetry that uses light reflectance through the nail bed. We used a rechargeable battery-powered fingertip CMS 50 pulse oximeter which measures both blood O_2 saturations and resting heart rate simultaneously. All the measurements were done on the middle or fourth finger of a resting and seated participant. Readings were noted down after the plethysmograph bar waveform and pulse signal strength bar were stable and maximal. Three readings were recorded at an interval of 30 seconds.

Ideally, the degree of tissue hypoxia caused by large CO exposures should not be measured by a simple pulse oximetry as it cannot differentiate between carboxy-haemoglobin (COHb) and oxy-haemoglobin (OxyHb). Simple pulse oximetry thereby can falsely overestimate the blood oxygen saturation (SPO_2). One should prefer automated co-oximeter that can differentiate different wavelengths of COHb and OxyHb to measure true hypoxic levels (Prockop and Chichkova, 2007). However, in this study simple pulse oximetry was used.

3.9.6.2 Brachial blood pressure and heart rate measurement

Pulse rate and brachial blood pressure of all the participating women were measured at their homes using an automated oscillometric device (Omron SEM-1; Omron Corp, Tokyo, Japan). Participants were asked to rest in a chair or an improvised chair with their feet flat on the ground and arms uncrossed at their side. Adult sized cuffs were then wrapped around the upper arm. The device automatically inflated and deflated and produced systolic blood pressure (SBP), diastolic blood pressure (DBP) and heart rate. Participants were kept at ease and were requested to remain quiet during the measurements. Measurements were repeated two minutes apart until three measurements within 10 mmHg were obtained. The average of three measures was used as the final blood pressure. Those with average SBP ≥ 140mmHg and/or DBP ≥ 90mmHg were considered hypertensive. Systolic hypertension was defined as SBP ≥ 140mmHg irrespective of DBP, and diastolic hypertension as DBP ≥ 90mmHg irrespective of SBP.

3.9.7 Pulmonary function testing

An introduction to spirometry and different lung indices including the choice of reference equations and diagnostic criteria for AO using either LLN cut-off or GOLD cut-off is discussed in detail in **section 2.5**.

In this study, lung function indices were measured using an EasyOne (NDD, Switzerland) portable spirometer in accordance with European Respiratory Society and American Thoracic Society guidelines (Pellegrino et al., 2005, Miller et al., 2005) All lung function measurements were conducted by the PhD candidate throughout the study to maintain uniformity of the procedure among the participants. The PhD candidate had received prior training under Prof Annalisa Cogo (collaborator of the host institution of the candidate), University of Ferrara, Italy on how to perform and interpret spirometry.

All the participants were requested to make at least three blows into the spirometer. Spirometry was considered successful if the participant produced at least two acceptable and reproducible blows, the two largest FEV1 and FVC within 150 mL as per the ATS/ERS criteria. (Miller et al., 2005, Pellegrino et al., 2005) Participants could make a maximum of eight attempts to obtain three satisfactory blows.

The spirometer produced a graphical display of the flow volume loops and instructions as shown in **Table 2.2** which helped to maintain the quality of the spirograms. Spirograms were individually reviewed by the PhD candidate and Dr Rainald Fischer for quality checks. Any discrepancy was mutually resolved; if further discrepancy persisted, a third independent reviewer provided the final verdict. Unacceptable spirometric traces were excluded from analysis.

Airway obstruction (AO) was diagnosed by two criteria, (i) using the lower limit of normal (FEV1/FVC < 5^{th} percentile, i.e. zFEV1/FVC < -1.645) as recommended by the Global Lung Initiative and using “GLI 2012 equation”(Quanjer et al., 2012b) and (ii) absolute FEV1/FVC cut-off of < 0.70 (Vestbo et al., 2013), where those with FEV1/FVC ≥ 0.70 were not considered to have airway obstruction. For airway obstruction outcome, both FEV1 and FVC had to be acceptable.

In case of an abrupt end of expiratory manoeuvre and FVC values were not usable, FEV1 values were considered acceptable (for analysis of FEV1 outcome) if the peak expiratory flow was achieved as seen in the graphical display and the forced expiratory time was more than 2 seconds.

3.9.8 Exposure assessment

Current practice: Many HAP studies in the past, and even today, have used questionnaire based exposure assessment of fuel use by only documenting the primary fuel type used for cooking without measuring pollutant concentration. This practice is likely to suffer from exposure misclassification. The importance of true exposure assessment need not be underscored. Measuring the concentration of different pollutants is pivotal in HAP studies as it helps researchers to causally relate their findings. Additionally, it is also necessary to test the effectiveness of new cookstove technologies by showing that they achieved desired pollutant reduction. When exposure levels and outcomes are well documented in studies it further allows researchers to perform exposure response analysis thus strengthening the evidence.

The last decade has seen considerable progress in exposure assessment methods available in HAP studies. (Clark et al., 2013) Nowadays, real time particulate matter monitors and carbon monoxide monitors are available that have the capability to detect and record pollutants every minute. These can be programmed to continuously measure for 24 hours or 48 hours depending on the device.

The currently adopted techniques to measure HAP exposure are mostly area based measurements of particulates (PM10 or PM2.5) and carbon monoxide conducted inside the kitchens where cooking is done. These area based quantitative measurement of HAP exposure are technically easier than personal measurement but they fail to capture personal exposures (Clark et al., 2013) as cooks and children are mobile and rarely spend all their time inside the kitchen (Perez-Padilla et al., 2010). These measurements are also extremely variable as they depend on a host of factors, like kitchen type, kitchen volume, ventilation status, weather conditions, cooking duration, and neighbourhood pollution. Supplementing the area measurement data with time activity diary by recording micro activities of the cooks and cooking practices serves to better capture and explain heterogeneity. (Clark et al., 2013)

Although personal exposure measurement devices are now available their high costs still hinder them to be easily used in field based research. In addition, as these devices have to be worn by the cooks during exposure measurement, they might find it obtrusive and uncomfortable and compliance could be an issue. But, because of the ability to capture personal exposure this remains the gold standard for now until better technologies evolve. These personal measurements can also be combined with area measurement and time activity diary to further capture relationship between personal and kitchen exposure. (Clark et al., 2013)

Although, personal exposure remains the gold standard, most epidemiological studies currently measure kitchen pollutant levels for different time durations ranging from 8 hours to 24 or 48 hours. Some studies only measure pollutants concentrations during cooking episodes. To reduce the uncertainties associated with these measurements, however, repeated measurement conducted over different seasons for prolonged duration is warranted. To capture all the cooking activities of a family and thereby exposure to pollutant, at least 24 hour measurement is needed. This also facilitates comparison across studies and with the WHO air quality guideline limits.

There are different kinds of devices available to measure exposure to particle matter. Gravimetric method which is based on weighing of the filters loaded with particle mass is the gold standard method for measuring PM2.5. However, this is very time consuming and has a high operating cost. Alternative method based on light scattering technology offers real time measurement of PM2.5. This is a relatively cheap, portable device and can be battery operated in the field; however, it has a disadvantage that a correction fraction should be identified for each fuel type studied and necessitates calibration with the gravimetric device.

Measuring CO is relatively straightforward compared to PM2.5 and can be done either by diffusion tubes or real time monitors fitted with CO sensors. Both of these are portable and can be used for personal CO monitoring.

Compared to CO, PM2.5 is a better marker of HAP and is also the most important parameter of interest for health effects as this is directly deposited in the lungs and inflicts several health damages. CO exposure has been used as an easily measured proxy of PM2.5 in HAP studies but area measurement of CO may not always reflect true personal exposure to PM2.5.

Device and method adopted in this study: We measured both the 24-hour indoor concentration of PM2.5 and CO inside the kitchens in summer. In a subset of houses measured in summer, we re-measured only 24 hour kitchen CO concentrations during winter. We used the University of California-Berkeley Particle Monitor (UCB PATS) from the Berkeley Air Monitoring Group and Indoor Air Pollution Team to measure the PM2.5 concentrations (in units of $\mu g/m^3$) in the kitchens. (Edwards et al., 2006) The UCB monitors record PM2.5 based on light scattering method and provide digital particle mass concentration measurements every minute. (Litton et al., 2004) Industrial Scientific Gas Badge Pro CO monitors were used for measuring CO concentration in units of parts per million (ppm) every minute.

Both the instruments were deployed indoors at head height, 1.5 meters off the floor and approximately 1m from the edge of the stove. The monitors were left overnight and collected the following day, after roughly 24 hours. Both date and time of start and end of the monitoring were recorded. In case the monitors were taken down after less than 24 hours' recording it was made sure that the monitors captured all the daily cooking routines of the family. Both the devices logged the data internally in real time. The detailed standard operating procedures developed by the University of California, Berkeley guided the routine procedures for instrument set-up, operation and documentation. (Indoor Air Pollution Team, 2005)

3.10 Data handling

3.10.1 Questionnaire data

Interview responses were recorded on paper forms and reviewed every night for typographical errors, and any missing responses. Whenever possible, missing responses were completed during the next visit for kitchen pollutant monitoring. Any typographical errors noticed were corrected the same night. The list of recruited households was updated every other night and household identification numbers and unique participant numbers were assigned. Although data entry was planned on site in the field, it was not possible due to severe power shortage. The data entry sheet was prepared in sequence similar to the structure of the questionnaire. Double data entry was done independently by two persons and any discrepancies were resolved referring to the original paper version of the questionnaire. An inconsistency check was run on both data entry files and discrepancies were corrected in one of the files, based on the original paper version of the questionnaire; to produce a master file for analysis. Data validation was undertaken and frequency distributions produced to assess if the data were clean. Data entry was done in SPSS v 17 and clean data were later imported to R for analysis.

3.10.2 Cardiovascular health data

Pulse oximetry, heart rate and blood pressure were recorded manually on paper forms. These were later double-entered into the SPSS data sheets. Similar inconsistency checks were applied as for the questionnaire data, and the corrected data imported into R.

3.10.3 Pulmonary function data

The EasyOne spirometer can store all the measurement data which can then be exported into Access, Excel and PDF files. The list of participants from the spirometer was extracted into an excel sheet which contained the identification details, age, weight, height and unique record number. This sheet was later merged with the participant's unique identification number. The spirograms for each participant were reviewed using the EasyOne desktop software and the PDF copies of the best three trials were printed for each participant. These were reviewed independently by the PhD candidate and Dr Fischer. After consensus, the lung function values were entered into the excel sheet. Data validation was done through double entry and inconsistency checks. The clean file was later exported to SPSS and merged with the rest of the data set.

3.10.4 Exposure assessment data

Both the PM2.5 and CO devices recorded per minute data of indoor kitchen pollutants. This was logged internally by the devices and could be downloaded into an excel sheet. However, due to practical constraints, only carbon monoxide data was analysed. 24 hour kitchen carbon monoxide concentration is defined as the arithmetic mean of minute-per-minute CO concentrations measured in parts per million (ppm) inside the kitchen for 24 continuous hours (1440 minutes). Measurements that recorded CO exposure for 24 ± 2 hours were accepted.

3.11 Statistical analysis: overview

All the statistical analyses were performed in R version 3.0.2 (R Core Team, 2013) using appropriate packages. **Table 3.5** summarizes the main analytical approach used for different research questions. The primary sample for analysis consisted data from a single female cook per household selected to avoid within-household correlation. In case more than one cook was recruited into the study for a household, the woman who could successfully do a spirometry (primary outcome) was selected. In case both women produced successful spirometry records, the woman who spent the most hours per day in the kitchen was selected.

Table 3.5: Study components, outcome measures and analytical approach

Study components	Outcome measures	Main analytical approach
Reasons for adoption and non adoption of biogas	Reasons for: i. Adoption ii. Non adoption iii. Factors facilitating adoption	Descriptive analysis on factors for adoption, non adoption using percentages and numbers
Kitchen pollutant concentrations	24 hour kitchen CO	Between group (households) crude differences --- untransformed
		Matched analysis on households matched by their socio-economic status ---- post matching weighted linear regression on log transformed data
	24 hour kitchen PM2.5	Not analyzed currently for practical reasons
Respiratory health	FEV1, zFEV1, FVC, MEF2575%	Between group (primary cooks) crude differences
		Matched analysis among primary cooks, matched by their age, height and socio-economic status --- post matching weighted linear regression to calculate the differences
	Airway obstruction (AO)	Between group (primary cooks) crude differences
		Matched analysis among primary cooks, matched by their age, height and socio-economic status --- post matching weighted logistic regression to calculate odds ratio
Cardiovascular health	Analysis further stratified by age group (30-50 years or >50 years)	
	Mean SBP, Mean DBP	Between group (primary cooks) crude differences
		Matched analysis among primary cooks, matched by their age, BMI and socio-economic status --- post matching weighted linear regression to calculate the differences
	Hypertension (HTN), Systolic HTN, Diastolic HTN	Between group (primary cooks) crude differences
		Matched analysis among primary cooks, matched by their age, BMI and socio-economic status --- post matching weighted logistic regression to calculate odds ratio
Questionnaire-based health symptoms	Cough, phlegm, wheeze, difficulty breathing, chest pain, palpitation	Between group (primary cooks) crude differences

All matched analyses use propensity score matching. All sensitivity analyses are unmatched.

3.11.1 Principal component analysis for wealth index

Many measures of socio-economic status (SES) like asset based measures, consumption expenditure, income, education or occupation have been used in health research. The strengths and limitations of these are compiled in **Table 3.6**. All of these methods eventually measure overlapping aspects of SES. (Howe et al., 2012) So, the choice depends on the research setting, time and resources available for data collection and whether one is interested in calculating a household's current or long-run welfare status.

Table 3.6: Different measures of socio-economic status-strengths and limitations

Measures of SES	Strengths	Limitations
Asset based measure: Measured by possession of durable goods, housing materials and access to basic facilities.	▪ Rapid, simple and computationally easier ▪ Required data can be reliably measured ▪ Stable and long term measure of SES ▪ Comparability across studies due to wide use	▪ Measure of relative rather than absolute SES ▪ Non-functional assets may give false SES ▪ Quality of the asset is not captured ▪ Associated with community infrastructure e.g. water supplies
Consumption expenditure: Measures how income is used by a household by aggregating expenditures on a wide range of items.	▪ Measures key aspects of how income is used ▪ Easier to collect than income	▪ Requires extensive, time consuming data collection ▪ Subject to inaccurate recall of expenses ▪ Unclear on the choice of expenditure items which vary across settings ▪ Complex calculation ▪ Short-term fluctuations
Income: Measured by asking about absolute household income.	▪ Best indicator of material living standards	▪ Sensitive information ▪ Difficult to measure income of those who are self-employed or receive income in kind ▪ Dynamic and liable to short term changes
Occupation: Reflects the social standing, income and intellect of a person according to his/her current occupation.	▪ Available in routine data sources	▪ Cannot be readily assigned to people who are currently not employed ▪ House makers or self employed are difficult to classify
Education: Measured as years of education or literacy.	▪ Easy and less contentious to measure, high response rate	▪ May suffer cohort effects and gender differences ▪ Does not account for the quality of education

(Filmer and Pritchett, 2001, Howe et al., 2012, Galobardes et al., 2006)

Income and expenditure data are often not available in developing countries, so researchers have to rely on proxies. (Howe et al., 2012) As the use of a single proxy is unreliable, a composite index of proxies like possession of a range of durable assets, access to basic facilities or housing characteristics and living conditions is often computed. In this study, we collected similar information as in the DHS on the ownership of assets and animals and access to basic services like electricity, water and a toilet. We also observed the housing construction materials.

We applied Principal Component Analysis (PCA), a data reduction technique, to generate a summary asset index. PCA uses the correlations between the covariates to generate a set of orthogonal uncorrelated components. Only the first principal component which explains the maximum data variance is finally used to calculate the asset index. (Filmer and Pritchett, 2001, Houweling et al., 2003) Those assets that are more unequally distributed between households are given more weight in PCA. (McKenzie, 2005)

PCA relies on the assumption that the data used are continuous, but the proxies collected for the asset index are mostly of binary or ordinal character. A technical solution to correct this violation is to calculate the tetrachoric or polychoric correlation coefficients. Other alternatives to PCA like multiple correspondence analysis (Traissac and Martin-Prevel, 2012), factor analysis (Sahn and Stifel, 2003) or multivariate regression have also been suggested. (Vyas and Kumaranayake, 2006) However, PCA remains intuitively easier and the asset index obtained appears stable and coherent - internally and externally. (Filmer and Pritchett, 2001)

Household assets (radio, television and watch) were coded as binary, housing materials (roof, wall and floor) and access to drinking water supply as ordinal, while the discrete animal counts (cattle, oxen, goats and pigs) were square root transformed to reduce excessively large variance. Descriptive statistics of the covariates were checked and those with poor variability (possession of mobile phone, land telephone, electricity, bicycle and scooter), i.e. when everybody or nobody owned a given asset, were excluded from the PCA. Households with missing values for one or more of the variables were excluded from the analysis. Only the first principal component explaining the maximum variance was retained and interpreted.

3.11.2 Descriptive analysis

All the variables of interest were summarized by group: biogas versus firewood users. Firstly, household-level variables like family size and number of rooms and secondly individual-level variables like age and height were analyzed by group. In each case, continuous variables were summarized as mean, median and inter-quartile range while categorical variables were summarized using frequency and percentage (%). Ranges were checked to ensure that no implausible values had accidently been recorded. Data normality was graphically evaluated using histograms. Crude between-group comparisons were based on the Wilcoxon test for continuous variables and Fisher's exact test for categorical ones.

3.11.3 Matching for causal inference

Matching is a technique to balance variables between an intervention and a control group; this technique to increase causal inference could be put into practice through the study design (i.e. by recruiting an intervention and a matched control household or woman) or through statistical techniques. Subsequent parametric analyses are far less model-dependent where matching results in groups that are balanced or without statistically significant differences across relevant variables. Since matching per se is not a method of effect estimation, applying common regression procedures after matching also improves causal inference by reducing bias and increasing the efficiency of the model.

3.11.4 Available matching methods

A brief overview of different statistical matching methods with their strengths and limitations is given in **Table 3.7**.

Table 3.7: Different matching techniques-their strengths and limitations

Matching methods	Strengths	Limitations
Exact matching: Matches all controls with exactly the same covariate values. So, each treated unit matches with all available exact controls.	▪ Makes the groups very similar and produces exact balance. ▪ Reduces the variance of causal effect estimates without increasing bias.	▪ High probability of discarding substantial numbers of subjects and reducing the effective sample size and power.
Nearest neighbour matching: Starts with a random treated unit and matches the closest control unit that has not yet been matched.	▪ Faster and easy to understand. ▪ Very useful when there are a limited number of control units with values similar to those in the treated group.	▪ When done 'with replacement', there is a chance that only a few unique controls may be selected as matches. ▪ When done 'without replacement', a significant number of treated groups may end up with poor matches.
Sub-classification: Stratifies the groups into fairly equal sized strata. In each stratum, the distributions of covariates between the groups are as similar as possible.	▪ Uses all of the available observations and stratifies them. ▪ Results in large reductions in bias.	▪ Produces biased results if within strata model adjustment is not done to correct for residual imbalance. ▪ Treatment effects are obtained separately for each subclass.
Optimal matching: Is a variant of nearest neighbor matching but performs better in minimizing the distance within each pair.	▪ Useful when there are few appropriate controls for treated units. ▪ Minimizes the total distance within matched units.	▪ Matching order in which the treated units are matched is indifferent.
Full matching: Combines sub classification and optimal matching so that numerous matched sets, each containing varying numbers of treated or controls units, are created.	▪ All available observations are placed into one of the subclasses. ▪ Optimal in minimizing the distance measure.	▪ Risk of matched sets with widely varying ratios of treated to control units which can lead to large variance of the effect estimate.

(Ho et al., 2006, Stuart and Green, 2008)

3.11.5 Selection of matching method

To prevent the loss of statistical power of the study, we decided on a matching technique that would retain the maximum number of data points. We thus ruled out exact and nearest neighbour matching *a priori*. Among the techniques which use all of the data points, we opted for full matching as it utilizes the principle of both the sub classification as well as optimal matching and allows varying numbers of subjects within a matched group.

Full matching, introduced by Rosenbaum (1991), does a fine stratification of all the available observations in an optimal way to create numerous subclasses such that each has either one treated unit and one or more control units, or one or more treated units and one control unit. (Hansen, 2004) Using the controls in their entirety, the full matching produces good balance between groups and removes observed confounding. (Stuart and Green, 2008, Hansen, 2004)

3.11.6 Propensity score: a matching estimator

Observational studies, unlike randomized controlled trials (RCT), are prone to selection bias due to non-randomly distributed chances of adopting the intervention between the two groups. Systematic differences between those adopting and those not, are therefore likely to result in a biased effect estimate. Introduced by Rosenbaum and Rubin in 1983 and widely used in econometrics and observational studies, the propensity score (PS) tries to yield unbiased effect estimates of such non-random interventions. The propensity score is defined as the conditional probability of receiving the intervention given the observed covariates. (Rosenbaum and Rubin, 1983) It is a scalar summary measure of several multidimensional covariates such that treatment assignment is ignorable between treated and untreated groups with an identical propensity score. Although a true propensity score can only be calculated from an RCT, observational studies make use of propensity scores estimated through a logit or probit regression model.

The PS has been used in four different ways in the literature: through matching, weighting, stratification and regression adjustment. (Williamson et al., 2012) Matching on an estimated PS appears to be more robust than weighting or regression (Zhao, 2008) while stratification reduces bias less than the other methods. (Rosenbaum and Rubin, 1983) Propensity score matching allows matching the treated and controls by many covariates at once such that the treated unit is matched to the control unit with the closest propensity score. The goal throughout is to make the overall matched groups balanced i.e. similar in observed covariates rather than the individual matched pairs. (Gelman and Hill, 2007) This best balance directed PS modelling is a key advantage because the analyst remains blinded to the outcome until a matched data set has been created. (Williamson et al., 2012)

3.11.7 Selection of matching covariates

The selection of covariates to be used in the propensity model is most important in reducing the selection bias while estimating the treatment effect. (Steiner, 2011) However, this does not mean the models should be over-fitted as this has its own concerns. (Judkins et al., 2007) One should trade-off between the bias of excluding relevant variables and the inefficiency of including the irrelevant ones. (Ho et al., 2007) So, a matching procedure should include all the known confounders except for the variables that are a consequence of treatment, i.e. any intermediate outcomes. (Rosenbaum, 1984, Gelman and Hill, 2007) Including additional predictors of outcome further corrects any chance imbalances and results estimates with greater precision. (Austin, 2008, Williamson et al., 2012) However, omitting any variable having a disproportionately large effect on the outcome is detrimental; rather it is crucial to obtain good balance on such covariates even after matching. (Ho et al., 2007)

In this study, for the matched analysis of 24 hour kitchen concentration of CO, which is a household level outcome, biogas and wood households were matched by their SES score. For individual level health outcomes like FEV1, FVC, risk of AO we decided to match the participants by their age and height, the most important biological determinants of lung function (Quanjer et al., 2012a), and additionally by their SES which is an important determinant of lung disease and overall health and should not be discounted in epidemiological studies. (Steinberg and Becklake, 1986, Hegewald and Crapo, 2007, Raju et al., 2005) SES has also been linked as an independent risk factor for COPD through large studies (Yin et al., 2011). Even in an economically well-developed country with a free health care system low SES has been associated with poor COPD prognosis. (Lange et al., 2014) Besides being the determinant of health, SES is also likely to be the key driver for biogas adoption thereby matching by SES also reduces selection bias.

For cardiovascular outcomes (SBP, DBP and hypertension), after stratification into two age groups (30-50 yrs and >50 yrs), we further matched cooks using biogas to those using wood by their age, BMI and socio-economic score, with all of these variables used on a continuous scale. Age and BMI were chosen *a priori* to account for differential risk of high blood pressure, and SES to account for differential rates of biogas adoption as above.

3.11.8 Effectiveness of matching

The goal of matching is to achieve as good a balance as possible in an effort to reduce bias. So, after running the matching algorithm, a balance test of covariates was undertaken using standardized differences of the means, also known as absolute standardized bias (ASB). ASB is defined as the weighted difference in means of a covariate between two groups divided by the standard deviation of the covariate in the pooled group. (Williamson et al., 2012) Balance was assumed to be well achieved when ASB was less than 0.25. (Ho et al., 2007, Stuart and Green, 2008) Jitter plots and histograms were additionally used to examine the distribution of propensity scores and weights assigned to each cook. Although statistical significance testing is frequently used, it is not recommended to assess balance (Austin, 2008) and was not tested. Graphical displays using histograms, quantile-quantile plots and jitter plots were evaluated.

3.11.9 Analysis after full matching

Due to the resultant varying number of cases in each subclass after full matching, the overall effect estimation should be weighted such that the treated receive a weight of one and the control receive a weight proportional to the number of treated in a matched subclass divided by the number of controls in the subclass. (Ho et al., 2007) We thus used weighted linear and logistic regression to calculate the effect estimate. All regression models contained matching covariates to account for any remaining imbalances and additional control variables in multivariable analysis.

However, it is still debated if one should account for the matched nature of the data during analysis. (Austin, 2008, Hill, 2008, Stuart, 2008) Austin argues that PSM forms part of the study design rather than an analytical component, which necessitates appropriate statistical methods that account for the lack of independence within matched pairs. (Austin, 2008) A contrary opinion is not to account for pairing because PSM creates matched groups during analysis rather than individually matched pairs as in data collection. (Gelman and Hill, 2007) Schafer and Kang state that: "*'Matching' erroneously suggests that the resulting data should be analyzed as if they were matched pairs. The treated and untreated samples should be regarded as independent, however, because there is no reason to believe that the outcomes of matched individuals are correlated in any way*." (Schafer and Kang, 2008) There is thus no consensus and researchers are left to make an informed choice or report results using both techniques. We opted to use a generalized estimating equation (GEE) method which takes into account the paired nature of the data.

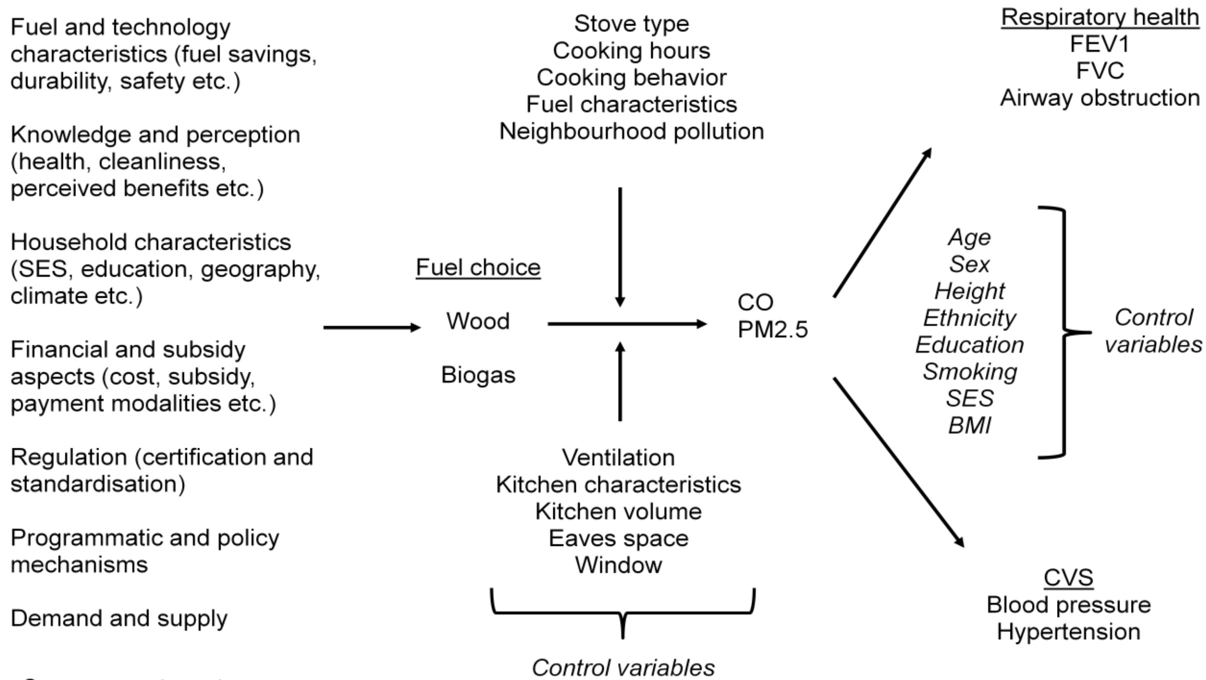
3.11.9.1 Univariate and multivariable analysis in matched dataset

After creating the matched datasets using PSM, univariate and multivariable analyses were run. In both the univariate and multivariable analysis, those covariates used for matching were again adjusted in the regression models to account for any remaining imbalance. Independent effect of key variables was analyzed for each outcome using weighted regression models and GEE.

All the variables to be adjusted in multivariable analysis were set *a priori*. Potential confounders were grouped into common domains like, biological (age, height, weight, BMI), socio-economic (PCA derived socio-economic score or education), kitchen and ventilation related [kitchen volume (as a continuous variable), windows (categorised as no window, one window, more than one window), quality of eave spaces (categorised as absent, poor or good) and categories of kitchen type], and additional fuels (owning LPG or rice cooker). These variables were introduced as a group in the regression models while calculating the adjusted effects. Linear and logistic regression analyses were conducted by sequentially adjusting for confounders which were known to be associated with outcome measures or have been shown by prior HAP studies to be associated with similar outcome measures. A conceptual framework as in **Figure 3.4** constructed based on literature review guided the analysis and control of variables in multivariable analysis.

24 hour kitchen CO: This outcome measure was log transformed for univariate and multivariable regression analysis owning to its skewed distribution. Weighted linear regression models were fitted with log CO as the dependent variable to estimate the effect of biogas fuel use (ref category: firewood) after propensity score matching of biogas and firewood using households by their SES score. In the multivariable regression analysis, control variables were introduced in a stepwise fashion such that the full model constituted two variables for additional fuel use (LPG and rice cooker) and four kitchen characteristics variables (kitchen volume, windows, eaves spaces and kitchen type) and SES again introduced despite using as a matching covariate.

Figure 3.4: Conceptual framework for regression analysis



Source: Puzzolo et al., 2013

Forced expiratory volume in one second (FEV1): Linear regression models were fitted with FEV1 (in litres) as the dependent variable to estimate the effect of independent variables like age, height, weight, biogas fuel use and etc in the univariate analysis. As for the analysis of kitchen CO, control variables were introduced in a stepwise fashion in the weighted multivariable linear regression analysis of dataset matched by age, height and SES. The full model controlled for smoking (categorised as current, never and former smoker), all matching covariates, additional fuel use and kitchen characteristics.

Airway obstruction**:** Logistic regression models were fitted with AO as the dependent variable to estimate the effect of independent variables like biogas use, smoking, age, kitchen characteristics etc. Weighted multivariable logistic regression analysis was run with the same control variables as used for analysis of FEV1 to calculate the odds ratio associated with biogas use.

Cardiovascular outcomes: All analyses of cardiovascular status were stratified into two age groups (30-50 years and >50 years) as outlined in **Table 3.5** owing to the differential risk of cardiovascular diseases in post menopausal women. (Miller et al., 2007, Liu et al., 2001)

--Systolic and diastolic blood pressure: For analysis of continuous outcome measures SBP (in mmHg) and DBP (in mmHg), weighted linear regression models were run as SBP or DBP as the dependent variable and biogas fuel use as independent variable in each age group. Besides the matching covariates (age, BMI and SES), the final model was adjusted for smoking, kitchen characteristics and additional fuel use as above.

--Hypertension: Weighted logistic regression models were fitted with HTN as the dependent variable to estimate the effect of biogas use in each age group. Full model for multivariable analysis was adjusted for the same control variables as used for analysis of SBP and DBP.

3.11.10 Sensitivity analysis

In the unmatched dataset, the independent effect of key variables was analyzed through univariate linear or logistic regression as conducted in the matched analysis. Multivariable regression models for unmatched sensitivity analyses contained same sets of potential confounders (as described in section **3.11.9.1**) as in the matched analyses. In the matched dataset, additional sensitivity analyses were run ignoring the matched nature of the data, i.e. ignoring the lack of independence.

Additional sensitivity analyses were carried out in all the recruited cooks for primary health outcomes with adjustment for multiple subjects per household to obtain regression coefficients with robust variance estimates using GEE with working independence.

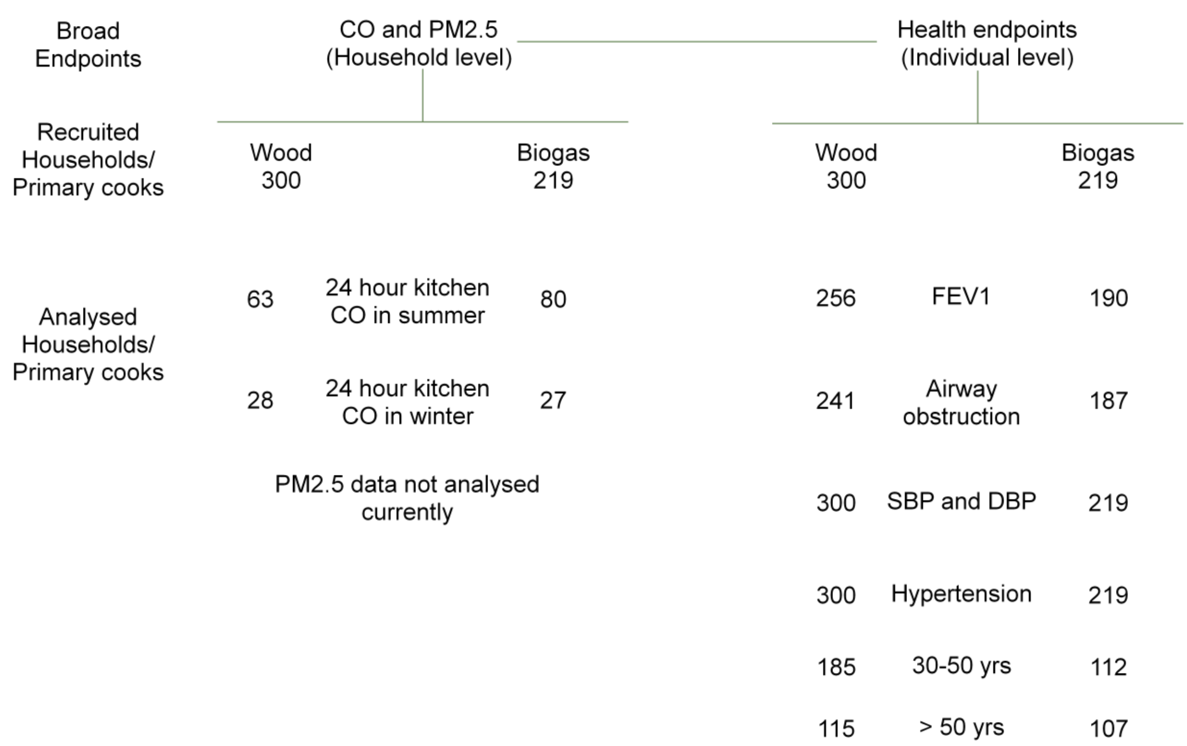
4 Results

4.1 Overview

Although a total of 555 cooks were recruited from 519 unique households, all analyses for this dissertation are based on single cook per household selected to avoid within-household correlation. The woman who spent the most hours per day in the kitchen was selected for analysis in case more than one cooks were recruited into the study for a household as explained in s**ection 3.11** which also details the analytical approach used.

Figure 4.1 shows the number of recruited and analysed sample size for each outcome. Although both pollutant and health measurements were intended to be undertaken in each household, unforeseen circumstances like power shortage, political movements and poor weather compromised kitchen pollutant monitoring and was carried out only in a subset of households. Additionally, due to necessity of further training and collaboration to analyse the large volume of data from the UCB PM2.5 monitors, analyses of PM2.5 outcome was not carried out for this dissertation. This is planned beyond the defence procedure.

Figure 4.1: Sample size analysed for each outcome



Only descriptive analyses are conducted for questionnaire-based health symptoms and further analyses are planned for publication purposes later. All other outcome measures were analysed based on the analytical approach as outlined in **Table 3.5**. Results in the sections below are organised first by crude differences, univariate analysis, and adjusted multivariable linear or logistic regression analysis using both matched and unmatched strategies.

4.2 Reasons for adoption, sustained use and non adoption of biogas

Adoption: 212 biogas-using households provided reasons for adoption of biogas plants with 345 different responses. Lack of firewood availability and trouble collecting the firewood was the major reason cited for adoption of household biogas plants in almost 60% of households. More than one third of the households were attracted to this alternative technology as they felt its use would keep their kitchen clean due to reduction in smoke and black soot. A significant number of households mentioned the co-benefit the biogas system offered as they did not have to worry about the septic system of the toilet. In the hilly villages, where public sewerage treatment and disposal system is absent, biogas plants connected with the toilet acted as a natural septic tank as well as a fuel source. **Table 4.1** presents other reasons cited for adoption of the plants and it is striking that only 10 households stated the possible health benefits of switching to biogas use.

Table 4.1: Reasons for adoption of household biogas plant

	N=212 households	% of households
Problem with fuel availability	127	59.9
Smoke filled dirty kitchen due to firewood use	79	37.3
Convenience for cooking	41	19.3
Co-benefit of septic system	35	16.5
Advice from local agent	22	10.4
Neighbors influence	12	5.7
Government subsidy and micro financing	11	5.2
For better health of family members	10	4.7
For lighting purposes	8	3.8

Non adoption: Among the wood users, expensive upfront investment was the main barrier to adoption of biogas plants in nearly half of the households. Construction of a biogas system was felt to be very labour-intensive and this discouraged uptake in households with small family size. Lack of adequate land with sufficient sun exposure prevented some households from installing the plant despite their willingness. More than 10% of households said that inability to move the biogas plant to a new site once constructed had deterred them from installing it, as they were planning to move to a new place in the near future. Another 10% reported daily operation, maintenance and feeding the plant as labour-demanding and discouraging them from adoption. Inadequate availability of the substrate due to few animals and social taboo restricting the connection of human waste from latrines to the biogas system were other reasons cited for non-adoption despite subsidy from the government. Less than 5% of the households believed that the bio-slurry produced from the digester would lack the natural quality of organic fertilizer and would decrease the yield from crops. **Table 4.2** provides more detail on the reasons for non adoption of biogas plants by wood users.

Table 4.2: Reasons for non adoption of household biogas plant

	N=265 households	% of households
Expensive upfront investment	128	49.2
Construction issues	32	12.4
lack of sufficient and suitable land	*15*	*5.8*
labour-intensive construction process	*9*	*3.5*
small family size and lack of manpower	*8*	*3.1*
Not feasible to relocate it to a new site later	29	11.2
Operational and maintenance issues	28	10.7
labour-intensive daily operations	*24*	*9.2*
lack of adequate water supply	*4*	*1.5*
Insufficient substrate for feeding the plant	21	8.1
difficulty in rearing large number of cattle	*15*	*5.8*
do not prefer connecting to toilet (taboo)	*6*	*2.3*
Poor quality manure	9	3.5
Inadequate fuel production	9	3.4
Happy with current energy situation	10	3.8
Easy availability of firewood	4	1.5
Planning to install it soon	13	5.0

We also enquired with the households that continued to rely on firewood if there were any factors that would prompt them to switch to biogas as shown in **Table 4.3**. Two fifths of these households responded that it would be easier if the upfront investment was made cheaper by further subsidy schemes. Nearly 20% of the users were not sure if any measures would facilitate adoption given the expensive upfront investment. Among those with limited land, some users mentioned that modifications to the design of the digester such that it would fit in a smaller space would facilitate uptake. Potential users with the intention to move also suggested design modifications so that the plant could be moved to a new place.

Table 4.3: Factors that would facilitate adoption of household biogas plant

	N=285 households	% of households
If it was cheaper and there was more subsidy from the government	116	42.8
If there was better information on how to obtain it	26	9.6
If it was easier to construct and operate	18	6.6
If a moveable biogas plant was available	14	5.2
If the plant could be designed to fit in a small area	10	3.7
If better training on use and after sales services were provided	7	2.6
If payment modalities were different	3	1.1
Other reasons	40	14.8
Do not know	54	19.9

4.3 Characteristics of biogas and firewood users

4.3.1 Household-level characteristics

Household-level characteristics like family size, number of children under five years of age, and number of males and females in the family were similar between the households using biogas or firewood (**Table 4.4**). Both groups of households owned 7 cattle on average. Households using biogas had more rooms in the house than firewood users ($p < 0.001$).

Table 4.4: Household characteristics in firewood- and biogas-using households

	All (N=519)	Wood (N=300)	Biogas (N=219)	p value
Family size	4.48, 5 (3-6)	4.49, 4 (3-5.25)	4.48, 5 (3-6)	0.877
Number of females	2.41, 2 (1-3)	2.41, 2 (1-3)	2.40, 2 (1-3)	0.845
Households with <5 years children				0.416
None	437 (84.20%)	250 (83.33%)	187 (85.39%)	
1-3	82 (15.80%)	50 (16.67%)	32 (14.61%)	
Number of all animals	7.20, 7 (5-9)	7.14, 7 (4-9)	7.29, 7 (5-9)	0.402
Number of rooms	4, 4 (3-5)	3.57, 4 (3-4)	4.58, 4 (4-5)	<0.001

Data are mean, median (IQR) or number (%) unless otherwise specified. P value based on Wilcoxon test for continuous data and Fisher's exact test for categorical data (based on simulation with B=10 000 for large tables)

Table 4.5 shows how biogas and wood users significantly differed by both the type and volume of the kitchen. In these villages, all of the households had their kitchen on the ground floor but most of them were connected to the living units on the first floor by a ceiling door through which smoke can easily spread. Nearly half of the biogas users had an external kitchen attached to the main building. Most of these kitchens were roofed with galvanized sheets leaving eave spaces between the walls and the roofs. One in ten firewood using households had detached, usually small kitchens some of them just large enough to accommodate a cook while cooking. These were made out of bamboo sticks with or without a mixture of mud and straw applied over the wall and roofed with either thatch or galvanized sheets. Nearly 15% of households cooked and lived in the same room.

Table 4.5: Kitchen characteristics in firewood- and biogas-using households

	All (N=519)	Wood (N=300)	Biogas (N=219)	p value
Kitchen volume in m^3 *	19.53, 18.72 (12.66-24.38)	16.87, 16.47 (10.39-22.20)	23.16, 22.15 (16.72-27.09)	<0.001
Kitchen type				<0.001
Separate kitchen	210 (40.46%)	123 (41%)	87 (39.73%)	
External kitchen	189 (36.42%)	85 (28.33%)	104 (47.49%)	
Kitchen and living same	74 (14.26%)	51 (17%)	23 (10.50%)	
Detached kitchen	39 (7.51%)	34 (11.33%)	5 (2.28%)	
3 walled kitchen	7 (1.35%)	7 (2.33%)	0	

*Data are mean, median (IQR) or number (%) unless otherwise specified. P value based on Wilcoxon test for continuous data and Fisher's exact test for categorical data (based on simulation with B=10 000 for large tables). *Data on kitchen volume is from 296 wood and 217 biogas users.*

Biogas and wood users significantly differed in terms of number of windows and doors in their kitchen as shown in **Table 4.6**. Nearly a quarter of the firewood using households did not have a window in their kitchen as many of these households had a detached kitchen or kitchen with an open face. These differences in kitchen characteristics may be the consequence of a higher SES of the households using biogas. Nearly three fourths of biogas using households did not have eave spaces in the kitchen as they instead built windows or additional doors in the kitchens. Although households had two or more doors in the kitchen most of the time only one remained open.

Table 4.6: Kitchen ventilation characteristics in firewood- and biogas-using households

	All (N=519)	Wood (N=300)	Biogas (N=219)	p value
Number of windows				<0.001
No window	79 (15.22%)	69 (23%)	10 (4.57%)	
One window	312 (60.12%)	181 (60.33%)	131 (59.82%)	
More than one	128 (24.66%)	50 (16.67%)	78 (35.62%)	
Number of doors				0.001
One door	305 (58.77%)	194 (64.67%)	111 (50.68%)	
More than one	214 (41.23%)	106 (35.33%)	108 (49.32%)	
Kitchen eave spaces				0.004
Completely closed	331 (63.78%)	174 (58%)	157 (71.69%)	
Partially open	108 (20.81%)	70 (23.33%)	38 (17.35%)	
Completely open	80 (15.41%)	56 (18.67%)	24 (10.96%)	

Data are mean, median (IQR) or number (%) unless otherwise specified. P value based on Wilcoxon test for continuous data and Fisher's exact test for categorical data (based on simulation with B=10 000 for large tables)

Biogas use was associated with more than 100 minutes (p<0.001) reduction in reported cooking duration per day (**Table 4.7**). However, in a subsample of 168 houses where 24 hour kitchen pollutant monitoring was done and the post-monitoring questionnaire was administered, mean cooking duration during 24 hours was reported to be 232 minutes among firewood users versus 179 minutes among biogas users (p<0.001). Although 42% of the biogas households owned an electric rice cooker compared to only around 20% of the firewood using households, this was rarely used due to severe power shortage. 71 houses (35 firewood users and 36 biogas users) owned additional LPG cylinders.

Table 4.7: Cooking duration and additional fuel use in firewood- and biogas-using households

	All (N=519)	Wood (N=300)	Biogas (N=219)	p value
Reported cooking duration (hours)*	4.37, 4 (3-5.50)	5.11, 5 (4-6)	3.34, 3 (2.50-4)	<0.001
Cooking duration during pollutant monitoring (hours)**	3.35, 3.15 (2.50-4)	3.87, 3.50 (2.75-5)	2.97, 3 (2.41-3.50)	<0.001
Households owning an electric rice cooker	152 (29.29%)	58 (19.33%)	94 (42.92%)	<0.001
Households using LPG	71 (13.68%)	35 (11.67%)	36 (16.44%)	0.123

*Data are mean, median (IQR) or number (%) unless otherwise specified. P value based on Wilcoxon test for continuous data and Fisher's exact test for categorical data (based on simulation with B=10 000 for large tables). *294 wood and 212 biogas users. **71 wood and 97 biogas users*

The major cooking tasks of families were preparing tea, boiling milk, preparing meals for the family including day time snacks and fodder for animals. Except for two households all other biogas-using households reported preparing tea on biogas stoves. Eleven firewood using households prepared tea with fuels other than firewood. Milk was invariably boiled in firewood stoves in both households but 8% of biogas using household also boiled milk occasionally with biogas fuel besides firewood. All of the families prepared animal fodder in firewood, except one household which cooked using biogas fuel. Only 20 households (17 firewood and 3 biogas users) had a chimney in the stoves to exhaust smoke outdoors. Families cooked a median number of eight dishes in a day. Biogas users cooked a median number of six dishes with biogas and one dish with firewood while wood users cooked almost all of the meals using firewood. Although 71 houses (35 firewood users and 36 biogas users) owned additional LPG cylinders as a reserve fuel for emergencies and adverse weather conditions, a cylinder lasted for at least a year and up to four years in these households, thus reflecting very rare use of these additional fuels.

4.3.2 Socio-economic status

Households using firewood and biogas differed significantly in their socio-economic status score derived using principal component analysis. Almost a third of the firewood users were from the lowest wealth quintile while less than 5% of biogas users fell in the same category. Two thirds of the biogas users were from the upper two quintiles in comparison to only one fifth of the firewood users (**Table 4.8**).

Table 4.8: Socio-economic status in firewood-and biogas-using households

	All (N=519)	Wood (N=300)	Biogas (N=219)	p value
Wealth quintile				<0.001
Lowest	105 (20.23%)	97 (32.33%)	8 (3.65%)	
Second	103 (19.85%)	73 (24.33%)	30 (13.7%)	
Middle	103 (19.85%)	69 (23%)	34 (15.53%)	
Fourth	104 (20.04%)	45 (15%)	59 (26.94%)	
Highest	104 (20.04%)	16 (5.33%)	88 (40.18%)	
Socio-economic score	0.00, 0.18, (-0.87-1.07)	-0.69, -0.47, (-1.56,0.41)	0.94, 1.02 (0.23-1.76)	<0.001

Data are mean, median (IQR) or number (%) unless otherwise specified. P value based on Wilcoxon test for continuous data and Fisher's exact test for categorical data (based on simulation with B=10 000 for large tables).

4.3.3 Individual-level characteristics

Table 4.9 compares the biological characteristics of the firewood- and biogas-using cooks. Primary cooks from households using biogas were significantly older than those using firewood. The median age of the cooks were 48 and 50 years respectively in firewood and biogas users. There was no significant difference in the height of the cooks but the median weight differed by 2.5 kg, biogas users being heavier. A quarter of the biogas users were overweight. A significant number of firewood users were from underprivileged caste groups- Dalits, Kumal or Miya, while biogas users were predominantly Brahmin or Chhetri, the privileged caste group.

Table 4.9: Biological characteristics of primary cooks in firewood- and biogas-using households

	All (N=519)	Wood (N=300)	Biogas (N=219)	p value
Age in years	49.70, 49 (40-59)	48.29, 48 (39-57)	51.63, 50 (42-60)	0.002
Weight in kilograms*	50.61, 50 (44-56)	49.72, 49 (39-57)	51.81, 51.50 (45-57)	0.006
Height in meters*	150.90, 151 (147-154)	150.80, 151 (147-154)	151.10, 151.50 (147.25-154)	0.362
Body mass index in kg/m^2*	22.17, 21.78 (19.78-24.20)	21.83, 21.37 (19.72-23.62)	22.64, 22.48 (19.94-24.88)	0.009
Underweight	74 (14.42%)	45 (15.25%)	29 (13.30%)	
Normal	343 (66.86%)	206 (69.83%)	137 (62.84%)	
Overweight	96 (18.71%)	44 (14.92%)	52 (23.85%)	
Ethnicity				<0.001
Brahmin/chhetri	260 (50.10%)	127 (42.33%)	133 (60.73%)	
Newar	63 (12.14%)	23 (7.67%)	40 (18.26%)	
Mangols	48 (9.25%)	22 (7.33%)	26 (11.87%)	
Dalits, Kumal and Miya	148 (28.52%)	128 (42.67%)	20 (9.13%)	

*Data are mean, median (IQR) or number (%) unless otherwise specified. P value based on Wilcoxon test for continuous data and Fisher's exact test for categorical data (based on simulation with B=10 000 for large tables). *Data based on 295 firewood users and 218 biogas users.*

There was a high prevalence of smoking among the cooks in both groups (see **Table 4.10**). 49% of biogas users and 56% of firewood users reported ever having smoked cigarettes. One in every four cooks using biogas was a current smoker compared to more than one in every three cooks using firewood. The median consumption of cigarettes was similar between the groups, 7.55 pack years in firewood users versus 7.33 pack years in biogas users. There was no statistical difference in smoking duration, age at which smoking started and pack years consumption between the two groups.

Table 4.10: Smoking among primary cooks in firewood- and biogas-using households

	All (N=519)	Wood (N=300)	Biogas (N=219)	p value
Ever or never smoking				0.091
Never smoker	245 (47.21%)	132 (44%)	113 (51.59%)	
Ever smoker	274 (52.79%)	168 (56%)	106 (48.41%)	
Smoking				0.022
Never	245 (47.21%)	132 (44%)	113 (51.59%)	
Former	107 (20.62%)	57 (19%)	50 (22.83%)	
Current	167 (32.18%)	111 (37%)	56 (25.57%)	
Pack years of smoking*	10.95, 7.50 (3.92-14.95)	11.17, 7.55 (4.00-14.77)	10.61, 7.33 (3.90-14.95)	0.612
Age in years at which smoking started*	17.33, 15 (12-20)	17.30, 15 (13-20)	17.39, 15 (12-20)	0.620
Duration smoked for in years*	32.12, 33 (20-44)	31.11, 30.50 (20-42)	33.71, 37 (21.50-46.50)	0.144

*Data are mean, median (IQR) or number (%) unless otherwise specified. P value based on Wilcoxon test for continuous data and Fisher's exact test for categorical data (based on simulation with B=10 000 for large tables). *Data based on 164 firewood users and 102 biogas users.*

4.4 Carbon monoxide levels in biogas and firewood users

24 hour kitchen concentrations of CO were measured in 80 biogas and 63 firewood users during summer. A total of 21 houses lacked complete 24 hour CO measurements (from 2 minutes up to 60 minutes) but these measurements captured all the cooking sessions of the family (morning, evening and day meals). Had the devices been placed longer they would not have contributed additional CO as all of the cooking and fuel use for the day was captured by the device already. One device went off 4 hours earlier and the measurement was discarded.

A typical 24 hour CO record showed two peaks - one during morning meal and another during evening meal preparation (**Figure 4.2**). Additional peaks can occur when the family ignites fire for other reasons, mostly for preparing tea. The absolute peak CO concentration was as high as 1348 ppm in firewood-using households and 807 ppm in biogas-using households. The median peak CO concentration was significantly lower in households using biogas than in households using firewood (47.50 ppm versus 235 ppm, Wilcoxon test: $p<0.001$). Households using biogas had 77% lower mean 24 hour kitchen CO levels than those using firewood. The mean CO among biogas users (4.60 ppm) was below the WHO guideline limit but wood users (20.05 ppm) were exposed to CO levels three times higher than the WHO recommended levels; differences between the two groups were statistically significant (Wilcoxon test: $p<0.001$).

Figure 4.2: Typical example of 24 hour kitchen CO recording

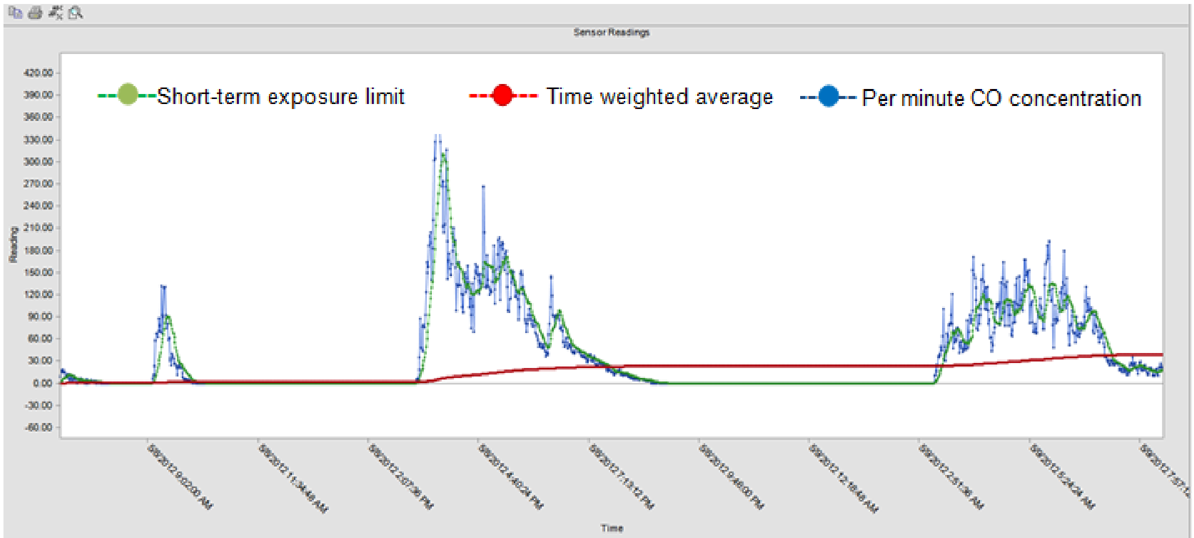


Table 4.11: 24 hour mean kitchen concentration of CO in firewood- and biogas-using households

	All (N=143)	Wood (N=63)	Biogas (N=80)	p value
24h average kitchen CO in summer in ppm	11.41, 7.06 (1.32-16.08)	20.05, 15.85 (9.80-26.76)	4.60, 2.10 (0.87-5.85)	<0.001
Peak CO level in summer in ppm	185.7, 141 (45.5-247)	284, 235 (150-341)	108.2, 47.5 (27-144.5)	<0.001
24 h average kitchen CO in winter in ppm*	6.42, 3.42 (1.02-8.05)	8.59, 6.03 (2.35-13.28)	4.17, 1.51 (1.01-5.04)	<0.001
Peak CO level in winter in ppm*	134.50,74 (47.50-156.50)	152.4, 130 (64.25-204.75)	116, 55 (40.50-90)	0.010

Data are mean, median (IQR) or number (%) unless otherwise specified.
*P value based on Wilcoxon test for continuous data. *Data based on 28 firewood users and 27 biogas users.*

In a subset of households measured in summer, we re-measured kitchen CO in winter. Households had lower levels of CO in winter than during summer but still the difference between biogas- and firewood-using household persisted as shown in **Table 4.11**.

4.4.1 Univariate analysis of CO

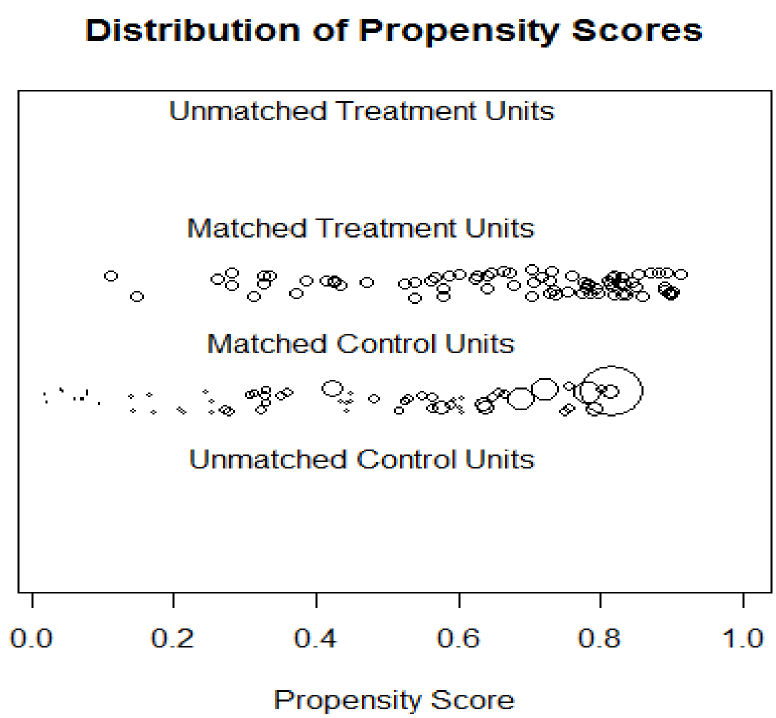
CO data were log transformed for regression analyses owing to their skewed distribution. Linear regression models were fitted with log CO as the dependent variable to estimate the effect of biogas fuel use on kitchen concentrations. **Table 4.12** shows the balance achieved in SES after matching.

Table 4.12: Balance improvement for analysis of CO concentrations through matching on socio-economic status score

	Biogas users	Wood users before matching	Wood users after matching	Standardized mean difference
Socio-economic status score (mean)	1.169	-0.334	1.035	0.119
Matched number	80	63	`63	NA

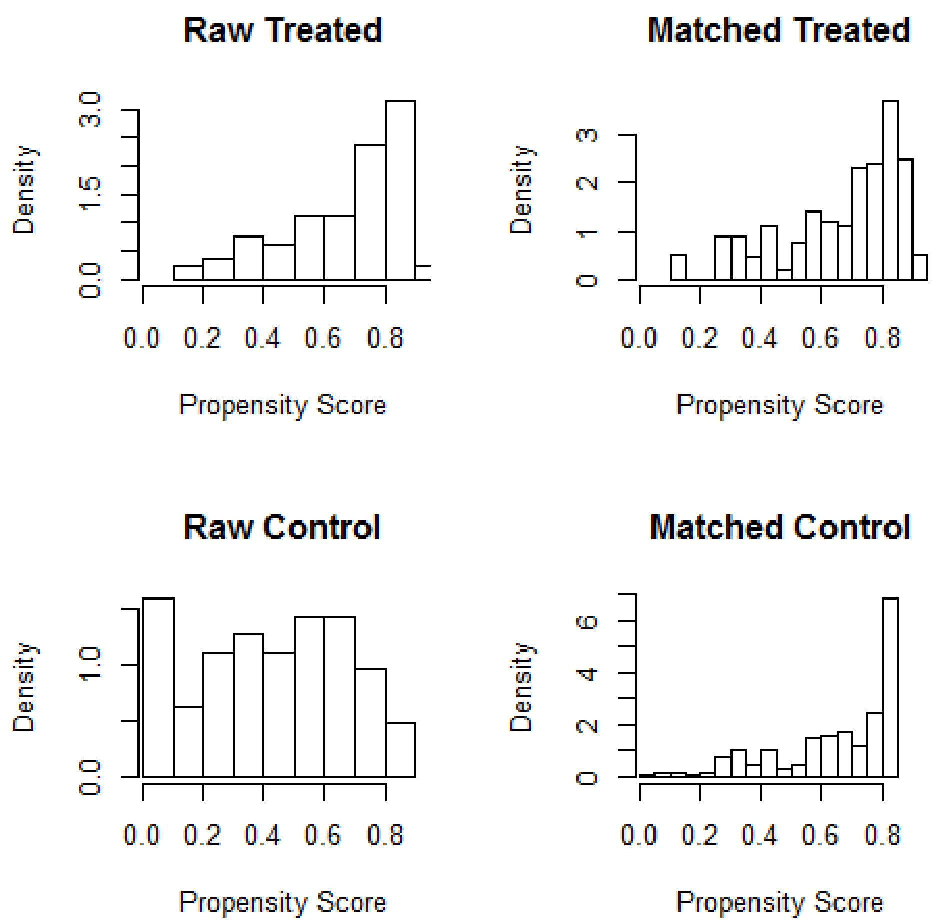
Figure 4.3 shows a jitter plot of the propensity score for households using biogas and firewood. Each circle represents one household and the size of the circle reflects that household's weight in the matched sample. All treated households received a weight of 1. The weight of the control households depended on how many treated and control units were in a matched subclass. Control units with small propensity scores received a lower weight because there were no treated households with propensity scores that low. Owing to the use of full matching there were no unmatched treated or control units.

Figure 4.3: Jitter plot of propensity scores for firewood and biogas using households. The size of each circle is proportional to the weight given to that household.



The jitter plot also shows the overlap of propensity scores in the two groups, in this case there was considerable overlap, which is a good precondition for obtaining valid causal estimates. The histograms of the density of propensity scores show the general improvement in balance achieved before and after matching. Despite matching, there were a few biogas-using households with an SES much greater than the firewood-using household as evidenced in **Figure 4.4.**

Figure 4.4: Histograms of the density of propensity scores for households before and after matching.



Univariate analysis was undertaken in both the matched and unmatched datasets. As shown in **Table 4.13** biogas fuel use was associated with significant reductions in the kitchen concentration of CO in both analysis strategies. In the matched analysis, having a window in the kitchen and a larger kitchen volume were independently associated with decreased log 24 hour kitchen CO concentrations. Interestingly, types of kitchen or additional fuel use did not significantly influence CO levels. The findings of the sensitivity analysis were largely in line with those of the main analysis.

Table 4.13: Unadjusted effect of various factors on log transformed 24 hour kitchen carbon monoxide

	Main analysis Matched		**Sensitivity analysis Unmatched**	
Independent variables	Coefficient (95% CI)	P value	Coefficient (95% CI)	P value
Biogas	-0.749 (-0.955, -0.542)	<0.001	-0.875 (-1.064, -0.686)	<0.001
Kitchen eave spaces (ref: completely closed)				
Partially open	-0.369 (-0.720, -0.018)	0.039	-0.073 (-0.353, 0.207)	0.607
Completely open	0.088 (-0.259, 0.435)	0.619	-0.064 (-0.364, 0.237)	0.676
Kitchen type (ref: living room)				
Separate kitchen	-0.113 (-0.685, 0.460)	0.700	-0.372 (-0.792, 0.047)	0.082
External kitchen	0.206 (-0.329, 0.742)	0.449	-0.137 (-0.498,0.224)	0.454
Detached kitchen	0.368 (-0.265, 1.001)	0.255	0.322 (-0.226, 0.869)	0.248
3 walled kitchen	-0.514 (-0.262, 1.291)	0.194	0.168 (-0.534, 0.870)	0.636
Window (ref: no window)				
One window	-0.492 (-0.780, -0.204)	0.001	-0.462 (-0.773, -0.151)	0.004
More than one window	-0.448 (-0.817, -0.079)	0.017	-0.598 (-0.935, -0.262)	<0.001
Kitchen volume in m^3	-0.020 (-0.032, -0.007)	0.002	-0.011 (-0.020, -0.002)	0.013
Use of LPG	0.253 (-0.090, 0.596)	0.148	0.033 (-0.262, 0.328)	0.825
Use of electric rice cooker	-0.072 (-0.334, 0.191)	0.593	-0.149 (-0.387, 0.089)	0.218
Wealth quintile (ref: lowest)				
Second	Not applicable	NA	0.141 (-0.269, 0.551)	0.498
Middle	NA	NA	-0.204 (-0.628, 0.219)	0.341
Fourth	NA	NA	-0.401 (-0.785, -0.017)	0.041
Highest	NA	NA	-0.648 (-1.006, -0.290)	<0.001

All estimates are expressed in log units unless otherwise specified.

4.4.2 Multi-variable analysis of 24 hour kitchen CO

In the matched analysis, use of biogas was associated with substantial reductions (β= -0.758, 95% CI [-1.030,-0.486], p<0.001) in log 24 hour CO concentrations after adjusting for additional fuel use and kitchen characteristics like eave spaces, type of kitchen, number of windows and kitchen volume.

Table 4.14: Effect of biogas on log 24 hour kitchen CO after stepwise adjustment for potential confounders

	Main analysis Matched		**Sensitivity analysis Unmatched**	
Adjusted for	Coefficient (95% CI)	p value	Coefficient (95% CI)	p value
Biogas (unadjusted)	*-0.749 (-0.955, -0.542)*	*<0.001*	*-0.875 (-1.064, -0.686)*	*<0.001*
Socioeconomic status score	NA	NA	-0.795 (-1.012, -0.577)	<0.001
SES, additional fuel use	-0.796 (-1.063, -0.530)	<0.001	-0.821 (-1.045, -0.596)	<0.001
SES, additional fuel use, kitchen characteristics	-0.758 (-1.030, -0.486)	<0.001	-0.871 (-1.110, -0.633)	<0.001

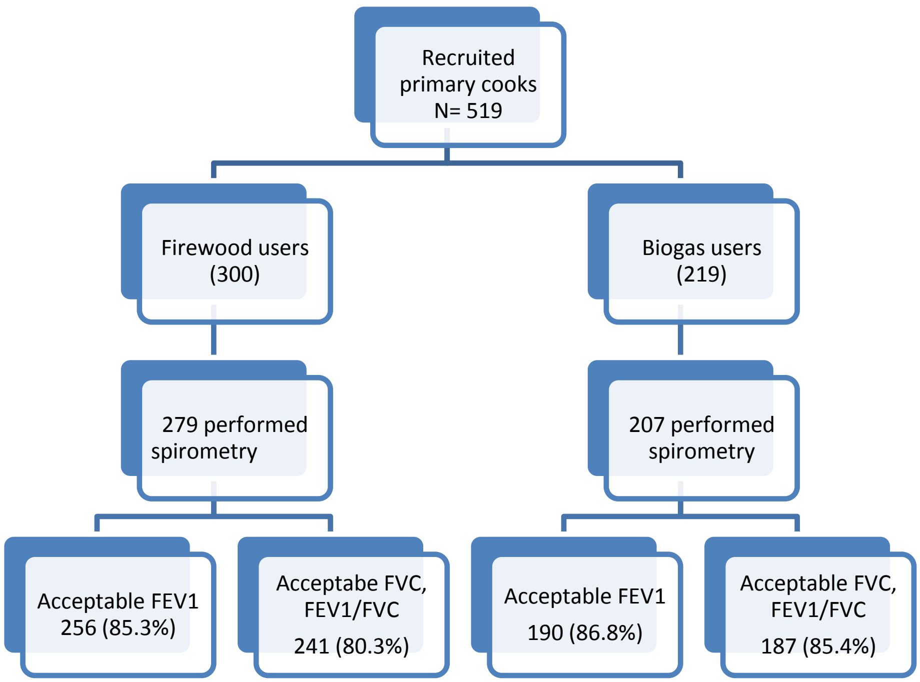
All estimates are expressed in log units unless otherwise specified.

In the unmatched sensitivity analysis this difference persisted and the effect size (β= -0.871, 95% CI [-1.110,-0.633], p<0.001) was even greater when adjusted for additional fuel use and kitchen characteristics.

4.5 Pulmonary function in biogas and firewood users

We enrolled 519 primary cooks of which 94% successfully performed spirometry. **Figure 4.5** shows the flow chart for participants' lung function measurement. 33 women (21 firewood users and 12 biogas users) felt it was challenging to perform spirometry and withdrew from the procedure without making an attempt.

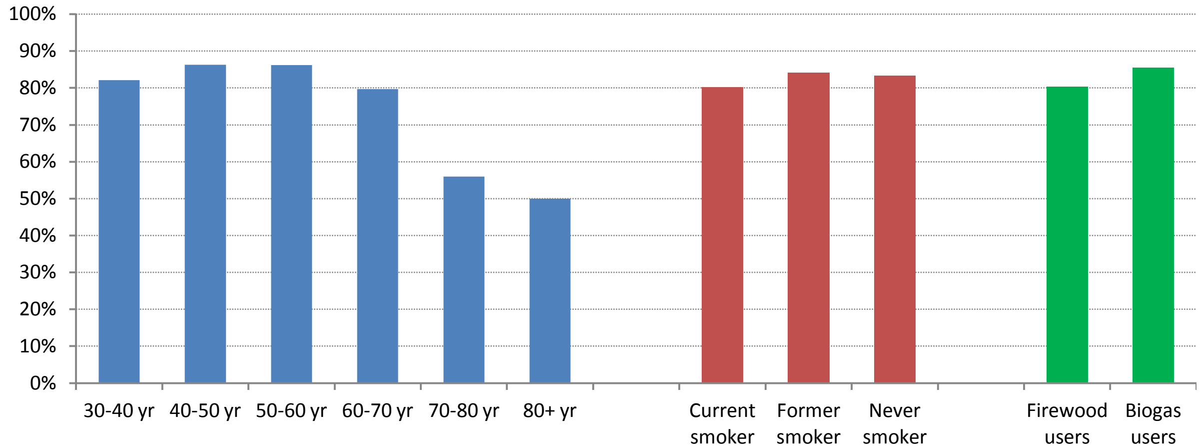
Figure 4.5: Flow chart of spirometry performance



4.5.1 Acceptable spirometry

Two medical doctors (Maniraj Neupane and Rainald Fischer) independently assessed the spirograms and any disagreement was settled through discussion. 446/519 (85.9%) spirograms were acceptable for FEV1 while only 428/519 (82.5%) FVC records met the quality criteria. Nearly 83% of the cooks produced complete records allowing classification of obstructive airway disease. **Figure 4.6** shows the success rate in terms of producing complete records in different age groups and according to the smoking status of cooks. Above the age of 40 years, successive age groups were less successful in producing complete spirometry records. The success rate did not differ by smoking status.

Figure 4.6: Spirometry success rate by age groups, smoking status and cooking fuel type



4.5.2 Between group crude comparison of lung indices

FEV1, FVC and $MEF_{2575,}$ all decreased with increasing age- intervals of 5 years as shown in **Figure 4.7**. Similarly, FEV1, FVC and MEF_{2575} increased with greater height. In an unmatched and unadjusted between-group comparison, there was no difference in FEV1, FVC, zFEV1, and MEF_{2575} between the two groups of cooks.

Table 4.15: Crude comparison of lung indices between firewood- and biogas-using cooks

	All	Wood	Biogas	p value
zFEV1 -from 256 firewood and 190 biogas users	-1.01, -0.93 (-1.84, -0.19)	-1.05, -0.93 (-1.85, -0.22)	-0.98, -0.91 (-1.83, -0.13)	0.619
FEV1 (L) -from 256 firewood and 190 biogas users	1.90, 1.96 (1.56, 2.24)	1.91, 2.00 (1.56, 2.24)	1.89, 1.90 (1.56, 2.24)	0.658
FVC (L) -from 241 firewood and 187 biogas users	2.51, 2.54 (2.13, 2.87)	2.53, 2.54 (2.16, 2.88)	2.48, 2.55 (2.09, 2.83)	0.392
MEF_{2575} (L/s) -from 239 firewood and 184 biogas users	1.759, 1.70 (1.03, 2.43)	1.74, 1.66 (1.03, 2.38)	1.78, 1.72 (1.03, 2.46)	0.705
PEF (L/s) -from 240 firewood and 185 biogas users	4.80, 4.94 (3.86, 5.88)	4.92, 5.08 (4.00, 6.00)	4.65, 4.69 (3.79, 5.61)	0.047

Data are mean, median (IQR) or number (%) unless otherwise specified. P value based on Wilcoxon test for continuous data.

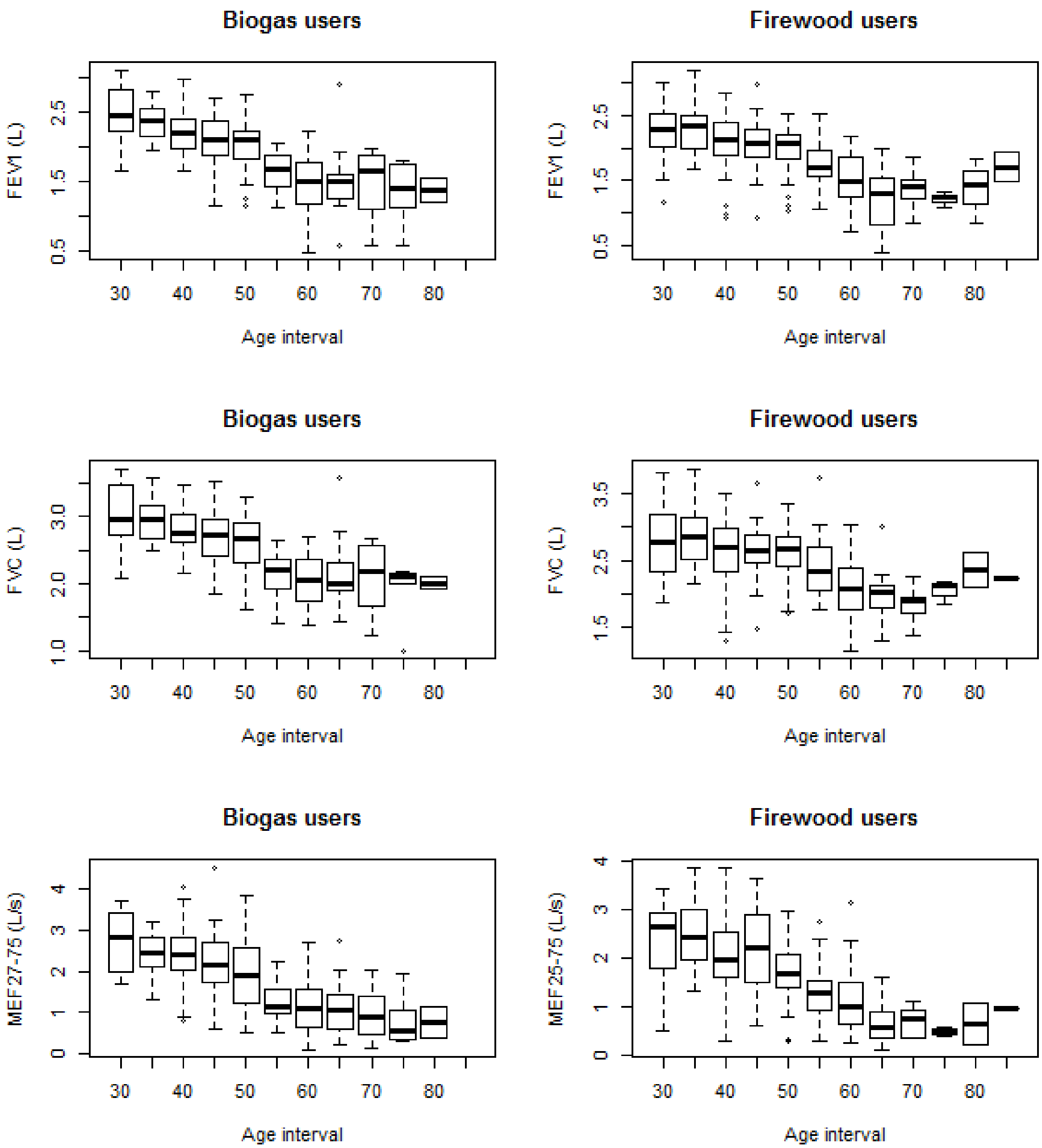


Figure 4.7: FEV1 (top), FVC (middle), MEF_{2575} (bottom) by age group in biogas and firewood users

4.5.3 Between group crude comparison of airway obstruction

The overall prevalence of airway obstruction in this population was more than 24% using a zFEV1/FVC score of less than -1.645 as a cut-off, i.e. the lower limit of normal (LLN). 26% of firewood users were diagnosed with obstructive airway disease compared to around 22% of biogas users; however the difference was not statistically significant in an unmatched and unadjusted analysis. Applying the GOLD definition yielded a prevalence of around 20% in both groups. Severe airway obstruction as defined by GOLD was present in less than 5% of cooks.

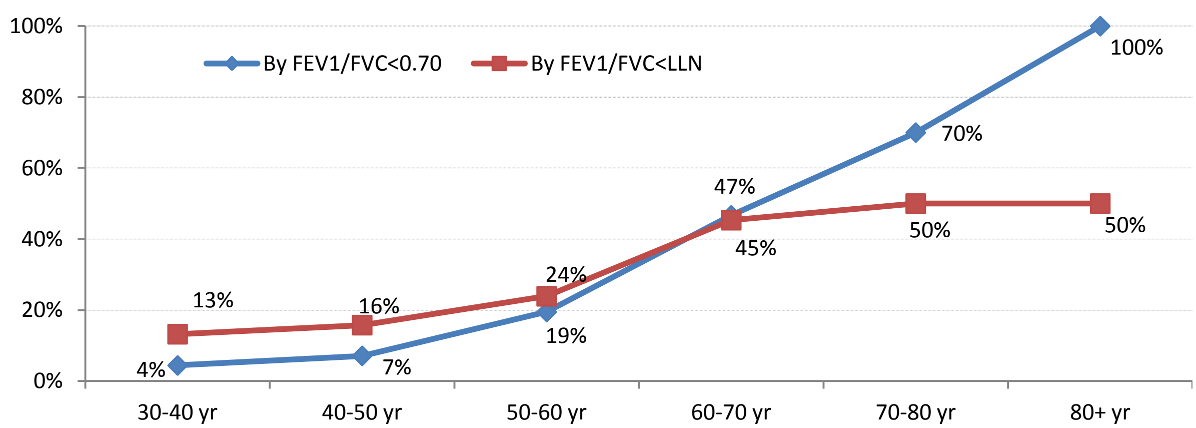
Table 4.16: Crude comparison of airway obstruction between firewood- and biogas-using cooks

	All (N=428)	Wood (N=241)	Biogas (N=187)	p value
Airway obstruction by zFEV1/FVC score less than -1.645 (LLN)	104 (24.30%)	63 (26.14%)	41 (21.93%)	0.363
Airway obstruction by GOLD criteria i.e. FEV1/FVC<0.7	86 (20.09%)	48 (19.92%)	38 (20.32%)	1
Severe airway obstruction by GOLD definition	18 (4.21%)	12 (4.98%)	6 (3.21%)	0.469

Data are number (%) unless otherwise specified. P value based on Fisher's exact test for categorical data (based on simulation with B=10 000 for large tables).

The prevalence of airway obstruction increased sharply with increasing age using both diagnostic criteria (**Figure 4.8**). The GOLD cut-off resulted in fewer airway obstructions than the LLN cut-off among the cooks under the age of 60. Among the cooks older than 60 years, the prevalence was strikingly higher based on GOLD criteria compared to the LLN cut-off. However, it should be noted that the total number of cooks producing acceptable and complete spirometry was small in these age groups (20 in 70-80 yrs and only 2 above 80 years). In any case, at least two fifths of female cooks of 60 years or more suffered from airway obstruction using either of the two diagnostic criteria.

Figure 4.8: Prevalence of airway obstruction by age group and using different diagnosis criteria



We stratified the prevalence of airway obstruction by the smoking status of cooks as shown in **Table 4.17**. Nearly 14% (11% of biogas vs. 16% of firewood users) of never smoking cooks were diagnosed to have AO using LLN criteria. AO prevalence increased from never smokers to current smokers to former smokers in both the biogas and firewood users; two fifths of former smokers were diagnosed with AO according to the LLN cut-off.

Table 4.17: Prevalence of airway obstruction by smoking status in firewood and biogas users

	AO defined by LLN (n=428/519)			AO by GOLD definition (n=428/519)		
Smoking status	Biogas	Wood	Total	Biogas	Wood	Total
Never smoker	11.00% (11/100)	16.35% (17/104)	13.73% (28/204)	9.00% (9/100)	7.69% (8/104)	8.33% (17/204)
Former Smoker	38.10% (16/42)	41.67% (20/48)	40.00% (36/90)	33.33% (14/42)	35.42% (17/48)	34.44% (31/90)
Current smoker	31.11% (14/45)	29.21% (26/89)	29.85% (40/134)	33.33% (15/45)	25.84% (23/89)	28.36% (38/134)
Total	21.93% (41/187)	26.14% (63/241)	24.30% (104/428)	20.32% (38/187)	19.92% (48/241)	20.09% (86/428)

A similar pattern of AO prevalence was observed using GOLD diagnostic criteria. Although more current smokers in the biogas group suffered from AO compared to the firewood group, it is not surprising given the differences in age of the participants.

4.5.4 Analysis of FEV1

Linear regression models were fitted with individual lung index as the dependent variable to estimate the effect of independent variables like biogas fuel use, using matched data in the main analysis and unmatched data in a sensitivity analysis.

Performance of matching and balance check

Single primary cooks from each household were matched by their SES, age and height using full matching. **Table 4.18** shows the balance in key variables achieved after matching. The standardized mean differences or ASB, defined as the weighted differences in means divided by the standard deviation in the original treated group all reduced after matching shown by the down-going slope of the line plots in **Figure 4.9**. All ASB were less than 0.25, implying that the groups are well matched.

Table 4.18: Balance achievement as shown by the reduction in absolute standardized bias after matching on socio-economic status score, age and height (for FEV1)

	Biogas	Wood before matching	Wood after matching	Standardized mean difference after (before) matching
Distance/propensity score	0.589	0.305	0.587	0.007 (1.214)
Age (mean)	51.176	48.386	52.701	-0.130 (0.237)
Height (mean)	151.314	150.819	151.508	-0.039 (0.099)
BMI (mean)	22.694	21.879	22.416	0.105 (0.216)
Weight (mean)	52.074	49.868	51.065	0.074 (0.229)
Socio-economic score (mean)	0.908	-0.587	0.848	0.055 (1.374)

Figure 4.9: Line plot of absolute standardized difference in means of selected covariates before and after matching for comparison of FEV1

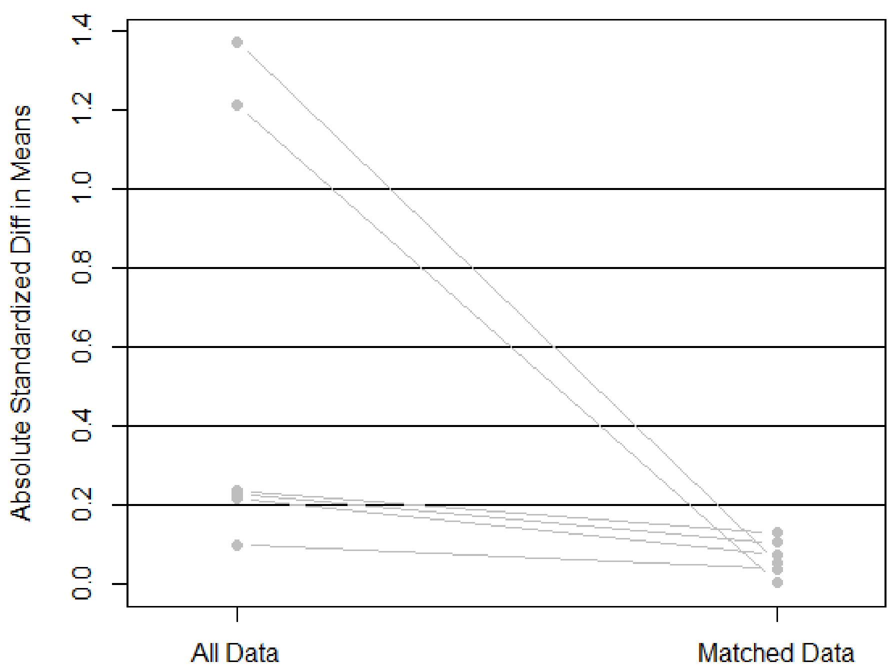
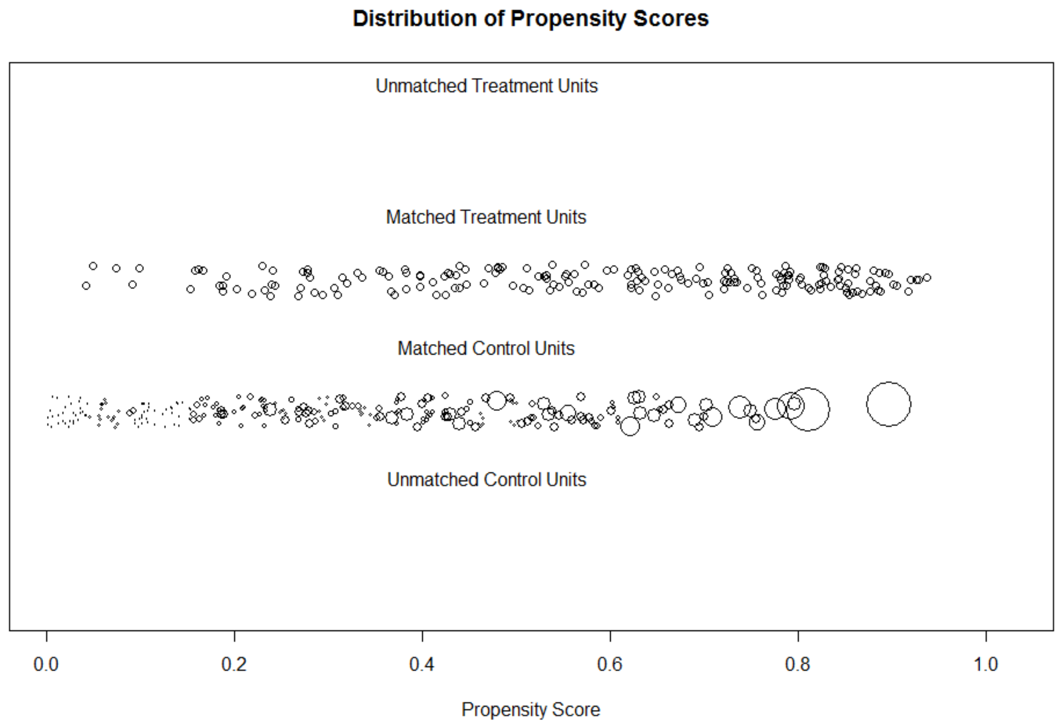


Figure 4.10 shows a jitter plot of the propensity score for primary cooks from households using biogas or firewood for cooking. Each circle represents a cook and the size of the circle reflects the assigned weight in the matched sample. All treated units received a weight of 1 while control units received weights ranging from 0.04 to 29.72. The jitter plot showed substantial overlap of the propensity scores in the two groups.

Figure 4.10: Jitter plot of propensity scores for primary cooks using either firewood or biogas for comparison of FEV1.The size of the circle reflects the weights assigned to each.



101 subclasses were formed during the matching procedure. The number of treated and control units in each subclass ranged from 1 treated and 31 control units to 1 control and 22 treated units. Such stark differences in the number of treated vs. control units were observed in only 5 subclasses, the remaining 96 subclasses had a more uniform distribution of treated and control units as shown in **Figure 4.11**.

Figure 4.11: Number of firewood and biogas users in each of the matched subclasses created during full matching for comparison of FEV1

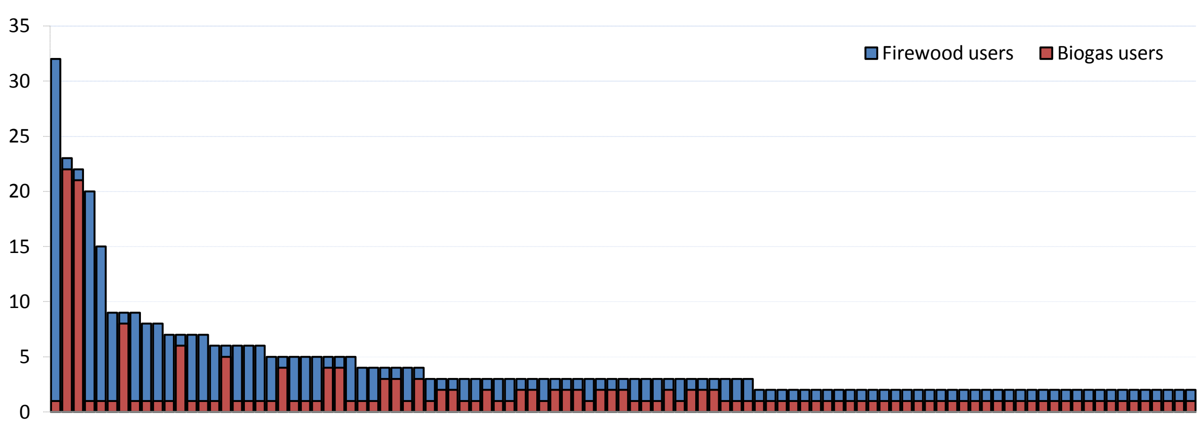
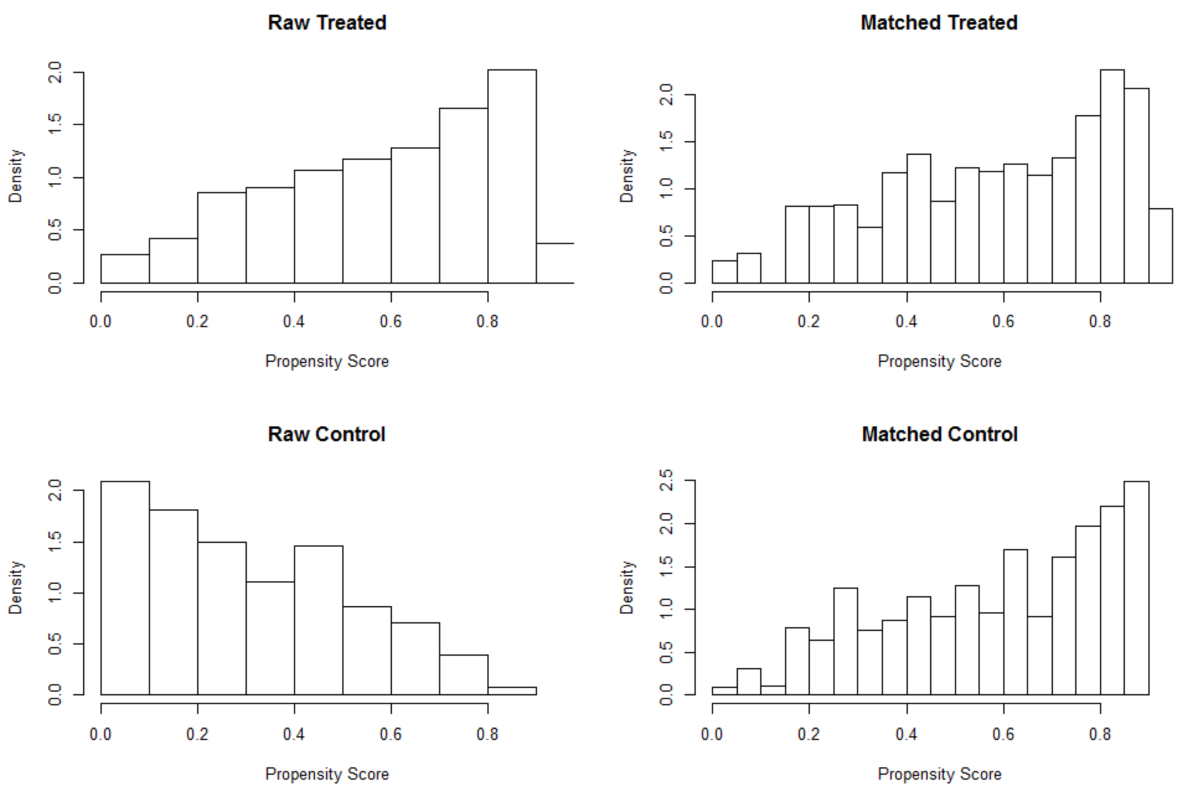


Figure 4.12 shows the distribution of the propensity scores of cooks in each fuel group before and after matching. Propensity score distributions were in contrast to each other before matching which improved markedly to more or less homogenous distribution after matching as shown by the histograms.

Figure 4.12: Histograms of the density of propensity scores for primary cooks before and after matching for comparison of FEV1



4.5.4.1 Univariate analysis of FEV1

In the univariate linear regression analysis of matched dataset, smoking status of the cook was the most important determinant of FEV1 (**Table 4.19**). Compared to a never smoker of similar age, height and SES, an ever smoking female cook had a 226 ml (345 ml – 106 ml, p<0.001) lower FEV1. Both former and current smokers had significantly lower FEV1 values than non smokers. Kitchen type and the use of an electric rice cooker were other significant determinants of FEV1 in the univariate linear regression analysis.

Table 4.19: Unadjusted effect of various factors on FEV1

	Main analysis Matched		Sensitivity analysis Unmatched	
Independent variables	Coefficient (95% CI)	P value	Coefficient (95% CI)	P value
Age	NA	NA	-0.027 (-0.030, -0.024)	<0.001
Height	NA	NA	0.044 (0.036, 0.053)	<0.001
Weight	0.008 (-0.001, 0.018)	0.081	0.018 (0.013, 0.023)	<0.001
BMI	0.017 (-0.003, 0.036)	0.094	0.027 (0.014, 0.040)	<0.001
Smoking (ref: never smoker)				
Former smoker	-0.168 (-0.309, -0.027)	0.019	-0.472 (-0.588, -0.356)	<0.001
Current smoker	-0.263 (-0.425, -0.101)	0.001	-0.340 (-0.443, -0.237)	<0.001
Ever smoker (ref: never smoker)	-0.226 (-0.345, -0.106)	<0.001	-0.394 (-0.484, -0.305)	<0.001
Wealth quintile (ref: lowest)				
Second	NA	NA	0.001 (-0.153, 0.155)	0.988
Middle	NA	NA	-0.100 (-0.254, 0.054)	0.201
Fourth	NA	NA	0.030 (-0.125, 0.185)	0.702
Highest	NA	NA	-0.080 (-0.235, 0.075)	0.309

All estimates are expressed in litres unless otherwise specified

With respect to cooking characteristics as shown in **Table 4.20**, compared to firewood, biogas use was associated with 150 ml (-21 ml – 322 ml) better FEV1 but this was not statistically significant (p=0.086). Having a separate kitchen was associated with 129 ml (12 ml – 246 ml, p=0.031) increased FEV1 compared to having the kitchen as part of the living room. Kitchen volume, quality of eave spaces or the number of windows in the kitchen were not significant determinants of FEV1 in linear regression. Biological characteristics like weight and BMI did not significantly influence FEV1 in the matched analysis.

Table 4.20: Unadjusted effect of fuel use and kitchen related variables on FEV1

Effect of fuel use and kitchen related variables on FEV1(L)				
	Matched analysis		Unmatched analysis	
Independent variables	Coefficient (95% CI)	P value	Coefficient (95% CI)	P value
Biogas	0.150 (-0.021, 0.322)	0.086	-0.016 (-0.114, 0.082)	0.747
Kitchen eave spaces (ref: completely closed)				
Partially open	-0.227 (-0.474, 0.021)	0.073	-0.070 (-0.191, 0.052)	0.263
Completely open	-0.091 (-0.222, 0.039)	0.171	-0.027 (-0.165, 0.111)	0.698
Kitchen type (ref: living room)				
Separate kitchen	0.129 (0.012, 0.246)	0.031	0.100 (-0.049, 0.249)	0.188
External kitchen	-0.066 (-0.248, 0.117)	0.482	-0.004 (-0.157, 0.147)	0.950
Detached kitchen	0.162 (-0.045, 0.369)	0.126	0.145 (-0.076, 0.367)	0.196
3 walled kitchen	-0.315 (-0.549, -0.081)	0.008	-0.288 (-0.761, 0.184)	0.232
Window (ref: no window)				
One window	-0.016 (-0.185,0.152)	0.849	0.034 (-0.106,0.174)	0.632
More than one window	0.061 (-0.117,0.239)	0.502	-0.027 (-0.186,0.131)	0.733
Kitchen volume in m^3	0.002 (-0.005,0.010)	0.558	<0.001 (-0.004,0.005)	0.988
Use of LPG	-0.190 (-0.448,0.067)	0.148	0.008 (-0.133,0.150)	0.909
Use of electric rice cooker	-0.198 (-0.333,-0.063)	0.004	-0.013 (-0.119,0.093)	0.809
			All estimates are expressed in litres unless otherwise specified	

In the unmatched sensitivity analysis, all biological characteristics like age, height, weight, BMI were significant (all p<0.001) determinants of FEV1. As in the matched analysis, an ever smoking female cook had 394 ml (305 ml – 484 ml, p<0.001) lower FEV1 compared to a never smoker. Both the former and current smokers had significantly lower FEV1 than a non smoker. None of the kitchen characteristics significantly influenced FEV1; neither did biogas use or any additional fuel use.

4.5.4.2 Multi-variable analysis of FEV1

Multi-variable linear regression analysis of FEV1 in the matched dataset revealed a significant effect of biogas use on FEV1. After stepwise adjustment for smoking status of the cooks; kitchen characteristics like type of kitchen, eave spaces, kitchen volume and number of windows; and additional fuel use, cooks using biogas fuel had a 123 ml (11 ml – 236 ml, p=0.032) greater FEV1 than the cooks using firewood (**Table 4.21**).

Table 4.21: Effect of biogas on FEV1 after adjustment for important confounders

	Main analysis Matched		Sensitivity analysis Unmatched	
Adjusted for	Coefficient (95% CI)	p value	Coefficient (95% CI)	p value
Unadjusted effect of biogas	0.150 (-0.021, 0.322)	0.086	-0.016 (-0.114, 0.082)	0.747
Age, height, SES	NA	NA	0.027 (-0.056, 0.111)	0.523
Age, height, SES, smoking	0.122 (-0.022, 0.266)	0.097	0.016 (-0.066, 0.098)	0.700
Age, height, SES, smoking and kitchen characteristics	0.119 (-0.003, 0.242)	0.057	0.002 (-0.085, 0.089)	0.977
Age, height, SES, smoking, kitchen characteristics, additional fuel use	0.123 (0.011, 0.236)	0.032	0.008 (-0.080, 0.096)	0.859

All estimates are expressed in litres unless otherwise specified.

In the unmatched sensitivity analysis, adjusting for the same set of variables in a stepwise fashion did not produce a statistically significant effect of biogas use on FEV1.

4.5.5 Analysis of airway obstruction

Logistic regression models were fitted with AO as the dependent variable to estimate the effect of independent variables like biogas use. As only 428 cooks had complete spirometry records, allowing for diagnosis of the presence or absence of AO, another matched dataset was created matching primary cooks from each household by their SES, age and height using full matching. **Table 4.22** shows the balance achieved after matching. All standardized mean differences were less than 0.25, implying that the groups are well matched.

Table 4.22: Balance achievement as shown by the reduction in absolute standardized bias after matching on socio-economic status score, age and height (for AO)

	Biogas	Wood before matching	Wood after matching	Standardized mean difference after (before) matching
Distance (propensity score)	0.598	0.311	0.596	0.007 (1.239)
Age (mean)	50.876	47.946	52.306	-0.123 (0.252)
Height (mean)	151.292	150.862	151.223	0.014 (0.086)
BMI (mean)	22.706	21.937	22.864	0.017 (0.217)
Weight (mean)	52.081	50.015	51.916	-0.042 (0.206)
SES (mean)	0.917	-0.599	0.870	0.044 (1.402)

The standardized mean differences i.e. the absolute standardized bias for the matching and other key covariates all decreased and were less than 0.25 after matching as shown by the down-going slope of the line plots in **Figure 4.13**.

Figure 4.13: Line plot of absolute standardized bias of selected covariates before and after matching for comparison of airway obstruction

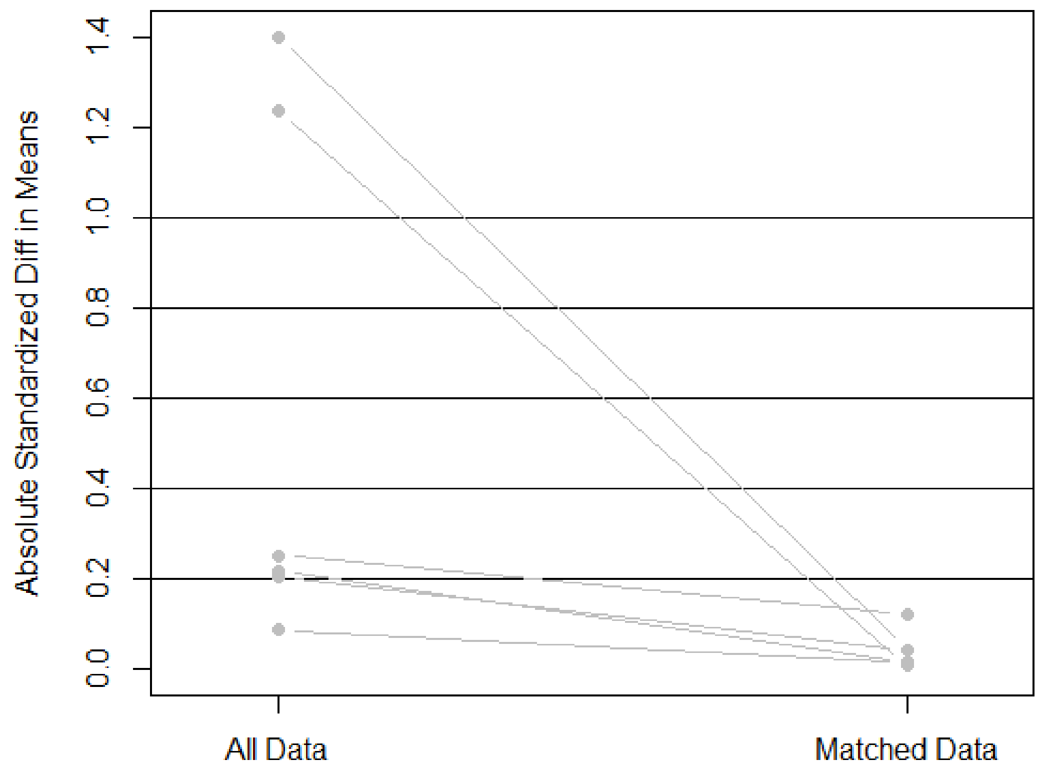
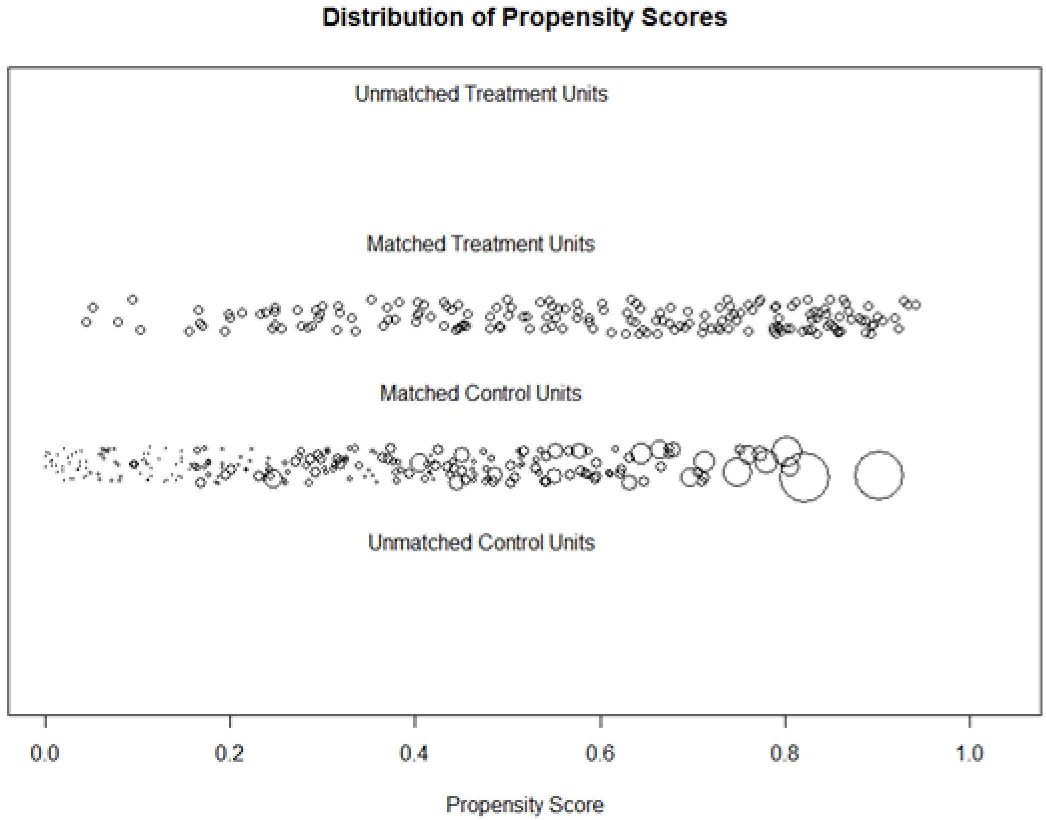


Figure 4.14 shows a jitter plot of the propensity scores. All treated units received a weight of one while control units received weights ranging from 0.04 to 27.13. 102 subclasses were formed during matching. The number of treated and control units in each subclass ranged from 1 treated and 31 control units to 1 control and 20 treated units (**Figure 4.15**).

Figure 4.14: Jitter plot of propensity scores for primary cooks using either firewood or biogas for comparison of airway obstruction. The size of the circle reflects the weights assigned to each.



The substantial overlap of the propensity scores in the two groups, as shown in the jitter plot, is a good precondition for obtaining valid causal estimates.

Figure 4.15: Number of firewood and biogas users in each of the matched subclasses created during full matching for comparison of airway obstruction

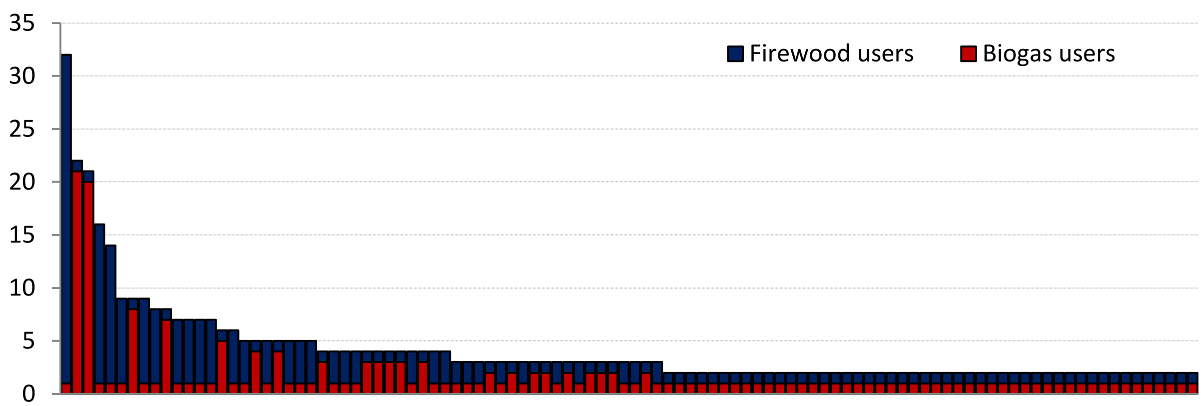
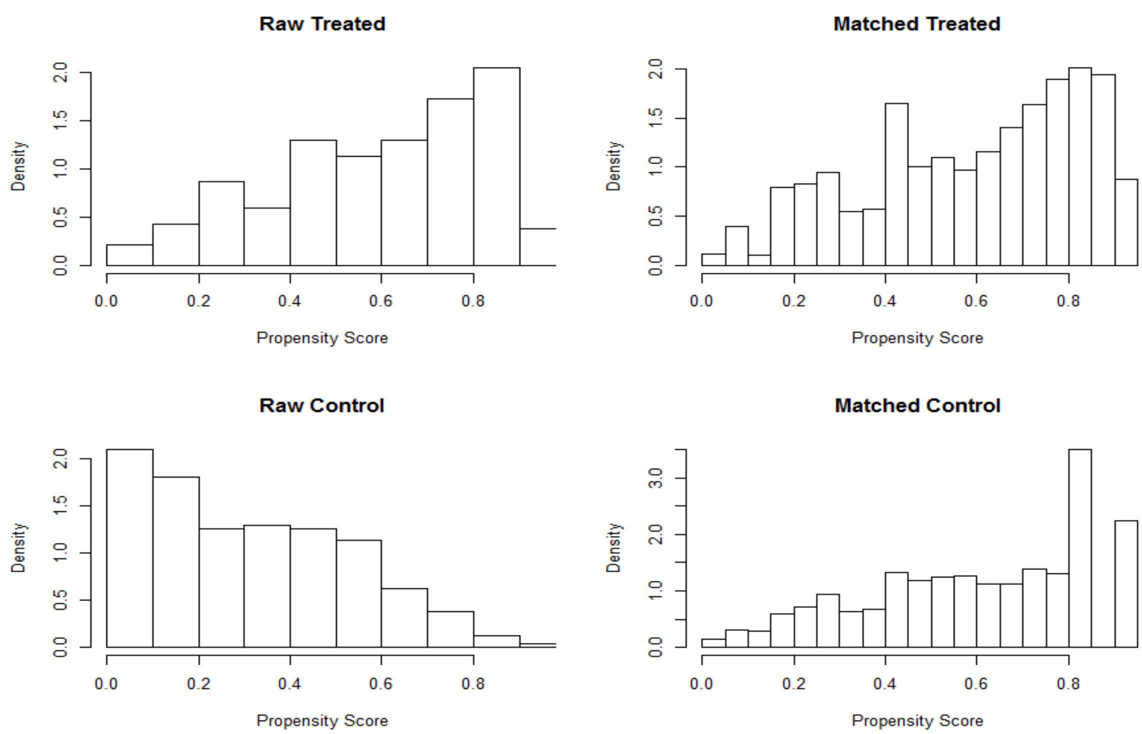


Figure 4.16 shows the distribution of the propensity scores of cooks in each fuel group before and after matching. Propensity score distributions were in contrast to each other before matching which improved markedly to more or less homogenous distribution after matching as shown by the histograms.

Figure 4.16: Histograms of the density of propensity scores for primary cooks before and after matching for comparison of airway obstruction.



4.5.5.1 Airway obstruction as defined using LLN

In the univariate logistic regression analysis of AO as defined by LLN in the matched dataset, past smokers were nearly 3 times (OR= 2.84 [1.02, 7.93]) more likely to develop AO compared to never smokers of similar socioeconomic status, age and height as shown in **Table 4.23**. There was a 46% reduced odds (OR= 0.54, [0.25, 1.19]) of developing AO with the use of biogas, but this was not statistically significant.

Out of the kitchen characteristics, poor quality eave spaces and a kitchen with only three walls were significantly associated with a substantially greater risk of developing AO. The number of windows in the kitchen, kitchen volume or use of additional fuel did not influence the outcome.

Table 4.23: Unadjusted effect of various factors on the risk of developing AO as diagnosed by LLN

	Main analysis Matched		Sensitivity analysis Unmatched	
Independent variables	Odds ratio (95% CI)	P value	Odds ratio (95% CI)	P value
Biogas	0.54 (0.25,1.19)	0.126	0.79 (0.51,1.24)	0.314
Age	NA	NA	1.06 (1.04,1.08)	<0.001
Smoking (ref: never smoker)				
Former smoker	2.84 (1.02,7.93)	0.046	4.19 (2.34,7.48)	<0.001
Current smoker	2.04 (0.75,5.59)	0.165	2.67 (1.55,4.61)	0.003
Ever smoker (ref: never smoker)	2.28 (0.91,5.69)	0.078	3.23 (1.99,5.24)	<0.001
Education (ref: none)	0.61 (0.18,2.05)	0.425	0.48 (0.27,0.86)	0.014
Kitchen eave spaces (ref: absent)				
Poor	2.46 (1.07,5.66)	0.033	1.01 (0.58,1.76)	0.973
Good	0.85 (0.20,3.60)	0.821	1 (0.53,1.87)	0.977
Kitchen type (ref: living room)				
Separate kitchen	2.14 (0.66,6.93)	0.206	1.35 (0.66,2.78)	0.409
External kitchen	2.49 (0.72,8.58)	0.148	1.22 (0.59,2.54)	0.590
Detached kitchen	4.04 (0.78,21.04)	0.097	1.64 (0.60,4.45)	0.335
3 walled kitchen	22.83 (3.08,169.25)	0.002	2.67 (0.40,17.79)	0.311
Window (ref: no window)				
One window	0.82 (0.24,2.83)	0.758	1.01 (0.53,1.92)	0.985
More than one window	0.65 (0.16,2.54)	0.533	1.09 (0.53,2.25)	0.810
Kitchen volume in m^3	0.98 (0.94,1.03)	0.486	0.99 (0.97,1.02)	0.559
Use of LPG	0.97 (0.31,3.07)	0.964	1.04 (0.56,1.96)	0.891
Use of electric rice cooker	1.91 (0.93,3.94)	0.080	1.02 (0.63,1.65)	0.920
Log10COSumAvg	--	`--	1.10 (0.637,1.94)	0.732
Wealth quintile (ref: lowest)				
Second	NA	NA	0.88 (0.42,1.85)	0.744
Middle	NA	NA	1.09 (0.53,2.25)	0.805
Fourth	NA	NA	0.95 (0.46,1.97)	0.884
Highest	NA	NA	1.56 (0.78,3.10)	0.210

In the unmatched sensitivity analysis, smoking status of the cook was an independent risk factor for developing AO. A former smoker was four times (OR= 4.19 [2.34-7.49] more likely to develop AO and a current smoker was at least 2.5 times (OR= 2.67 [1.55-4.61]) more likely to develop AO when diagnosed by LLN. A cook with some formal education had a 52% reduced odds (OR=0.48 [0.27-0.86]) of developing AO compared to a cook without any formal schooling. None of the kitchen characteristics were associated with the risk of AO in the unmatched univariate analysis.

Multivariable analysis of AO as defined by LLN

Multi-variable logistic regression analysis of AO as diagnosed by LLN revealed significant reductions in the risk of developing AO among the cooks using biogas. The effect size increased progressively with the stepwise addition of control variables in the model. When adjusting for smoking status of the cooks and kitchen characteristics, biogas use was associated with more than a 55% (OR= 0.44 [0.20-0.94]) reduction in the odds of developing AO compared to cooks using firewood and of similar socio-economic status, age and height. Further adjustments for additional fuel use resulted in a further reduction in the odds of developing AO (OR=0.35 [0.16-0.76]) for biogas use.

Table 4.24: Effect of biogas on AO after stepwise adjustment for important confounders (LLN)

AO diagnosed by values less than LLN	Main analysis Matched		Sensitivity analysis Unmatched	
Adjusted for	Odds ratio (95% CI)	p value	Odds ratio (95% CI)	p value
Unadjusted effect of biogas	0.54 (0.25, 1.19)	0.126	0.79 (0.51, 1.24)	0.314
Age, height, SES	NA	NA	0.47 (0.27, 0.83)	0.009
Age, height, SES, smoking	0.51 (0.24, 1.11)	0.092	0.48 (0.27, 0.85)	0.012
Age, height, SES, smoking and kitchen characteristics	0.44 (0.20, 0.94)	0.035	0.51 (0.27, 0.94)	0.030
Age, height, SES, smoking, kitchen characteristics, additional fuel use	0.35 (0.16, 0.76)	0.008	0.51 (0.27, 0.95)	0.033

The unmatched multi-variable sensitivity analysis produced similar findings, showing a significantly decreased odds of developing AO of about 50% (OR= 0.51 [0.27-0.95]) for biogas users in the fully adjusted model.

4.5.5.2 Airway obstruction as diagnosed by GOLD criteria

In the univariate logistic regression analysis of AO as defined by GOLD criteria in the matched dataset, cooking with biogas was not significantly (OR= 0.83 [0.34-2.02]) associated with the odds of developing AO compared to cooking with firewood as shown in **Table 4.25**. Cooks who were either current or former smokers were nearly three times (OR=

2.89[1.05-7.98]) more likely to develop AO compared to never smokers of similar socioeconomic status, age and height.

It seems that cooking in a three walled kitchen is associated with a substantial risk of developing AO, however this is not meaningful due to the distribution of the variable (all 7 households with a three walled kitchen are wood users). None of the other kitchen- and ventilation-related characteristics were associated with the risk of developing AO.

Table 4.25: Unadjusted effect of various factors on the risk of developing AO as diagnosed by GOLD criteria

	Main analysis: Matched		Sensitivity analysis: Unmatched	
Independent variables	Odds ratio (95% CI)	P value	Odds ratio (95% CI)	P value
Biogas	0.83 (0.34, 2.02)	0.683	1.02 (0.64, 1.65)	0.918
Age	NA	NA	1.12 (1.09, 1.15)	<0.001
Smoking (ref: never smoker)				
Former smoker	2.83 (1.09, 7.36)	0.033	5.78 (2.99, 11.18)	<0.001
Current smoker	2.92 (0.93, 9.18)	0.067	4.35 (2.34, 8.11)	<0.001
Ever smoker (ref: never smoker)	2.89 (1.05, 7.98)	0.041	4.90 (2.76, 8.67)	<0.001
Literacy	0.31 (0.07, 1.40)	0.129	0.30 (0.14, 0.62)	0.001
Kitchen eave spaces (ref: absent)				
Poor	2.43 (0.85, 6.95)	0.099	0.94 (0.52, 1.71)	0.846
Good	0.48 (0.10, 2.40)	0.374	0.75 (0.37, 1.53)	0.437
Kitchen type (ref: living room)				
Separate kitchen	2.18 (0.67, 7.10)	0.195	1.16 (0.55, 2.46)	0.695
External kitchen	2.02 (0.57, 7.19)	0.278	1.04 (0.49, 2.24)	0.912
Detached kitchen	2.12 (0.44, 10.28)	0.349	1.30 (0.45, 3.77)	0.630
3 walled kitchen	47.87(8.40, 272.70)	<0.001	2.97 (0.42,19.95)	0.263
Window (ref: no window)				
One window	0.87 (0.27, 2.84)	0.818	1.18 (0.58, 2.43	0.649
More than one window	0.96 (0.21, 4.34)	0.955	1.32 (0.60, 2.91)	0.493
Kitchen volume in m^3	0.98 (0.95, 1.01)	0.228	0.99 (0.97, 1.02)	0.540
Use of LPG	0.68 (0.22, 2.10)	0.502	0.88 (0.43, 1.77)	0.714
Use of electric rice cooker	1.64 (0.78, 3.46)	0.195	1.06 (0.64, 1.77)	0.818
Log10COSumAvg	--	--	1.29 (0.70, 2.40)	0.412
Wealth quintile (ref: lowest)				
Second	NA	NA	1.04 (0.48, 2.24)	0.928
Middle	NA	NA	0.97 (0.45, 2.13)	0.950
Fourth	NA	NA	0.75 (0.33, 1.69)	0.488
Highest	NA	NA	1.67 (0.80, 3.45)	0.169

In the unmatched sensitivity analysis increased age was associated with a greater odds (OR=1.12 [1.09-1.15]) of AO. Having some formal education significantly reduced the odds of AO by 70% (OR= 0.30 [0.14-0.62]). As in the matched analysis, cooks who were either current or former smokers had a nearly five times (OR=4.90 [2.76-8.67]) increased odds of developing AO.

Multivariable analysis of AO as diagnosed by GOLD criteria

When airway obstruction was diagnosed by GOLD criteria, the matched multivariable analysis adjusting for important confounders resulted in reduced odds of developing AO among biogas users compared to firewood users. However, none of the models yielded significant association as shown in **Table 4.26**.

Table 4.26: Effect of biogas on AO after stepwise adjustment for important confounders (GOLD)

AO diagnosed by GOLD criteria	Main analysis: Matched		Sensitivity analysis: Unmatched	
Adjusted for	Odds ratio (95% CI)	p value	Odds ratio (95% CI)	p value
Unadjusted effect of biogas	0.83 (0.34, 2.02)	0.683	1.02 (0.64, 1.65)	0.918
Age, height, SES	NA	NA	0.58 (0.30, 1.11)	0.101
Age, height, SES, smoking	0.87 (0.36, 2.13)	0.767	0.59 (0.30, 1.15)	0.122
Age, height, SES, smoking and kitchen characteristics	0.73 (0.28, 1.86)	0.505	0.71 (0.34, 1.46)	0.350
Age, height, SES, smoking, kitchen characteristics, additional fuel use	0.60 (0.23, 1.58)	0.300	0.71 (0.34, 1.49)	0.369

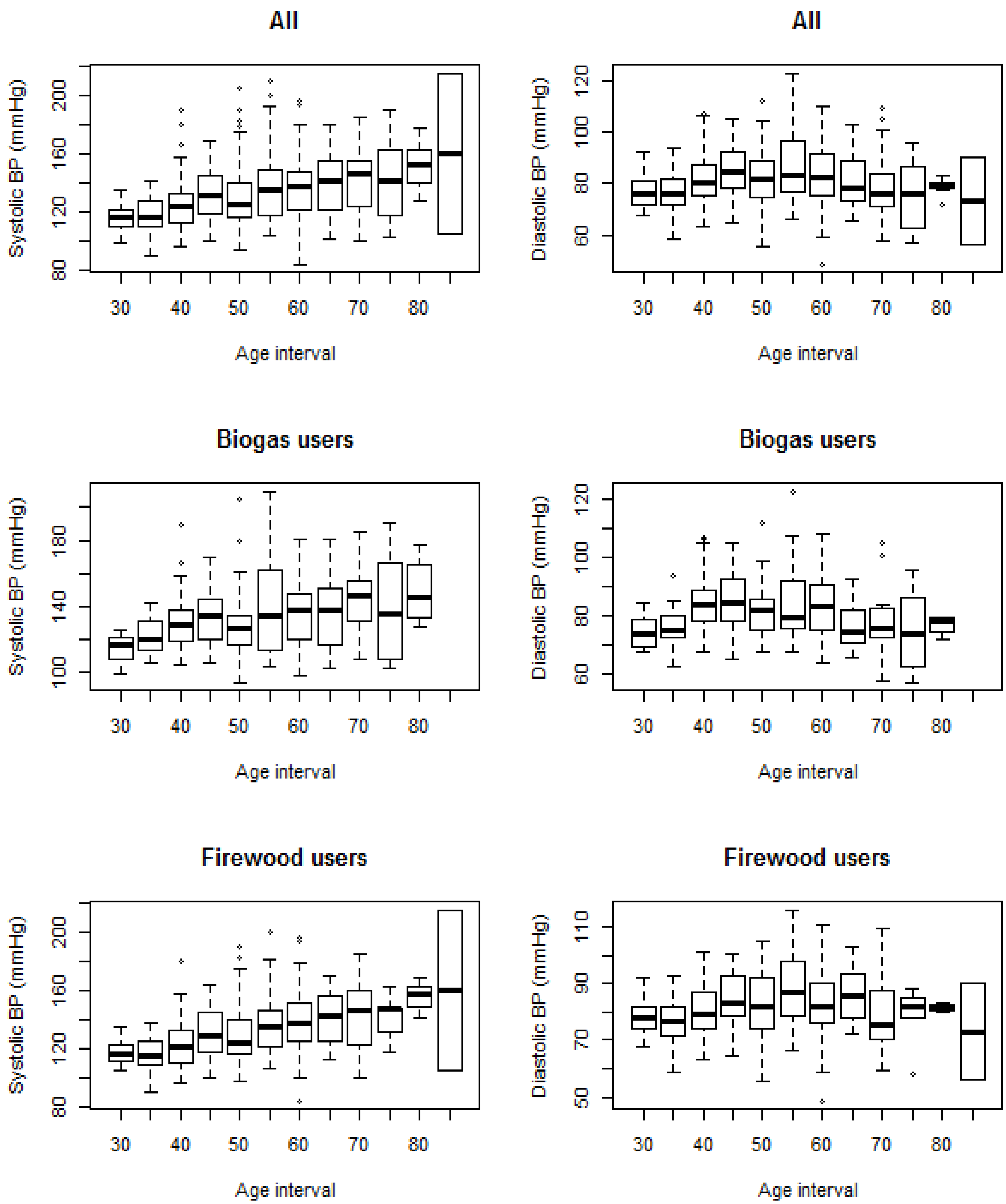
In the unmatched multi-variable sensitivity analysis, the effect of biogas use on the risk of developing AO as diagnosed by GOLD criteria was also not statistically significant.

4.6 Cardiovascular health in biogas and firewood users

All analyses of cardiovascular status were stratified into two age groups (30-50 years and >50 years) as outlined in **Table 3.5** owing to the differential risk of cardiovascular diseases in post menopausal women. (Miller et al., 2007, Liu et al., 2001)

SBP progressively increased with age in this population. DBP increased up to the age of 50 years and then decreased thereafter. With both SBP and DBP measures, we observed a notch around the age of 50 years as in **Figure 4.17**.

Figure 4.17: Distribution of systolic and diastolic blood pressure in firewood- and biogas-using cooks



4.6.1 Between group crude comparison of cardiovascular outcomes

The crude estimates of between-group comparisons of SBP, DBP and prevalence of hypertension are shown in **Table 4.27**. As expected, women aged more than 50 years had higher SBP and DBP and a higher rate of hypertension than women aged 30-50 years. In the older age group, one in two cooks had average blood pressure readings ≥140/90 mmHg, and the prevalence of high blood pressure in the overall population was 34.5%. Biogas users had lower overall SBP and DBP and also lower prevalence of hypertension than wood users; for DBP and diastolic hypertension, these differences were statistically significant. In the younger age group, biogas users had higher SBP and DBP than wood users but these differences were not statistically significant.

Table 4.27: Crude comparisons of blood pressure and prevalence of hypertension by age group and primary fuel use

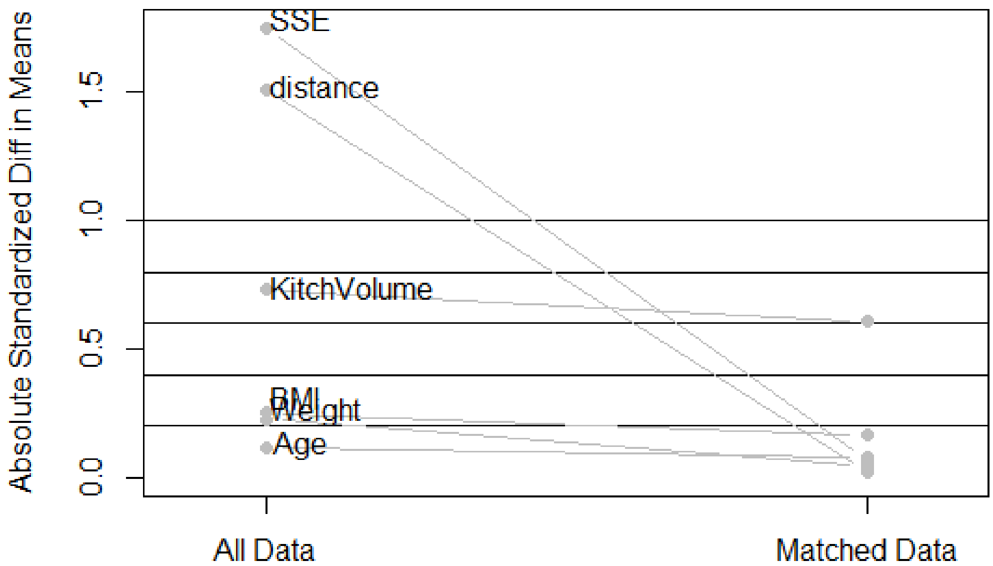
	30-50 years (N=297)			>50 years (N=222)		
Characteristics	Wood (185)	Biogas (112)	P value	Wood (115)	Biogas (107)	P value
SBP	121.33 (111.50,132.33)	124.00 (115.00,135.33)	0.07	139.00 (121.33,155.67)	136.50 (118.42,152.50)	0.44
DBP	78.67 (73.50, 86.33)	81.00 (74.50,87.00)	0.19	82.33 (76.33,92.00)	79.33 (73.42,87.67)	0.03
Hypertension	42 (22.95%)	25 (22.52%)	1	59 (52.21%)	51 (48.11%)	0.60
Systolic HTN	25 (13.66%)	20 (18.02%)	0.32	54 (47.79%)	48 (45.28%)	0.79
Diastolic HTN	33 (18.03%)	20 (18.02%)	1	36 (31.86%)	19 (17.92%)	0.02

Data are median (IQR) or number (%) unless otherwise specified. P value based on Wilcoxon test for continuous data and Fisher's exact test for categorical data (based on simulation with B=10 000 for large tables).

4.6.2 Impact of biogas on blood pressure among cooks older than 50 years

Figure 4.18 shows the reduction in the absolute standardized bias and balance achieved for key variables after matching biogas-using cooks to wood-using cooks older than 50 years. The ASB for each of the matching covariates (age, BMI and SES) was reduced to less than 0.25. Before matching, participants differed significantly in their PCA-derived socio-economic scores. After full matching, participants were well balanced in their socio-economic score (ASB was reduced from 1.746 to 0.068) and distance measure (propensity score).

Figure 4.18: Balance achievement as shown by the reduction in absolute standardized bias after matching biogas users and wood users older than 50 years



SBP and DBP among >50 years

After matching and additional adjustments for smoking status, kitchen characteristics and additional fuel use, no statistically significant differences were observed for SBP. However, both the unadjusted and adjusted model yielded more than 6 mmHg lower average DBP among biogas users compared to wood users in this age group as shown in **Table 4.28**. Unmatched sensitivity analysis yielded results that were similar to those of the matched analysis. However, the effect sizes were lower and did not reach statistical significance.

Table 4.28: Unadjusted and adjusted differences in SBP and DBP in biogas- vs wood-using cooks older than 50 years

Main analysis: Matched				
Matched by age, BMI and SES	SBP (mmHg)		DBP (mmHg)	
	Difference (95% CI)	p value	Difference (95% CI)	p value
Unadjusted effect of biogas	*-9.22 (-20.25, 1.81)*	*0.101*	*-6.14 (-11.56,-0.71)*	*0.027*
Smoking	-9.45 (-21.06, 2.16)	0.110	-6.51 (-12.28,-0.74)	0.027
Smoking, kitchen characteristics, additional fuel use	-9.84 (-20.43, 0.76)	0.069	-6.49 (-12.15,-0.82)	0.025
Sensitivity analysis: Unmatched				
Unadjusted effect of biogas	*-2.34 (-8.77, 4.11)*	*0.475*	*-3.11 (-6.37,0.15)*	*0.061*
Age, BMI, Smoking	-3.82 (-10.27, 2.63)	0.245	-3.24 (-6.45,-0.03)	0.048
Age, BMI, Smoking, SES	-2.72 (-10.45, 5.01)	0.489	-2.47 (-6.32,1.37)	0.206
Age, BMI, Smoking, SES, kitchen characteristics, additional fuel use	-4.47 (-12.95, 4.01)	0.300	-3.26 (-7.49,0.96)	0.129

Hypertension among >50 years

The adjusted and unadjusted estimates of the risk of developing hypertension are shown in **Table 4.29**. After matching and adjustment there was a 68% reduced odds (OR=0.32, 95% CI [0.14-0.71]) of developing hypertension among biogas users compared to wood users. Biogas users showed a substantial reduction (82%) in the odds of developing diastolic hypertension compared to their wood-using counterparts, whereas the observed differences in systolic hypertension were not statistically significant.

Table 4.29: Unadjusted and adjusted differences in the risk of developing hypertension in biogas- vs wood-using cooks older than 50 years

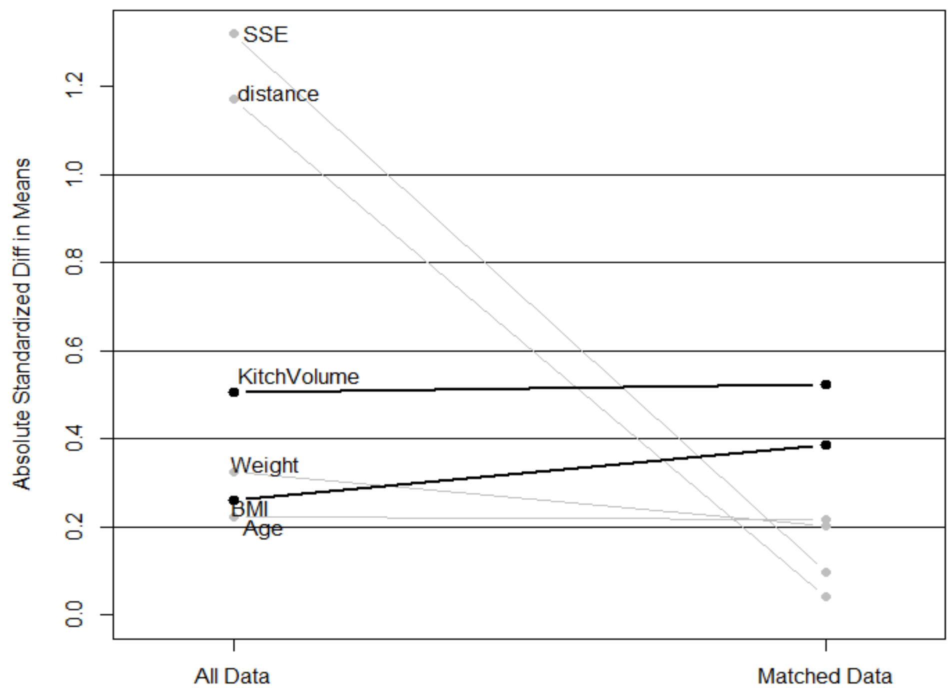
Main analysis: Matched						
Matched by age, BMI and SES (>50 years)	HTN		Systolic HTN		Diastolic HTN	
	Odds ratio (95% CI)	p value	Odds ratio (95% CI)	p value	Odds ratio (95% CI)	p value
Unadjusted effect of biogas	0.40 (0.16-1.00)	0.051	0.48 (0.16-1.39)	0.178	0.25 (0.07-0.88)	0.031
Smoking	0.39 (0.16-0.92)	0.033	0.49 (0.17-1.38)	0.176	0.23 (0.06-0.83)	0.024
Smoking, kitchen characteristics, additional fuel use	0.32 (0.14-0.71)	0.005	0.42 (0.17-1.02)	0.054	0.18 (0.05-0.60)	0.005
Sensitivity analysis: Unmatched						
Unadjusted effect of biogas	0.85 (0.50-1.44)	0.544	*0.90 (0.53-1.54)*	*0.710*	*0.47 (0.25-0.88)*	*0.019*
Age, BMI, Smoking	0.79 (0.46-1.36)	0.400	0.85 (0.49-1.47)	0.554	0.42 (0.22-0.82)	0.010
Age, BMI, Smoking, SES	0.83 (0.43-1.59)	0.572	0.85 (0.44-1.64)	0.634	0.51 (0.23-1.10)	0.085
Age, BMI, Smoking, SES, kitchen characteristics, additional fuel use	0.64 (0.30-1.33)	0.231	0.69 (0.33-1.43)	0.320	0.44 (0.18-1.05)	0.063

Unmatched sensitivity analysis showed effect in similar direction as matched analysis but was not statistically significant in the final model.

4.6.3 Impact of biogas on blood pressure among cooks aged 30-50 years

In the younger age group, however, balance was not well achieved using the same *a priori* agreed set of matching covariates as shown in **Figure 4.19**. The ASB for BMI actually worsened from 0.262 in the unmatched dataset to 0.387 after matching, and age displayed only minimal improvement (from 0.223 to 0.217). SES and the overall distance measure (propensity score) were well balanced, with the ASB for SES being reduced from 1.319 in the unmatched dataset to 0.099 in the matched dataset.

Figure 4.19: Balance achievement as shown by the reduction in absolute standardized bias after matching biogas users and wood users aged 30-50 years



SBP and DBP among 30-50 years

Contrary to older cooks, the adjusted matched analysis in the younger group showed a statistically significant 4mmHg higher SBP among biogas users compared to wood users but no differences for DPB as in **Table 4.30**. Results from the unmatched sensitivity analysis were in accordance with the matched analysis but did not reach statistical significance.

Table 4.30: Unadjusted and adjusted differences in SBP and DBP in biogas-vs wood-using cooks aged 30-50 years

Main analysis: Matched				
Matched by age, BMI and SES (30-50 years age)	SBP (mmHg)		DBP (mmHg)	
	Difference (95% CI)	p value	Difference (95% CI)	p value
Unadjusted effect of biogas	*3.59 (-0.77, 7.95)*	*0.106*	*1.14 (-2.04, 4.32)*	*0.482*
Smoking	3.76 (-0.37, 7.89)	0.075	1.37 (-1.64, 4.39)	0.372
Smoking, kitchen characteristics, ventilation and additional fuel use	4.38 (0.86, 7.90)	0.015	1.49 (-0.95, 3.93)	0.231
Sensitivity analysis: Unmatched				
Unadjusted effect of biogas	*3.77 (0.02, 7.52)*	*0.049*	*1.84 (-0.41, 4.09)*	*0.109*
Age, BMI, Smoking	1.92 (-1.85, 5.69)	0.318	0.85 (-1.40, 3.10)	0.457
Age, BMI, Smoking, SES	1.85 (-2.37, 6.08)	0.388	0.73 (-1.80, 3.25)	0.571
Age, BMI, Smoking, SES, kitchen characteristics, additional fuel use	2.80 (-1.72, 7.32)	0.223	1.33 (-1.39, 4.05)	0.337

Hypertension among 30-50 years

Table 4.31 shows the risk of hypertension among younger cooks, where no statistically significant differences between the two groups of fuel users were observed in both the matched and unmatched sensitivity analysis.

Table 4.31: Unadjusted and adjusted differences in the risk of developing hypertension in biogas- vs wood-using cooks aged 30-50 years

Main analysis: Matched						
Matched by age, BMI and SES (30-50 years age)	HTN		Systolic HTN		Diastolic HTN	
	Odds ratio (95% CI)	p value	Odds ratio (95% CI)	p value	Odds ratio (95% CI)	p value
Unadjusted effect of biogas	0.96 (0.37-2.44)	0.925	0.94 (0.32-2.70)	0.901	1.14 (0.38-3.39)	0.811
Smoking	1.08 (0.46-2.52)	0.857	1.07 (4.16-2.74)	0.890	1.32 (0.51-3.41)	0.572
Smoking, kitchen characteristics, additional fuel use	1.66 (0.75-3.72)	0.213	1.67 (0.75-3.72)	0.213	1.78 (0.67-4.76)	0.247
Sensitivity analysis: Unmatched						
Unadjusted effect of biogas	0.98 (0.56, 1.71)	0.932	1.39 (0.73, 2.64)	0.316	1.00 (0.54, 1.84)	0.997
Age, BMI, Smoking	0.81 (0.44, 1.50)	0.506	1.06 (0.53, 2.13)	0.859	0.86 (0.44, 1.67)	0.645
Age, BMI, Smoking, SES	0.87 (4.34, 1.74)	0.692	1.23 (0.56, 2.70)	0.612	0.88 (0.42, 1.87)	0.743
Age, BMI, Smoking, SES, kitchen characteristics, additional fuel use	1.05 (0.49, 2.27)	0.894	1.50 (0.63, 3.59)	0.361	1.05 (0.46, 2.37)	0.912

4.7 Questionnaire-based health symptoms in biogas and firewood users

Only unmatched between-group crude comparisons were done for health symptoms owing to the possibility of recall bias. No further univariate or multivariable analyses were done.

Table 4.32: Between groups crude comparison of health symptoms and any health care visit

	All (N=519)	Wood (N=300)	Biogas (N=219)	p value
Chronic bronchitis	75 (14.45%)	48 (16.00%)	27 (12.33%)	0.257
Cough	130 (25.05%)	83 (27.67%)	47 (21.46%)	0.124
Phlegm	122 (23.51%)	76 (25.33%)	46 (21.00%)	0.295
Wheeze	60 (11.56%)	34 (11.33%)	26 (11.87%)	0.890
Difficulty breathing	148 (28.52%)	98 (32.67%)	50 (22.83%)	0.018
Chest pain	87 (16.76%)	65 (21.67%)	22 (10.05%)	<0.001
Palpitation	98 (18.92%)	75 (25.00%)	23 (10.55%)	<0.001
Headache	338 (65.13%)	212 (70.67%)	126 (57.53%)	0.002
Cooks seeking healthcare for any cardio respiratory complaints in the last one year	155 (29.86%)	109 (36.33%)	46 (21.00%)	<0.001

Data are number (%) unless otherwise specified. P value based on Fisher's exact test for categorical data (based on simulation with B=10 000 for large tables.

As shown in **Table 4.32**, prevalence of all of the symptoms was lower or similar in biogas users compared to firewood users. Cardiac symptoms were significantly lower in the biogas using women, as was the prevalence of headache.

5 Discussion

5.1 Adoption of household biogas plants

This study also tried to explore the reasons for adoption and non adoption of biogas plants through semi closed-ended questions, although factors influencing the sustained use of the biogas plants were not explored. Shortage of firewood was the major reason to install biogas plants in majority of the households. When firewood collection was restricted and controlled to conserve the community forest, villagers had scarcity of firewood. Promotion of biogas plants by local agents from the BSP Nepal around the same time promoted biogas adoption among those who could afford it.

A systematic review by Puzzolo et al. (2013) identified 33 different factors influencing the adoption of household biogas plants across seven broad domains. Our findings are in accordance with the factors summarised within these seven broad domains which included fuel and technology characteristics (plant feeding, design requirements), household characteristics (SES, education, ownership of land and animal), knowledge (smoke, cleanliness, health benefits), subsidy, regulation, policy and market (supply and demand) issues. (Puzzolo et al., 2013)

Efficient human excreta disposal from the latrines directly into the biogas digester was an important factor attracting households in the hilly area devoid of centralised sewerage disposal system to adopt household biogas digesters. This factor identified in our study however, was not acknowledged by other studies included in the systematic review. Also, unlike the systematic review which identified perceived health benefits as widely recognized factor for adoption it is surprising that less than 5% of the households from our study installed the plants for potential health benefits. This might be because of the promotion of biogas plants by local agents who highlighted only on fuel savings, subsidy schemes, micro-financing and economic benefits neglecting the potential health benefits of switching to clean fuel.

Other reasons as pointed by the systematic review that deterred adoption like the lack of ownership of land and animals were also identified in this study. But the most important barrier for adoption is obviously the expensive upfront investment. Biogas specific issues like the fixed underground design of the digester made relocation of the plant to a new site impossible and this deterred households from adopting the plant until they moved to a permanent location.

5.2 Impact of biogas use on carbon monoxide concentrations

Although past household air pollution studies have measured kitchen levels of PM and CO in households burning wood in traditional or improved stoves and using other fuels (e.g. LPG), this is the first study to measure such pollutants in households adopting and continuously using biogas for a long period under real life cooking conditions and from intervention perspective. We documented substantial reduction in kitchen CO levels associated with biogas compared with traditional firewood stoves. Biogas users in average were exposed to 24 hour mean CO levels 25% lower than the WHO Air Quality Guideline limit (7mg/m^3~equivalent to 6.1ppm using conversion factor) (WHO, 2010) while wood users were exposed to very high levels of kitchen CO. The mean 24 hour CO in wood users (20.05 ppm) was more than four times higher than in biogas users (4.60 ppm). However, there was still substantial overlap in the distribution of CO exposure in these two groups which might be due to random variation in fuel use. It might also be due to variation in cooking behaviours or measurement error introduced by the device, especially on winter data when we hired four additional monitors from a local agency.

In our setting, households using biogas also burnt wood in open fires inside their kitchen to boil milk and to prepare animal fodder for their cattle every day. This could have resulted in higher readings documented among biogas users. Besides, households using biogas were interspersed with the majority of households using wood in these villages. So, smoke leaking from neighbouring houses that burnt wood entered the kitchens of nearby biogas users contributing to relatively high exposure levels experienced by households using biogas. This 'neighbourhood pollution' is a well observed phenomenon in HAP studies. (Smith et al., 1994, Zhang and Smith, 2007) Despite biogas being a gaseous fuel, these underlying fuel use characteristics and household cooking behaviour could explain the relatively higher kitchen CO levels in biogas users (4.6 ppm) in our study unlike the improved plancha users (1.1 ppm) in Guatemala (Smith et al., 2010) where plancha use was exclusive. Besides, the controlled nature of their study with weekly surveillance visits and repair and maintenance of plancha could have further resulted in substantially reduced CO post intervention. They achieved 90% reductions in the kitchen CO exposure with plancha while biogas users in our study had only 77% lower mean exposure than wood users.

In addition to boiling milk and preparing animal fodder in firewood, households using biogas also supplemented it with firewood at times when biogas supply ran out inadvertently while preparing main family meals. Some traditional dishes (like *selroti*- doughnut shaped deep fried bread made out of rice flour) were always cooked with firewood. This incomplete transition to biogas fuel could have largely negated its potential benefits in pollution reduction when open fire stoves were simultaneously used in the same kitchen or near outdoors.

Eight households using firewood had 24 hour kitchen CO levels less than 6.1ppm (WHO cut-off). Although these households did not posses chimney or smoke-hood for venting smoke outside, they had either good ventilation as reflected by large windows or large eave spaces. In addition, kitchens of three of these households were completely open on one side, while six households also used additional rice cooker or LPG for meeting some of their cooking needs which could have contributed to the lower levels of CO in these wood users. Fuel type, windows in the kitchen, partially open eave spaces and large kitchen volume were significant predictors of kitchen CO in our study consistent with Balakrishnan et al. (2013) from a study in India. Unlike for them, kitchen type did not influence CO levels in our study. Bruce et al. (2004) also reported stove/fuel type as the most important determinant of kitchen CO along with some effect of eave spaces.

5.2.1 Effect of interventions to reduce pollutant concentration-locating the findings

Biogas users in our study had more than four times lower kitchen CO levels than the wood users. Lack of studies measuring pollutants concentration inside biogas using kitchens prevents us from comparing our findings. However, relating the results with other studies using either improved stove or LPG provides useful insights. A study from Nepal reported more than 10 times lower respirable PM among LPG users than the biomass users. (Kurmi et al., 2008) However, this study compared wood users from rural villages to LPG users from urban areas thereby differing in background pollution level, cooking needs as well as socio-economic status etc. Another study from India comparing biomass with LPG- a gaseous fuel similar to biogas observed 3 times lower particulates among LPG users (Dutta et al., 2011) and this is consistent with our study, except that we observed similar trend with kitchen CO. **Table 5.1** compares kitchen CO and PM associated with different fuel types or interventions across several study settings.

Despite the fact that we observed significantly lower CO levels among households using biogas the overlap of exposure between the two groups warrants long periods of monitoring, repeated in different season along with recording of detailed cooking history and time activity pattern to get a true picture of HAP exposure.

Table 5.1: Carbon monoxide and particulate concentrations in relation to published data

Country	Exposure measured	Fuel/stove type	Mean levels
Nepal (Current study, 2014)	24h kitchen CO (summer)	Biogas (n= 80) Firewood (n=63)	4.60 ppm 20.05 ppm
Nepal (Current study, 2014)	24h kitchen CO (winter)	Biogas (n= 27) Firewood (n=28)	4.17 ppm 8.59 ppm
Nepal (Kurmi et al., 2013)	24h kitchen CO	Biomass (n=30) LPG (n=23)	13.4 ppm 2 ppm
Nepal (Kurmi et al., 2013)	24h PM2.5	Biomass (n=30) LPG (n=23)	455 μg/m^3 101 μg/m^3
Nepal (Singh et al., 2012)	24h kitchen CO	ICS (n=36) Traditional stove (n=36)	8.35 ppm 22.2 ppm
India (Dutta et al., 2011)	8h kitchen PM2.5	Biomass (n=244) LPG (n=236)	156 μg/m^3 52 μg/m^3
Guatemala (Smith et al., 2010)	48h kitchen CO	Improved plancha (n=36) Open fire wood (n=36)	1.10 ppm 8.60 ppm
India (Chengappa et al., 2007)	24h kitchen CO	Improved stove (n=15) Open fire (n=15)	2.68 ppm 8.67 ppm
Guatemala (Bruce et al., 2004)	24h kitchen CO	Improved planchas (n=16) Open fire (n=99) Gas (n=20)	3.09 ppm 12.4 ppm 7.75 ppm
Guatemala (Albalak et al., 2001)	24h kitchen PM3.5	Improved plancha (n=59) Open fire (n=58) LPG/open fire (n=60)	280 μg/m^3 1560 μg/m^3 850 μg/m^3

Although repeat winter measurements in a subsample of households was planned to validate the reductions, to our surprise, we noticed lower levels of CO during winter in both the firewood and biogas users. It has been indicated that moisture content in the fuel affects CO concentration (Demirbas, 2004). Firewood might be soaked and wet during rainy days observed in summer while in winters we noticed that households used their wood reserve kept dried for a long time. Temperature never reaches below freezing in our study site and households did not use any space heating methods, so this might also be reason for not observing very high exposure during winter. Further, our winter measurements might also have been influenced by additional monitors that we used during winter measurements. Devices used for summer monitoring were all brand new and factory calibrated. These same devices were used after factory re-calibration in Munich for winter measurements. However, for logistic reasons we borrowed four additional monitors from a local agency that were being used for a similar purpose in another study and those were not calibrated even after their long use.

Although we observed lower CO levels with biogas use and studies have suggested that CO being easy to measure could be used as proxy for PM2.5 exposure (Naeher et al., 2000), there are concerns that CO may not be a valid surrogate for particulates when using gas stoves or other clean fuels. (Naeher et al., 2001) It is also argued that mean 24 hour CO levels may not indicate their peak concentrations which might play a role in ill health of the cooks. (Naeher et al., 2001) Differences in the physical characteristics of CO and PM and the combustion processes of different fuels may lead to a differential reduction in their levels as seen in a study in India, where CO exposure was reduced by 70% but the simultaneous reduction in PM2.5 was only 44%. (Chengappa et al., 2007) This can have important health as well as research implications depending on the mechanistic pathways of the disease involving HAP.

In addition, because we did not measure personal CO exposure of the cooks, we are not sure if the reduction in kitchen CO exposure also translates to reduction in personal CO exposure. Evidence from past studies show that kitchen CO measurements are not always representative of personal CO measurements. (Clark et al., 2013) Personal CO measurement using dosimeter techniques would have better captured this difference however, data from RESPIRE trial shows that the personal CO measurements were only lowered by 50-60% compared to the 90% lowering of kitchen CO level (Smith et al., 2010).

Alternative technologies should not only aim for reduction in exposure but it should also be culturally appropriate and meet diverse cooking needs. Although biogas was well adopted by its users, some high-power consuming cooking activities were not done with biogas-including boiling of large quantity of milk every day or preparing *selrotis* and animal fodder and users felt that high intensity of wood flame would be appropriate for such activities. This phenomenon promotes fuel stacking and incomplete transition to clean fuel thereby still using traditional stoves and compromising the potential health benefits associated with clean fuel use.

Summary of CO findings

We documented substantial reduction in kitchen CO levels associated with biogas use compared to traditional firewood use in rural Nepal. Despite the overlap in the distribution of kitchen CO exposure in the two fuel groups, marked reduction in kitchen CO levels associated with biogas provides evidence that household biogas plants could be a clean alternative fuel for rural households relying on animal rearing and subsistence farming. Further change in cooking practice, installing additional improved stoves to replace open fires and improving ventilation would potentiate the benefits from biogas.

5.3 Impact of biogas on respiratory health

5.3.1 Lung indices (FEV1, zFEV1, FVC, MEF_{2575})

One of the primary aims of this study was to assess the impact of sustained use of biogas on respiratory health of cooks. We hypothesized that biogas user compared to wood user of same age and height will have at least 100 ml better FEV1 and associated lower risk of developing airway obstruction. We observed 123 ml (11 - 236ml, p=0.032) better FEV1 among biogas users compared to firewood users of same age, height and SES when adjusted for kitchen and ventilation characteristics and additional fuel use. We also observed positive effect of biogas use on other lung indices; zFEV1, FVC and MEF2575. This was significantly higher for MEF2575 (0.263 [0.120, 0.407] L/sec) while effect on zFEV1 (0.339 [-0.011, 0.689] standard deviation) and FVC (0.034 [-0.114, 0.183] L) did not reach statistical significance.

As confirmed by other studies, we found age and height to be significant biological predictor of lung function. (Quanjer et al., 2012b) BMI and weight did not have predictive ability on FEV1 when cooks were matched by age, height and SES. Smoking was found to adversely affect FEV1 as in other studies linking smoking and impaired lung function or airway obstruction. (Willemse et al., 2004)

Mean FEV1 in our study (1.90 L) is similar to what Pandey reported (1.89 L in nonsmoker and 1.75 L in smokers) among biomass exposed cooks on the outskirts of Kathmandu. (Pandey et al., 1985) In a recent study, biomass exposed non-smoker females had mean FEV1 of 2.12 L (Kurmi et al., 2013) comparably higher than what we observed in our study. However, participants in that study were much younger (mean age 34.8 years) compared to those in our study (mean age 49.7 years) and thereby age is likely to explain the difference in mean FEV1 in these two studies.

5.3.2 Effect of interventions to reduce HAP on FEV1- locating the findings

Table 5.2 summarizes the findings from comparable studies which researched different interventions aiming to reduce HAP. As none of these studies have analyzed the effect of biogas on FEV1, we again compare our findings with studies using either ICS or LPG. Out of all the studies summarized, we report the highest difference in FEV1 (123ml [11-236], p=0.032) and this was statistically significant. Kurmi et al. (2013) reported 74ml lower FEV1 among biomass users compared to LPG users, however, participants in this study were recruited from two different community settings rural (for biomass) and urban area (for LPG). Another study from Ecuador unlike our study found contrary effect i.e. reductions of FEV1 with LPG use, although this was statistically not significant. This study however had small sample size-24 'LPG only' vs. 22 'biomass only' females and the duration of exposure to biomass or clean fuel was not known.(Rinne et al., 2006) Another study from Mexico associated 81 ml lower FEV1 among firewood users exposed to more than 2.6mg/m^3 of PM10. (Regalado et al., 2006)

Table 5.2: Comparison of differences in FEV1 from this current study with other published studies

Country/ *Study design* (Reference)	Adjusted for	Exposure/Fuel/Stove type compared	Duration of exposure to intervention	FEV1 difference
Nepal (30-83 yrs) *Cross-sectional* (Current study, 2014)	Matched by age, height, SES and adjusted for kitchen characteristics, ventilation, additional fuel	Effect of biogas compared with wood user [Ref: Wood]	At least 10 years of biogas use	123ml (11, 236 ml) $p = 0.032$
Nepal (≥16 yrs) *Cross-sectional* (Kurmi et al., 2013)	Age, height, gender, literacy, BMI, income, smoking, SHS	Effect of biomass (rural) compared to LPG (urban) users [Ref: LPG]	NA	-74 ml (-148, 1 ml) $p = 0.046$
Guatemala (15-50 yrs) *RCT* (Smith-Sivertsen et al., 2009)	Age, time, altitude, SES	Effect of 'plancha' stoves 18 months post intervention [Ref: Open fire]	18 months	-10 ml * (-90, 50 ml) $p > 0.05$
Mexico (14-45 yrs) *RCT* (Romieu et al., 2009)	Age, height, SES, SHS, BMI, community, crowding, separate kitchen, place of cooking and eating	Yearly decline rate of FEV1 in Patsari stove group Vs. open fire stove group	1 year	31 ml/yr decline vs 62 ml/yr decline $p = 0.012$
Mexico (≥38 yrs) *Cross-sectional* (Regalado et al., 2006)	Age, income, passive smoking, hour-years of biomass exposure	Exposure to biomass PM10 > 2.6 mg/m^3 [Ref: PM10 < 2.6 mg/m^3]	At least 6 months of exposure to biomass smoke	-81ml (-0.5, -150 ml) $p = 0.04$
Ecuador (≥16 yrs) *Cross-sectional* (Rinne et al., 2006)	Age, height, SHS	Effect of biomass compared to LPG users [Ref: LPG]	Not known	50ml (-280, 380 ml) $p>0.05$
India (35.5 ± 14.6 yrs) *Cross-sectional* (Saha et al., 2005)	Age, weight, height, house type, family size, occupation	Between group difference among LPG vs. Biomass users	More than 10 years	2.29 ± 0.55 Vs. 1.96 ± 0.61

* Excess change (relative to baseline) in the plancha group relative to the control group across follow up time

Two randomized controlled trials assessing the impact of ICS failed to observe any differences in FEV1 in an intention-to-treat analysis. (Romieu et al., 2009, Smith-Sivertsen et al., 2009) Significant reductions in kitchen CO achieved with improved plancha stoves used in the RESPIRE trial could not simultaneously translate into FEV1 gains among the cooks despite using the ICS for 18 months. (Smith-Sivertsen et al., 2009) Given these findings and likewise from the studies studying the effects of sustained smoking cessation (Anthonisen et al., 2002), it is likely that sustained exposure reduction for a prolonged period of time would be necessary to detect meaningful changes in FEV1 after switching to cleaner alternatives. Although the study from Mexico was able to document relatively slower age related FEV1 decline among ICS users (31ml decline) than the traditional open fire users (62 ml decline), adherence to the improved stoves was very poor. (Romieu et al., 2009)

Balance improvement through matching especially in age and height, the two most important biological determinants of lung function (Quanjer et al., 2012a) and sustained biogas use for at least a decade in this study could have contributed to our effect estimates being larger than obtained in other studies except for the two RCTs which measured rate of yearly decline. Before matching, firewood users were significantly younger by 3.34 years (51.6yrs vs. 48.2yrs) than the biogas users which could explain the differences on the results between the matched and unmatched sensitivity analysis as well as the crude comparisons which had a potential for large age related bias. Similarly, biogas users and wood users belonged mostly to either the upper two quintiles or the lower two quintiles of SES respectively and they differed significantly in their PCA derived SES. Although the magnitude of influence of SES in FEV1 is variable, in women the effect of low SES could be as large as 200ml reduction. (Hegewald and Crapo, 2007) This could have resulted in higher effect of FEV1 among already better off biogas users but matching was successful in removing the imbalance in SES as shown by the reduced standardized difference in means before and after matching, and thus ruling out this influence.

The decade long reduced HAP exposure achieved by sustained biogas use additionally explains the positive effect of biogas over firewood users. Again due to lack of comparable studies, comparison with the effects of smoking cessation is likely to give us more insights. Quitting smoking won't be able to regain the already lost FEV1 due to prior smoking. Indeed, it has been shown that maintenance of smoking cessation only normalizes the smoking induced rapid decline in FEV1 (Fletcher and Peto, 1977, Burchfiel et al., 1995), especially when quitting at an early age (Kohansal et al., 2009), and the decline thereafter continues to be age related. Anthonisen et al. (2002) observed 22 mL/yr decline in sustained quitters versus 54 mL/yr decline in FEV1 in continuous smokers in their 11 years of follow up. So, hypothetically, women who had prior HAP exposure when adopting and maintaining clean biogas fuel use for continuous ten years would have lower age related FEV1 decline than those women who continue using wood and being exposed to harmful pollutants. This could explain the differences we observed due to biogas fuel use over wood users.

5.3.3 Airway obstruction (AO)

Prevalence of AO

Owing to the large age-related bias (under-diagnosis in younger age group and over-diagnosis in older age group) in the AO diagnosis using GOLD definition (Quanjer et al., 2013, Quanjer et al., 2014), we defined AO using both criteria- the LLN cut-off (FEV1/FVC < 5^{th} percentile i.e. z score < -1.645) and the GOLD cut-off (FEV1/FVC < 70%). This also allowed comparing our results with prior studies which mostly used GOLD criteria.

The crude prevalence of AO by LLN was more than 24% (26% among firewood users vs. 22% among biogas users). This is twice the prevalence reported by Kurmi et al. (2013) probably because of older participants in our study (49.7±12.3 yrs vs. 34.8±16yrs). Among the non-smoker biomass exposed females, we observed 16% prevalence of airway obstruction compared to nearly 20% by Kurmi (2010). Participant characteristics differed in these studies such that we investigated one primary female cook from each household while the former study recruited other participants besides the cook. Different choice of reference lung equation, the use of GLI 2012 equation (using ethnicity as ‘others’) in this study vs. the European Community for Steel and Coal reference equation (Quanjer et al., 1993) (with 10% reduction for non-Caucasians) in Kurmi, to determine the LLN also explains the difference in the prevalence of AO.

By GOLD criteria, we diagnosed AO in one among every five cooks in both fuel types similar to what Kurmi et al. (2013) reported among biomass users. This is also consistent with one of the earlier studies in Nepal which reported around 19% prevalence of chronic bronchitis based on respiratory symptoms among biomass exposed females. (Pandey, 1984a)

5.3.4 Risk of developing AO

Compared to firewood use, biogas use was associated with more than 65% (OR= 0.346 [0.157-0.762], p=0.008) reduced odds of developing AO (by LLN) after adjustment for smoking, kitchen characteristics and additional fuel use. GOLD criteria also yielded reduced odds of developing AO with biogas use, but statistically not significant and it may be owing to the reduced power to detect the difference due to lower overall prevalence of AO by GOLD.

Smoking which remains the most important cause of AO globally (Mannino and Buist, 2007), was also independently associated with the risk of developing AO in this study by using either of the diagnostic criteria (LLN or GOLD). Kitchen characteristics like windows and kitchen volume did not exert a significant impact on the risk of developing AO in univariate analysis.

Discordance in the diagnosis of airway obstruction when using LLN or GOLD criteria has been a topic of wide discussion. Although there has been no firm consensus (Pellegrino et al., 2008, Miller et al., 2009) on which criteria to use, experts are now arguing to switch to the more robust LLN method acknowledging that the GOLD criteria is susceptible to under-diagnosis of AO in younger age groups and over-diagnosis in the older age groups. (Quanjer et al., 2010) This phenomenon was well observed in this study as reported in **Figure 4.8** where we note the discordance in the diagnosis above and below the 60-70 year age group. Although, we do not report the exact age at which this occurs, some other studies have reported this to be around 52 years. (Cerveri et al., 2009, Miller et al., 2009) The use of GOLD cut-off can over-diagnose by 50% in the older age groups because it does not take into account the inherent nature of the FEV1/FVC ratio which decreases with the increase in age and height. (Quanjer et al., 2010) This can lead to unwarranted treatment of elderly subjects who in reality do not suffer from airway obstruction. This is equally problematic in the younger age group where the use of fixed 70% cut-off could lead to false negatives.

5.3.5 Effect of interventions to reduce HAP on AO-locating the findings

Table 5.3 summarizes the effect of biomass or clean fuel intervention on the risk of developing AO diagnosed either by standard spirometry or by the physicians in the hospital. Studies have consistently linked biomass exposure to higher risk of developing AO, although findings are heterogeneous due to different fuel use and different diagnostic criteria used. There are no comparable studies assessing the risk reduction after biogas use, however we report 65% reduced odds of developing AO with sustained use of biogas for at least 10 years. This is in line with the odds ratio calculated from the systematic reviews if we switched the reference category to biogas users.

Table 5.3: Comparison of this current study with other HAP studies with respect to risk of AO (diagnosed by a physician or by spirometry) among women

Country/ *Study design* (Reference)	Mean age and sample size	Diagnosis criteria	Exposure/Fuel/Stove type compared	Odds ratio (95 % CI)
Nepal (30-83 yrs) *Cross-sectional* (Current study, 2014)	(49.7±12.3 yrs) Wood= 241 Biogas= 187	LLN	Effect of biogas [Ref: Wood]	0.35 (0.16-0.76)
Nepal (30-83 yrs) *Cross-sectional* (Current study, 2014)	(49.7±12.3 yrs) Wood= 241 Biogas= 187	GOLD	Effect of biogas [Ref: Wood]	0.60 (0.23-1.58)
Nepal (≥16 yrs) *Cross-sectional* (Kurmi et al., 2013)	34.8 yrs Biomass= 369 LPG= 367	LLN	Effect of biomass /rural [Ref: LPG/urban]	2.38 (0.94-5.99)
Colombia (35-70 yrs) Case-control (Dennis et al., 1996)	65.2 yrs Hospital based 104 cases 104 controls	GOLD with FEV1<70%	Effect of years of wood use (32.8 ±16 yrs in cases, 18±14 yrs in controls)	3.92 (1.70-9.10)
Mexico (≥38 yrs) *Cross-sectional* (Regalado et al., 2006)	55.66 yrs Wood= 778 Gas= 67	GOLD	Effect of biomass [Ref: Natural gas]	1.50 (0.50-4.30)
China (≥40 yers) Cross sectional (Liu et al., 2007)	1089 women	Post bronchodilator FEV1/FVC<70%	Effect of biomass [Ref: LPG]	3.11 (1.63-5.94)
Turkey Case control (Sezer et al., 2006)	74 each Case: 57.1±11.1 Control: 56.4±10.8 yrs	Hospital based clinical diagnosis	≥30 years of biomass exposure [Ref: No exposure]	6.61 (2.17-20.18)
Systematic reviews				
(Smith et al., 2014)	24 studies	Spirometry, clinical, or symptom recall	Effect of biomass on women	2.30 (1.73-2.06)
(Po et al., 2011)	6 studies	Spirometry or at hospital	Effect of biomass on women	2.40 (1.47-3.93)
(Kurmi et al., 2010)	20 studies	Spirometry or at hospital	Effect of biomass (both sexes)	2.80 (1.85-4.23)

Effect estimates from recent systematic reviews show at least doubling of the risk of AO among women using biomass compared to women using some form of cleaner fuel.

Summary of respiratory health findings

Sustained use of biogas is associated with significantly larger FEV1 and MEF2575 when comparing age, height and socio-economically matched groups of biogas users and firewood users. The prevalence of airway obstruction is very high in rural Nepal but the risk of developing AO was substantially lower in biogas users versus firewood users, in particular when defining AO based on LLN diagnostic criteria.

5.4 Impact of biogas use on cardiovascular health

SBP, DBP and Hypertension

More than one in three (35%, 177/513) cooks we measured had blood pressure reading ≥140/90 mmHg, similar to the global prevalence of high blood pressure. We found sustained use of biogas for at least ten years associated with lower levels of SBP and DBP among cooks beyond the fifth decade of their life. We observed a surprising finding among young biogas users (30-50 yrs) who actually showed 4 mmHg higher SBP with biogas use. This may be because of SBP being sensitive to age and BMI. We also observed 68% reduced odds (0.32 [0.14-0.71], p=0.005) of developing hypertension among biogas users compared to wood users older than 50 years. This was, however, not observed in the younger age group. This may be because of persistent large imbalances in matching covariates, in particular in relation to BMI, even after matching. BMI imparts a significant effect on blood pressure (Kaufman et al., 1997), and the worsened balance of this covariate may have led to an estimate of the effect of biogas use which is biased towards the null.

5.4.1 Effect of interventions to reduce HAP in blood pressure-locating the findings

The lack of comparable studies assessing the impact of biogas use on blood pressure prevents us from comparing our findings. However, our results are consistent with those of the randomized trial in Guatemala which observed reduction in SBP and DBP after switching from an open fire to an improved ‘plancha’ stove. We observed 9.8 ([-20.4 to 0.8] mmHg, p=0.069) and 6.5 ([-12.15 to -0.82], p=0.025) lower SBP and DBP in biogas users while the differences observed in Guatemala were 3.7(-8.1 to 0.6) mmHg and 3.0 (-5.7 to -0.4) mmHg respectively. Decade-long use of biogas fuel for cooking in our study could have led to greater reductions in mean BP as opposed to only around a year (293 days, 2-700 days) use of improved stoves in Guatemala. (McCracken et al., 2007) Although we observed larger mean effect, overlap of effect size between ours and the RESPIRE estimates points towards consistent direction and magnitude of the estimates achievable by reduction in the HAP exposure.

The age-related effect of HAP on blood pressure observed in our study was also reported by a similar study from China. (Baumgartner et al., 2011)They reported a 4.1 mmHg and 1.8 mmHg increases in SBP and DBP respectively associated with each one log unit increase in PM2.5 mass among > 50 years old cooks. But, as in our study, the Chinese study also failed to identify similar associations among cooks aged ≤50 years. (Baumgartner et al., 2011) For these younger cooks, they reported a lowering of DBP with increased PM2.5, although not significant, and a very small effect on SBP. In our case, both SBP and DBP tend to be higher among young biogas users.

We found a high prevalence (35%, 177/513) of high blood pressure in this population similar to the prevalence (34%) reported by Sharma et al. (2011) in a large community-based screening program in Eastern Nepal. Other studies conducted in Nepal also reported similar prevalence of hypertension; 31% by Ministry of Health and Population (2008) and 34% by Vaidya et al (2012). However, HAP studies in neighbouring China and India reported only 13% (Baumgartner et al., 2011) and 20% prevalence (Dutta et al., 2011) respectively. However the population characteristics studied in these studies was heterogeneous. Study from India investigated only pre-menopausal women while the Chinese study included only non-smokers. These important differences in population characteristics and urban rural differences are likely to be the main reason for the stark contrast in prevalence observed in these studies compared to ours.

The high prevalence of smoking among the cooks is of potential concern as it may dilute the effect estimates for biogas. However, both fuel groups had similar rates of ‘ever smokers’ and median number of pack-years of cigarettes smoked (7.5 years, p=0.61). Additionally, exposure through neighbourhood air pollution could also contribute to a reduction in the effects observed for biogas and therefore bias the effect estimate towards the null.

The matched analysis yielded differences associated with fuel type with less bias owing to reduced ASB of the matching covariates, age and BMI, which are both biological determinants of blood pressure. Matching by SES helped to overcome selection bias in self-adoption of biogas plants. Before matching, participants differed significantly in their PCA-derived SES scores. After full matching, participants were well balanced in their SES. Effective balance achieved through matching resulted in a more precise effect estimate in cooks more than 50 years old but was less successful in the younger age group.

5.5 Strengths and limitations of the study

We conducted an epidemiological study to explore if the adoption and sustained use of biogas plants by households impacts pollution levels and cardio-respiratory health compared to households that have continued to use traditional wood stoves. In doing so, we used an opportunity to study the true field-performance of a self adopted intervention in a real-life setting. Although we found significant impact of biogas intervention in both pollutants reduction and cardio-respiratory health benefits, these findings should be considered in the context of following important strengths and limitations.

Study design: This is a cross-sectional study so the temporal relationship of cause and effect cannot be ascribed to biogas. Besides, we made an assumption that some of the variables like kitchen characteristics (windows, doors, eaves space etc) or fuel use characteristics were always the same during the last ten years period. But ten years of sustained intervention use without intermediate follow-ups is a long duration during which many unmeasured factors including changes in health practices and household behaviour could have interplayed. These went unmeasured and undocumented when we made a cross-sectional assessment at a single point after ten years. These unmeasured and unknown factors could impart residual confounding in our results despite an attempt to balance the measured covariates through matching and regression.

Although cross-sectional, this is a pragmatic study which assessed real-life impact of self adopted intervention in the community. Propensity score matching technique, rarely used in HAP studies, was used as an innovative technique to account for the non random distribution of intervention thereby reducing selection bias and to achieve good balance between the comparison groups. This was further strengthened by *a priori* protocol with stringent recruitment criteria for example cattle ownership to further reduce selection bias.

Standard questionnaire were adopted to verify fuel use and kitchen characteristics and to minimise recall bias.

Study sampling and population: A purposive sampling was undertaken to select study district and village based on road density network among the districts with higher rate of biogas adoption so the generalisability of findings from this study could be limited to similar rural district and villages only. However, more than 80% of the Nepalese population resides in the rural villages, the majority relying on subsistence farming and animal rearing thus our findings are likely to be observed in those rural settings as well. Due to difficult geographical terrain of the study villages and lack of reliable sampling frame, we adopted convenience 'complete enumeration of household' approach but due to time constraints and logistic issues, this was not a complete census and neither a random sampling of the households.

The initial design of the study was to recruit only non smokers but high smoking rates, although not heavy, observed in the villages negated this possibility. This could dilute our effect estimates in addition to what already affected by neighbourhood pollution. However, both fuel groups had similar rates of 'ever smokers' and median number of pack-years of cigarettes smoked (7.5 years, p=0.61) minimising the effect of smoking.

Although the selection of households was based on convenience, this study was implemented in remote rural villages far away from the effect of major exposures to industrial emissions as well as vehicular exhaust fumes thus providing a location to study the pure effect of HAP exposure and intervention aimed to reduce it. Adult female primary cooks from these rural households who were exposed to HAP from early life were ideal to assess the long term impact of HAP and its reduction strategy. A relatively large sample size with high response rate among households and women for participation in the study due to interest in measuring their health status offers an important strength to the study.

Data collection: Pollutants monitoring was carried out only in a subset of the households due to feasibility constraints (e.g. electricity shortage) and personal exposures were not at all measured. So, dose dependent exposure response analyses for both respiratory and cardiovascular outcomes were not possible. The use of additional four CO monitors from a local agency besides the brand new factory calibrated monitors could have introduced measurement error in the winter concentration of CO.

Spirograms acceptance rate was above 80%, similar in both fuel groups and comparable to other studies but unknown outcome status on the remaining 20% cooks could influence our effect estimates in any direction there by not ruling the possibility of bias. It is noteworthy, however that the spirometry failure rate was similar between the groups thus minimising this bias.

Qualified medical doctors and medical students who had prior training and experience in community-based research and interview techniques administered the questionnaire and performed health evaluations on site at participant's home following stringent operating manuals thereby strengthening data quality. Pollutant monitoring was done by a field staff specifically trained and hired for this purpose by a local agency studying the emission standards of smoke-hoods. All lung function measurement was performed by the same medical doctor throughout the study thereby maintaining the consistency of the procedure and high data quality.

Questionnaires and instruments: We did not enquire how long the cooks using biogas currently had a prior exposure of cooking with firewood before adopting biogas plants. Questions about physical activity, amount of salt intake and use of anti-hypertensive medication were not included in the questionnaire and thus were not controlled for in subsequent analysis. Although, the questionnaires were framed in English and administered in Nepali these were standard questionnaires validated and used in other HAP and relevant health impact studies locally and abroad and these were thus adapted to suit our need after a field pretesting. High quality equipment tested for their portability, reliability and accuracy were used for lung function, blood pressure, and carbon monoxide measurement.

Data entry: Data were recorded in paper forms and later entered into electronic data base so were prone to errors. However, double data entry was done to reduce any inconsistency. In addition, data checks were done on site which gave an opportunity to "go back" immediately and verify any missing information. Consistency checks and data validations added further to ensuring high quality data. Pollutant monitoring data and lung function data were electronically imported from the respective equipment thus reducing any manual errors.

Data analysis: An *a priori* analysis plan guided all the analysis except for the blood pressure outcome which was a post hoc decision based on literature review. Matching did not achieve effective balance among younger biogas users for comparison of blood pressure outcome possibly compromising the effect estimates in that group. Some analyses have not been undertaken yet e.g. particulate matter data and self reported health outcomes. These analyses are planned after setting up further collaboration beyond the defence and will strengthen our analysis.

Although we cannot exclude the possibility of incomplete adjustment of measured or unmeasured confounders or any findings just by chance alone, all primary and secondary outcomes were well defined *a priori* and analyses were limited to these pre-specified outcome measures. Choice of control variables to adjust in the models *was a priori* and based on a conceptual framework. We used both propensity score matching (PSM) and statistical regression model adjustment to account for potential selection bias and confounding. PSM is widely used in the analysis of observational studies when randomization is not feasible, but rarely used in HAP studies. In addition, unmatched sensitivity analyses mostly showed same but lower/less precise effects. This strong analysis strategy with additional sensitivity analyses aimed to report results with less bias and greater precision.

The possibility of persistent imbalance cannot be negated despite matching. But we used weighted linear and logistic regression models after propensity score matching which additionally included matching covariates to account for any remaining imbalances. This method is considered doubly robust allowing two chances to control for confounding.

Ambiguity remains in the literature, in particular, if one should account for the lack of independence in the matched groups or not. Thus, the variance of the estimates calculated in this study may be different if one ignores the lack of independence. But we made an informed choice based on the literature review and adopted the generalised estimating equation methods to account for the lack of independence in matched data set.

5.6 Significance of findings

This study tried to fill the gap in the knowledge of at least how long a switch to a primarily clean intervention should be sustained by those exposed to prior HAP before a meaningful change in their cardio-respiratory functions could be detected. Although, we specifically compared biogas fuel use against firewood use, this study has significant implications for other possible HAP interventions in that such interventions should aim for long term acceptability, durability and sustained use.

The findings of this study are also of global public health importance given that, globally, 2.8 billion people are exposed to HAP (Bonjour et al., 2013) and more people are dying prematurely every year from its associated health complications, 4.3 million deaths in 2012 (WHO, 2014), almost all of them in low-and middle- income countries. COPD and cardiovascular diseases are already the leading causes of global deaths. Any intervention with the potential to reduce these disease risks is likely to have significant impacts on global health and wellbeing.

This study is the first evaluation of biogas programme and findings from our study give evidence that the Nepal Biogas Support Program has been successful in reducing the pollutant level, especially the kitchen CO, and its associated cardiovascular health risks among its female users. In the context where 80% of the Nepalese population resides in rural areas with similar socio-cultural practices and beliefs, and relying mainly on subsistence farming and animal rearing, findings from this study conducted in four rural villages are likely to be observed in other similar rural settings as well.

The BSP Nepal has served as a model for other SNV Netherlands Development Organisation funded biogas programmes in several Asian countries including Vietnam, Cambodia, Indonesia and Bangladesh. Recently, Africa Biogas Partnership Programme in six African countries (Ethiopia, Kenya, Senegal, Tanzania, Uganda and Burkina Faso) has been started. (Netherlands Development Organisation, 2014) Our results may be directly applicable in these countries due to socio-economic and biogas program similarities. Nevertheless, our results are also of broad importance to biogas programs of neighbouring China and India where more than 46 million household have already adopted household biogas plants. Differences in cooking preferences and cooking needs in these countries may result in findings contrary to ours so well-designed longitudinal studies carried out in different socio-cultural settings practices should be carried out before applicability of findings to all of these settings can be assumed.

5.7 Implications for policy and practice

The National Biogas Support Program has installed around 0.3 million households biogas digesters throughout the country however its scaling-up potential remains largely un-exploited. Findings from this study therefore have important policy and practice implications and advocate for:

Adding a health perspective to biogas adoption and use:

The current biogas promotion strategy in Nepal at the users level largely focuses on the gains due to firewood and fertiliser saved while neglecting the health perspective. But any policies and programmes aiming to reduce dependence on biomass fuels (and thereby HAP) should incorporate and reflect health agenda. Unless health agenda is brought into this context, the scaling up potential of the biogas program could remain unfulfilled.

This study could serve as an example to promote biogas adoption using the health perspective. Achieved sanitation in the household, improved quality of life of women and their families with reduced smoke, reduced burns and scalds and time saved on collecting firewood are other added gains that should be imparted at the population level.

Combining biogas installation with other HAP reduction strategies:

The current practice under the BSP promotes one time adoption of biogas plants through subsidy schemes without emphasizing the long-term impacts that it can potentially bring. Given that biogas installation is relatively expensive and adoption is currently limited to socio-economically advantaged households, these households are also likely to have the potential to install additional ICS so that supplemental wood fire activities like preparing animal fodder or boiling milk could be carried out under a relatively clean combustion process. Such a holistic approach of supplementing biogas adoption with ICS installation as well as kitchen ventilation improvement is likely to bring more substantial health benefits than promoting biogas alone.

Reaching the poorest:

Mechanisms to reach the poorest households still seem to be lacking while changing their cooking practice would have much more overall impact in reducing the disease burden. A strategy to promote biogas adoption among these households may include their identification and increasing the subsidy (e.g. through a tiered subsidy approach) or reducing the upfront investment associated with biogas adoption by spreading the microcredit payback time over a longer duration.

Addressing social, technical, and financial barriers to adoption:

Improving structural designs of the biogas plants through innovative research and development so that they could fit in a relatively small space or could be moved to a new location would promote more families to adopt these digesters as we identified a significant number of families wishing to install these plants but unable to do so owing to small land space or planning to move to a new location. Similarly many households are reluctant to connect latrines to biogas digesters due to social taboos. Effective awareness raising activities involving community leaders and role models would address this. Reducing the overall cost associated with adoption without compromising quality and functionality of the biogas plants and maintaining continuous after sales services are other important factors.

Targeting tobacco smoking and HAP together:

This study additionally revealed a high prevalence of smoking among rural women who are already exposed to effects of household air pollution. So, the health benefits of HAP reduction strategies if implemented will be diluted by the smoking habits of the cooks. In terms of a holistic approach for better health, combination of HAP reduction strategy and smoking cessation programs would likely translate into more substantial health gains than either of them alone. HAP and tobacco smoking being the leading risk factors for COPD further justifies this approach.

Breaking the vicious cycle of HAP and poverty:

As poverty and solid fuel use are inextricably linked to each other in a bidirectional fashion, the rural population is unlikely to switch to the next rung of energy ladder unless they are lifted out of poverty or provided with specific programmatic incentives (e.g. subsidies) to do so. Equally true is the fact that reliance on solid fuel has been restricting any economic development. The challenge is immense but this chain has to be broken to promote better health and economic development.

5.8 Implications for future research

The findings of this study, although cross-sectional are likely to impart implications on future research. Collaborative research with the BSP so as to design a prospective before-after-intervention study could result in stronger conclusions. Given that only one high quality RCT has ever been done in HAP domain, a community-based randomized trial with biogas is not only logistically challenging but needs a very long-term follow-up. So, quasi-experimental study designs with biogas are likely to result in useful insights.

This study also provides a ground for converting this study into a cohort study by following up the participants we recruited in this study at predefined intervals (e.g. every two years) to closely follow their lung functions and to compare the trends of decline in FEV1 or other changes in blood pressure.

Besides the kitchen CO concentration, additional personal exposure measurement of the cooks would have allowed better exposure classification and ability to conduct exposure response analysis. We suggest researchers to include such measurement, cost allowing, so that evidence would be strengthened. In addition, area measurements should be sampled from other living environments as well like verandah, living room and outdoor so as to determine overall community exposure. Additional gravimetric PM measurements of biogas smoke would help to establish the conversion coefficient to later use cheaper light scattering technology in the field.

We are not aware of studies which have investigated cooks by echocardiography of the heart or Doppler study of blood vessels to study the flow and possible atherosclerotic changes due to HAP. Adding such investigations would provide more information to confirm or refute the relationship of HAP exposure with cardiovascular diseases.

Other short-term health outcomes among children (e.g. birth weight, pneumonia) or other health outcomes (e.g. lung cancer, cataract) could also be studied in relation with biogas. Similarly, health outcome studies with biogas use can be repeated in other settings or countries for repeatability and generalisability of findings.

Adding qualitative component to quantitative assessment of impact could capture behavioural practices on why the transition to clean fuel has been partial, why families continue stacking multiple fuels and multiple types of stoves. Designing a mixed method research of impact assessment would help to address adoption and sustained use issues.

6 Conclusion

This study primarily aimed to explore if sustained use of household biogas as a main cooking fuel for at least ten years would reduce harmful exposure to kitchen pollutants and translate into objectively measured cardio-respiratory health gains among adult female cooks in rural Nepal.

With the use of a cross-sectional design and propensity score matching of women and households using either biogas or firewood as their main cooking fuel, our results show that sustained use of biogas is significantly associated with a) 77% lower 24 hour CO concentrations in the kitchen, b) 123 ml higher forced expiratory volume in one second (FEV1) and 65% reduced odds of developing airway obstruction (diagnosed using LLN criteria) among women aged 30 to 83 years and c) lower mean systolic and diastolic blood pressure along with significantly reduced odds of high blood pressure among women beyond the fifth decade of their life.

These findings suggest that switching from traditional firewood to clean biogas fuel and its sustained use is likely to result in overall health benefits among female cooks. However, owing to the cross sectional nature of our study, a causal relationship with biogas use cannot be attributed with certainty. Exposure response analysis would have further strengthened our study; nevertheless, current findings suggest that household biogas plants could be an alternative energy source to improve cardio-respiratory health of millions of cooks who are potential beneficiaries of this technology based on geographic location and cattle ownership but are still reliant on solid fuels.

The findings from this pragmatic study designed to assess the real-life impact of self-adopted household biogas plants could assist in promotion and scaling up of biogas interventions among rural households relying on subsistence farming and animal rearing in developing countries like Nepal, India and China. Further mechanisms to reduce the cost or decrease the upfront investment are likely to facilitate adoption of these plants at scale. Promotional activities along with supply and market development should also penetrate further to the very remote areas where designs of the plant could be changed to suit local needs and facilitate adoption.

The objectively assessed cardio-respiratory health benefits of biogas outlined in this study are also of broad importance to the more than 46 million households in China, India and Nepal who have installed and continue to use biogas plants without a clear evidence base of health impacts. Large scale programs in these countries could further build up from these findings. It is also important to underscore that besides the scaling up potential of these programs, they also have the potential to collaborate with researchers to design large scale longitudinal studies to further substantiate our findings and add new insights for other pollutant measures and short-term as well as other longer-term health outcomes.

Given that almost half of humanity still relies on solid fuels for cooking and heating needs and is thereby exposed to harmful smoke during cooking, these findings are of global health importance and direct policy relevance. In particular, global concerted efforts such as the Global Alliance for Clean Cookstoves are trying to find ways to deliver clean cooking options to the poorest households of South East Asia and Sub-Saharan Africa. In that regard, technologies already well adopted by households across many countries cannot be neglected, rather a sustainable mechanism should be identified by which the technology can be further enhanced and scaled up.

Sadly, as of today, the poorest of the poor around the world are silently dying while cooking to feed their children and elderly with whatever resources they have. Unless these households are lifted up to socioeconomic affluence, they will have to continue burning solid fuel and inhale toxic smoke. It is imperative in this regard that a global effort should identify and further add to the existing mechanisms to address the complex issue of household air pollution in a comprehensive way and break the vicious cycle between poverty and ill health so that children, women and elderly throughout these remote areas could be lifted up to live in an environment conducive to health. Appropriate policy and programmatic action should be taken by the governments, public and private sector alike to prevent any premature deaths resulting from cooking.

Bibliography

AEPC. 2013a. *Household Biogas* [Online]. Kathmandu: Alternative Energy Promotion Centre. Available: http://www.aepc.gov.np/?option=renewable&page=subsubrenewable&mid=2&sub_id=16&ssid=16&cat=Household%20Biogas [Accessed April 20 2014].

AEPC. 2013b. *Metallic ICS* [Online]. Kathmandu: Alternative Energy Promotion Centre (AEPC). Available: http://www.aepc.gov.np/?option=renewable&page=biomassics&mid=2&sub_id=15&ssid=12&cat=Metallic%20ICS [Accessed April 22 2014].

AEPC. 2013c. *Nepal Alliance for Clean Cookstoves (NACC)* [Online]. Available: http://www.nepalcookstoves.org/background.php [Accessed April 30 2014].

AEPC. 2103. *Alternative Energy Promotion Centre* [Online]. Alternative Energy Promotion Centre. Available: http://www.aepc.gov.np/index.php# [Accessed April 25 2014].

AGUSTI, A., CALVERLEY, P. M., CELLI, B., COXSON, H. O., EDWARDS, L. D., LOMAS, D. A., MACNEE, W., MILLER, B. E., RENNARD, S., SILVERMAN, E. K., TAL-SINGER, R., WOUTERS, E., YATES, J. C. & VESTBO, J. 2010. Characterisation of COPD heterogeneity in the ECLIPSE cohort. *Respir Res,* 11**,** 122.

ALBALAK, R., BRUCE, N., MCCRACKEN, J. P., SMITH, K. R. & DE GALLARDO, T. 2001. Indoor respirable particulate matter concentrations from an open fire, improved cookstove, and LPG/open fire combination in a rural Guatemalan community. *Environ Sci Technol,* 35**,** 2650-5.

ALTERNATIVE ENERGY PROMOTION CENTRE 2010. *Biogas Users' Survey 2009/2010,* Kathmandu, Alternative Energy Promotion Centre.

AMERICAN THORACIC SOCIETY 1991. Lung function testing: selection of reference values and interpretative strategies. *Am Rev Respir Dis,* 144**,** 1202-18.

ANTHONISEN, N. R., CONNETT, J. E. & MURRAY, R. P. 2002. Smoking and lung function of Lung Health Study participants after 11 years. *Am J Respir Crit Care Med,* 166**,** 675-679.

AUSTIN, P. C. 2008. A critical appraisal of propensity-score matching in the medical literature between 1996 and 2003. *Stat Med,* 27**,** 2037-2049.

BALAKRISHNAN, K., GHOSH, S., GANGULI, B., SAMBANDAM, S., BRUCE, N., BARNES, D. F. & SMITH, K. R. 2013. State and national household concentrations of PM2.5 from solid cookfuel use: results from measurements and modeling in India for estimation of the global burden of disease. *Environ Health,* 12**,** 77.

BATES, L. 2007a. *Health questionnaire* [Online]. Household Energy Network (HEDON). Available: http://www.hedon.info/docs/Health_questionnaire_Round3.pdf [Accessed April 22 2014].

BATES, L. 2007b. *Household questionnaire* [Online]. Household Energy Network (HEDON). Available: http://www.hedon.info/docs/Household_questionnaire_Round3.pdf [Accessed April 22 2014].

BAUMGARTNER, J., SCHAUER, J. J., EZZATI, M., LU, L., CHENG, C., PATZ, J. A. & BAUTISTA, L. E. 2011. Indoor air pollution and blood pressure in adult women living in rural China. *Environ Health Perspect,* 119**,** 1390.

BEELEN, R., STAFOGGIA, M., RAASCHOU-NIELSEN, O., ANDERSEN, Z. J., XUN, W. W., KATSOUYANNI, K., DIMAKOPOULOU, K., BRUNEKREEF, B., WEINMAYR, G., HOFFMANN, B., WOLF, K., SAMOLI, E., HOUTHUIJS, D., NIEUWENHUIJSEN, M., OUDIN, A., FORSBERG, B., OLSSON, D., SALOMAA, V., LANKI, T., YLI-TUOMI, T., OFTEDAL, B., AAMODT, G., NAFSTAD, P., DE FAIRE, U., PEDERSEN, N. L., OSTENSON, C. G., FRATIGLIONI, L., PENELL, J., KOREK, M., PYKO, A., ERIKSEN, K. T., TJONNELAND, A., BECKER, T., EEFTENS, M., BOTS, M., MELIEFSTE, K., WANG, M., BUENO-DE-MESQUITA, B., SUGIRI, D., KRAMER, U., HEINRICH, J., DE HOOGH, K., KEY, T., PETERS, A., CYRYS, J., CONCIN, H., NAGEL, G., INEICHEN, A., SCHAFFNER, E., PROBST-HENSCH, N., DRATVA, J., DUCRET-STICH, R., VILIER, A., CLAVEL-CHAPELON, F., STEMPFELET, M., GRIONI, S., KROGH, V., TSAI, M. Y., MARCON, A., RICCERI, F., SACERDOTE, C., GALASSI, C., MIGLIORE, E., RANZI, A., CESARONI, G., BADALONI, C., FORASTIERE, F., TAMAYO, I., AMIANO, P., DORRONSORO, M., KATSOULIS, M., TRICHOPOULOU, A., VINEIS, P. & HOEK, G. 2014. Long-term Exposure to Air Pollution and Cardiovascular Mortality: An Analysis of 22 European Cohorts. *Epidemiology,* 25**,** 368-78.

BEHERA, D., DASH, S. & MALIK, S. K. 1988. Blood carboxyhaemoglobin levels following acute exposure to smoke of biomass fuel. *Indian J Med Res,* 88**,** 522-4.

BONJOUR, S., ADAIR-ROHANI, H., WOLF, J., BRUCE, N. G., MEHTA, S., PRUSS-USTUN, A., LAHIFF, M., REHFUESS, E. A., MISHRA, V. & SMITH, K. R. 2013. Solid fuel use for household cooking: country and regional estimates for 1980-2010. *Environ Health Perspect,* 121**,** 784-90.

BOY, E., BRUCE, N. & DELGADO, H. 2002. Birth weight and exposure to kitchen wood smoke during pregnancy in rural Guatemala. *Environ Health Perspect,* 110**,** 109-14.

BROOK, R. D., FRANKLIN, B., CASCIO, W., HONG, Y., HOWARD, G., LIPSETT, M., LUEPKER, R., MITTLEMAN, M., SAMET, J., SMITH, S. C., JR. & TAGER, I. 2004. Air pollution and cardiovascular disease: a statement for healthcare professionals from the Expert Panel on Population and Prevention Science of the American Heart Association. *Circulation,* 109**,** 2655-71.

BROOK, R. D., RAJAGOPALAN, S., POPE, C. A., BROOK, J. R., BHATNAGAR, A., DIEZ-ROUX, A. V., HOLGUIN, F., HONG, Y., LUEPKER, R. V. & MITTLEMAN, M. A. 2010. Particulate matter air pollution and cardiovascular disease an update to the scientific statement from the American Heart Association. *Circulation,* 121**,** 2331-2378.

BRUCE, N., MCCRACKEN, J., ALBALAK, R., SCHEI, M. A., SMITH, K. R., LOPEZ, V. & WEST, C. 2004. Impact of improved stoves, house construction and child location on levels of indoor air pollution exposure in young Guatemalan children. *J Expo Anal Environ Epidemiol,* 14 Suppl 1**,** S26-33.

BRUCE, N., REHFUESS, E., MEHTA, S., HUTTON, G. & SMITH, K. 2006. Indoor Air Pollution. *In:* JAMISON, D., BREMAN, J., MEASHAM, A., ALLEYNE, G., CLAESON, M., EVANS, D., JHA, P., MILLS, A. & MUSGROVE, P. (eds.) *Disease Control Priorities in Developing Countries.* 2nd ed. Washington (DC): World BAnk.

BSP-NEPAL 2012. BSP 2011/12. Kathmandu: BSP-Nepal.

BURCHFIEL, C. M., MARCUS, E. B., CURB, J. D., MACLEAN, C. J., VOLLMER, W. M., JOHNSON, L. R., FONG, K.-O., RODRIGUEZ, B. L., MASAKI, K. H. & BUIST, A. S. 1995. Effects of smoking and smoking cessation on longitudinal decline in pulmonary function. *Am J Respir Crit Care Med,* 151**,** 1778-1785.

BURNETT, R. T., POPE, C. A., EZZATI, M., OLIVES, C., LIM, S. S., MEHTA, S., SHIN, H. H., SINGH, G., HUBBELL, B., BRAUER, M., ANDERSON, H. R., SMITH, K. R., BALMES, J. R., BRUCE, N. G., KAN, H., LADEN, F., PRUSS-USTUN, A., TURNER, M. C., GAPSTUR, S. M., DIVER, W. R. & COHEN, A. 2014. An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. *Environ Health Perspect,* 122**,** 397-403.

CARVALHO, T. C., PETERS, J. I. & WILLIAMS III, R. O. 2011. Influence of particle size on regional lung deposition – What evidence is there? *Int J Pharm,* 406**,** 1-10.

CBS 2011a. Nepal Living Standards Survey 2010/11, Statistical Report, Volume I. Kathmandu, Nepal: Central Bureau of Statistics (CBS), National Planning Commission Secretariat.

CBS 2011b. Nepal Living Standards Survey: 2010/11, Statistical Report, Volume II. Kathmandu, Nepal: Central Bureau of Statistics (CBS), National Planning Commission Secretariat.

CBS 2012a. National Population and Housing Census 2011-National Report. Kathmandu, Nepal: Central Bureau of Statistics, National Planning Commission Secretariat.

CBS 2012b. National Population and Housing Census 2011-Village Development Committee/Municipality. Kathmandu, Nepal: Central Bureau of Statistics (CBS), National Planning Commission Secretariat.

CERVERI, I., CORSICO, A. G., ACCORDINI, S., CERVIO, G., ANSALDO, E., GROSSO, A., NINIANO, R., TSANA TEGOMO, E., ANTÓ, J. M., KÜNZLI, N., JANSON, C., SUNYER, J., SVANES, C., HEINRICH, J., SCHOUTEN, J. P., WJST, M., POZZI, E. & DE MARCO, R. 2009. What defines airflow obstruction in asthma? *Eur Respir J,* 34**,** 568-573.

CHAPMAN, R. S., HE, X., BLAIR, A. E. & LAN, Q. 2005. Improvement in household stoves and risk of chronic obstructive pulmonary disease in Xuanwei, China: retrospective cohort study. *Bmj,* 331**,** 1050.

CHENGAPPA, C., EDWARDS, R., BAJPAI, R., SHIELDS, K. N. & SMITH, K. R. 2007. Impact of improved cookstoves on indoor air quality in the Bundelkhand region in India. *Energy for Sustainable Development,* 11**,** 33-44.

CLARK, M. L., PEEL, J. L., BALAKRISHNAN, K., BREYSSE, P. N., CHILLRUD, S. N., NAEHER, L. P., RODES, C. E., VETTE, A. F. & BALBUS, J. M. 2013. Health and household air pollution from solid fuel use: the need for improved exposure assessment. *Environ Health Perspect,* 121**,** 1120-8.

CSIKESZ, N. G. & GARTMAN, E. J. 2014. New developments in the assessment of COPD: early diagnosis is key. *Int J Chron Obstruct Pulmon Dis,* 9**,** 277-86.

CULVER, B. H. 2006. Interpretation of spirometry: we can do better than the GOLD standard. *Respir Care,* 51**,** 719-21.

DECRAMER, M. & COOPER, C. B. 2010. Treatment of COPD: the sooner the better? *Thorax,* 65**,** 837-41.

DEMIRBAS, A. 2004. Combustion characteristics of different biomass fuels. *Prog Energy Combust Sci,* 30**,** 219-230.
DENNIS, R. J., MALDONADO, D., NORMAN, S., BAENA, E. & MARTINEZ, G. 1996. Woodsmoke exposure and risk for obstructive airways disease among women. *Chest Journal,* 109**,** 115-119.
DEVAKUMAR, D., SEMPLE, S., OSRIN, D., YADAV, S. K., KURMI, O. P., SAVILLE, N. M., SHRESTHA, B., MANANDHAR, D. S., COSTELLO, A. & AYRES, J. G. 2014. Biomass fuel use and the exposure of children to particulate air pollution in southern Nepal. *Environ Int,* 66c**,** 79-87.
DHERANI, M., POPE, D., MASCARENHAS, M., SMITH, K. R., WEBER, M. & BRUCE, N. 2008. Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis. *Bull World Health Organ,* 86**,** 390-398c.
DHIMAL, M., DHAKAL, P., SHRESTHA, N., BARAL, K. & MASKEY, M. 2010. Environmental burden of acute respiratory infection and pneumonia due to indoor smoke in Dhading. *J Nepal Health Res Counc,* 8**,** 1-4.
DHINGRA, R., CHRISTENSEN, E. R., LIU, Y., ZHONG, B., WU, C. F., YOST, M. G. & REMAIS, J. V. 2011. Greenhouse gas emission reductions from domestic anaerobic digesters linked with sustainable sanitation in rural China. *Environ Sci Technol,* 45**,** 2345-52.
DUTTA, A., MUKHERJEE, B., DAS, D., BANERJEE, A. & RAY, M. 2011. Hypertension with elevated levels of oxidized low-density lipoprotein and anticardiolipin antibody in the circulation of premenopausal Indian women chronically exposed to biomass smoke during cooking. *Indoor Air,* 21**,** 165-176.
EDWARDS, R., SMITH, K. R., KIRBY, B., ALLEN, T., LITTON, C. D. & HERING, S. 2006. An inexpensive dual-chamber particle monitor: laboratory characterization. *Journal of the Air & Waste Management Association,* 56**,** 789-799.
EHRLICH, R. I., WHITE, N., NORMAN, R., LAUBSCHER, R., STEYN, K., LOMBARD, C. & BRADSHAW, D. 2004. Predictors of chronic bronchitis in South African adults. *Int J Tuberc Lung Dis,* 8**,** 369-76.
EIGEN, H., BIELER, H., GRANT, D., CHRISTOPH, K., TERRILL, D., HEILMAN, D. K., AMBROSIUS, W. T. & TEPPER, R. S. 2001. Spirometric pulmonary function in healthy preschool children. *Am J Respir Crit Care Med,* 163**,** 619-23.
ENRIGHT, P. L. & RUPPEL, G. L. 2009. Don't use the flawed fixed ratio to diagnosis COPD. *Respir Care,* 54**,** 1500.
EPSTEIN, M. B., BATES, M. N., ARORA, N. K., BALAKRISHNAN, K., JACK, D. W. & SMITH, K. R. 2013. Household fuels, low birth weight, and neonatal death in India: The separate impacts of biomass, kerosene, and coal. *International Journal of Hygiene and Environmental Health,* 216**,** 523-532.
ERNST, A. & ZIBRAK, J. D. 1998. Carbon Monoxide Poisoning. *N Engl J Med,* 339**,** 1603-1608.
EZZATI, M. & KAMMEN, D. 2001. Indoor air pollution from biomass combustion and acute respiratory infections in Kenya: an exposure-response study. *Lancet,* 358**,** 619-24.
FATMI, Z., COGGON, D., KAZI, A., NAEEM, I., KADIR, M. M. & SATHIAKUMAR, N. 2014. Solid fuel use is a major risk factor for acute coronary syndromes among rural women: a matched case control study. *Public Health,* 128**,** 77-82.
FAUSTO, N., KUMAR, V. & ABBAS, A. K. 2004. *Robbins and Cotran's Pathologic Basis of Disease*, Elsevier Saunders.
FERGUSON, G. T., ENRIGHT, P. L., BUIST, A. S. & HIGGINS, M. W. 2000. Office spirometry for lung health assessment in adults: A consensus statement from the National Lung Health Education Program. *Chest,* 117**,** 1146-61.
FILMER, D. & PRITCHETT, L. H. 2001. Estimating wealth effects without expenditure Data—Or tears: An application to educational enrollments in states of india. *Demography,* 38**,** 115-132.
FLETCHER, C. 1960. Standardised questionnaire on respiratory symptoms: a statement prepared and approved by the MRC Committee on the Aetiology of Chronic Bronchitis (MRC breathlessness score). *BMJ,* 2**,** 1665.
FLETCHER, C. & PETO, R. 1977. The natural history of chronic airflow obstruction. *BMJ,* 1**,** 1645.
GACC. 2014. *Alliance mission and goals* [Online]. Washington DC: Global Alliance for Clean Cookstoves (GACC). Available: http://www.cleancookstoves.org/the-alliance/ [Accessed April 29 2014].
GALOBARDES, B., SHAW, M., LAWLOR, D. A. & LYNCH, J. W. 2006. Indicators of socioeconomic position (part 2). *Journal of Epidemiology and Community Health,* 60**,** 95.
GELMAN, A. & HILL, J. 2007. *Data analysis using regression and multilevel/hierarchical models*, Cambridge University Press.
GOLD 2014. Global Strategy for the Diagnosis, Management and Prevention of COPD (Updated 2014). Global Initiative for Chronic Obstructive Lung Disease (GOLD).
GOVERNMENT OF NEPAL 2000. Local Self-Governance Act, 2055.
HANSEN, B. B. 2004. Full matching in an observational study of coaching for the SAT. *Journal of the American Statistical Association,* 99**,** 609-618.

HANSEN, J. E., SUN, X.-G. & WASSERMAN, K. 2007. Spirometric Criteria for Airway Obstruction Use Percentage of FEV1/FVC Ratio Below the Fifth Percentile, Not< 70%. *CHEST Journal,* 131**,** 349-355.

HEGEWALD, M. J. & CRAPO, R. O. 2007. Socioeconomic status and lung function. *CHEST Journal,* 132**,** 1608-1614.

HILL, J. 2008. Discussion of research using propensity-score matching: Comments on 'A critical appraisal of propensity-score matching in the medical literature between 1996 and 2003'. *Stat Med,* 27**,** 2055-2061.

HO, D., IMAI, K., KING, G. & STUART, E. 2006. MatchIt: Nonparametric Preprocessing for Parametric Casual Inference. *R package version***,** 2.2-11.

HO, D. E., IMAI, K., KING, G. & STUART, E. A. 2007. Matching as nonparametric preprocessing for reducing model dependence in parametric causal inference. *Political Analysis,* 15**,** 199-236.

HOGG, J. C. 2004. Pathophysiology of airflow limitation in chronic obstructive pulmonary disease. *Lancet,* 364**,** 709-21.

HOGG, J. C., CHU, F., UTOKAPARCH, S., WOODS, R., ELLIOTT, W. M., BUZATU, L., CHERNIACK, R. M., ROGERS, R. M., SCIURBA, F. C., COXSON, H. O. & PARE, P. D. 2004. The nature of small-airway obstruction in chronic obstructive pulmonary disease. *N Engl J Med,* 350**,** 2645-53.

HOGG, J. C., MACKLEM, P. T. & THURLBECK, W. M. 1968. Site and nature of airway obstruction in chronic obstructive lung disease. *N Engl J Med,* 278**,** 1355-60.

HOSGOOD, H. D., WEI, H., SAPKOTA, A., CHOUDHURY, I., BRUCE, N., SMITH, K. R., ROTHMAN, N. & LAN, Q. 2011. Household coal use and lung cancer: systematic review and meta-analysis of case–control studies, with an emphasis on geographic variation. *Int J Epidemiol,* 40**,** 719-728.

HOUWELING, T. A., KUNST, A. E. & MACKENBACH, J. P. 2003. Measuring health inequality among children in developing countries: does the choice of the indicator of economic status matter? *Int J Equity Health,* 2**,** 8.

HOWE, L. D., GALOBARDES, B., MATIJASEVICH, A., GORDON, D., JOHNSTON, D., ONWUJEKWE, O., PATEL, R., WEBB, E. A., LAWLOR, D. A. & HARGREAVES, J. R. 2012. Measuring socio-economic position for epidemiological studies in low-and middle-income countries: a methods of measurement in epidemiology paper. *Int J Epidemiol,* 41**,** 871-886.

HUTCHINSON, J. 1846. On the capacity of the lungs, and on the respiratory functions, with a view of establishing a precise and easy method of detecting disease by the spirometer. *Med Chir Trans,* 29**,** 137-252.

ICF INTERNATIONAL 2011. Demographic and Health Surveys Methodology - Questionnaires: Household, Woman's, and Man's. MEASURE DHS Phase III. Calverton, Maryland, USA: ICF International.

IHME. 2013a. *GBD Profile: Nepal* [Online]. Seattle, USA: Institute for Health Metrics and Evaluation (IHME). Available: http://www.healthmetricsandevaluation.org/sites/default/files/country-profiles [Accessed April 7 2014].

IHME. 2013b. *Search GBD Data* [Online]. Seattle, USA: Institute for Health Metrics and Evaluation (IHME). Available: http://www.healthmetricsandevaluation.org/search-gbd-data [Accessed April 7 2014].

INDOOR AIR POLLUTION TEAM. 2005. Installing Indoor Air Pollution Instruments in a Home version 5.1. Available: http://berkeleyair.com/wp-content/publications/guidelines-for-instrument-placement.pdf [Accessed April 22 2014].

INDOOR AIR POLLUTION TEAM. 2006. *Indoor air pollution monitoring protocols Version 05.1* [Online]. Berkeley: Schoold of Public Health, University of California.

INTENSIVE STUDY RESEARCH CENTRE 2007. *District profile of Nepal, 2007/2008: a socio-economic development data base of Nepal*, Intensive Study & Research Centre.

JOSHI, S. K., SINGH, A. & TULADHAR, B. 2011. Lung function among improved and traditional cooking stove users. *Environmental Medicine*.

JUDKINS, D. R., MORGANSTEIN, D., ZADOR, P., PIESSE, A., BARRETT, B. & MUKHOPADHYAY, P. 2007. Variable selection and raking in propensity scoring. *Stat Med,* 26**,** 1022-1033.

KAN, H., HEISS, G., ROSE, K. M., WHITSEL, E., LURMANN, F. & LONDON, S. J. 2007. Traffic exposure and lung function in adults: the Atherosclerosis Risk in Communities study. *Thorax,* 62**,** 873-879.

KAUFMAN, J. S., ASUZU, M. C., MUFUNDA, J., FORRESTER, T., WILKS, R., LUKE, A., LONG, A. E. & COOPER, R. S. 1997. Relationship between blood pressure and body mass index in lean populations. *Hypertension,* 30**,** 1511-1516.

KIRALY, A. 2005. History of spirometry. *Journal for Pre-Health Affiliated Students,* 4.

KOHANSAL, R., MARTINEZ-CAMBLOR, P., AGUSTÍ, A., BUIST, A. S., MANNINO, D. M. & SORIANO, J. B. 2009. The natural history of chronic airflow obstruction revisited: an analysis of the Framingham offspring cohort. *Am J Respir Crit Care Med,* 180**,** 3-10.

KULKARNI, N. S., PRUDON, B., PANDITI, S. L., ABEBE, Y. & GRIGG, J. 2005. Carbon loading of alveolar macrophages in adults and children exposed to biomass smoke particles. *Sci Total Environ,* 345**,** 23-30.

KURMI, O. 2010. *Health effects of indoor air pollution in both rural and urban Nepal.* Doctor of Philosophy Traditional, University of Aberdeen.

KURMI, O. P., DEVEREUX, G. S., SMITH, W. C., SEMPLE, S., STEINER, M. F., SIMKHADA, P., LAM, K. B. & AYRES, J. G. 2013. Reduced lung function due to biomass smoke exposure in young adults in rural Nepal. *Eur Respir J,* 41**,** 25-30.

KURMI, O. P., GAIHRE, S., SEMPLE, S. & AYRES, J. G. 2011. Acute exposure to biomass smoke causes oxygen desaturation in adult women. *Thorax,* 66**,** 724-5.

KURMI, O. P., SEMPLE, S., SIMKHADA, P., SMITH, W. C. & AYRES, J. G. 2010. COPD and chronic bronchitis risk of indoor air pollution from solid fuel: a systematic review and meta-analysis. *Thorax,* 65**,** 221-8.

KURMI, O. P., SEMPLE, S., STEINER, M., HENDERSON, G. D. & AYRES, J. G. 2008. Particulate matter exposure during domestic work in Nepal. *Ann Occup Hyg,* 52**,** 509-17.

LAKSHMI, P. V. M., VIRDI, N. K., SHARMA, A., TRIPATHY, J. P., SMITH, K. R., BATES, M. N. & KUMAR, R. 2013. Household air pollution and stillbirths in India: Analysis of the DLHS-II National Survey. *Environmental Research,* 121**,** 17-22.

LANGE, P., MAROTT, J. L., VESTBO, J., INGEBRIGTSEN, T. S. & NORDESTGAARD, B. G. 2014. Socioeconomic Status and Prognosis of COPD in Denmark. *COPD*.

LEE, M. S., HANG, J. Q., ZHANG, F. Y., DAI, H. L., SU, L. & CHRISTIANI, D. C. 2012. In-home solid fuel use and cardiovascular disease: a cross-sectional analysis of the Shanghai Putuo study. *Environ Health,* 11**,** 18.

LIM, S. S., VOS, T., FLAXMAN, A. D., DANAEI, G., SHIBUYA, K., ADAIR-ROHANI, H., AMANN, M., ANDERSON, H. R., ANDREWS, K. G., ARYEE, M., ATKINSON, C., BACCHUS, L. J., BAHALIM, A. N., BALAKRISHNAN, K., BALMES, J., BARKER-COLLO, S., BAXTER, A., BELL, M. L., BLORE, J. D., BLYTH, F., BONNER, C., BORGES, G., BOURNE, R., BOUSSINESQ, M., BRAUER, M., BROOKS, P., BRUCE, N. G., BRUNEKREEF, B., BRYAN-HANCOCK, C., BUCELLO, C., BUCHBINDER, R., BULL, F., BURNETT, R. T., BYERS, T. E., CALABRIA, B., CARAPETIS, J., CARNAHAN, E., CHAFE, Z., CHARLSON, F., CHEN, H., CHEN, J. S., CHENG, A. T., CHILD, J. C., COHEN, A., COLSON, K. E., COWIE, B. C., DARBY, S., DARLING, S., DAVIS, A., DEGENHARDT, L., DENTENER, F., DES JARLAIS, D. C., DEVRIES, K., DHERANI, M., DING, E. L., DORSEY, E. R., DRISCOLL, T., EDMOND, K., ALI, S. E., ENGELL, R. E., ERWIN, P. J., FAHIMI, S., FALDER, G., FARZADFAR, F., FERRARI, A., FINUCANE, M. M., FLAXMAN, S., FOWKES, F. G., FREEDMAN, G., FREEMAN, M. K., GAKIDOU, E., GHOSH, S., GIOVANNUCCI, E., GMEL, G., GRAHAM, K., GRAINGER, R., GRANT, B., GUNNELL, D., GUTIERREZ, H. R., HALL, W., HOEK, H. W., HOGAN, A., HOSGOOD, H. D., 3RD, HOY, D., HU, H., HUBBELL, B. J., HUTCHINGS, S. J., IBEANUSI, S. E., JACKLYN, G. L., JASRASARIA, R., JONAS, J. B., KAN, H., KANIS, J. A., KASSEBAUM, N., KAWAKAMI, N., KHANG, Y. H., KHATIBZADEH, S., KHOO, J. P., KOK, C., LADEN, F., et al. 2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet,* 380**,** 2224-60.

LIN, C. M. & KUO, H. W. 2013. Sex-age differences in association with particulate matter and emergency admissions for cardiovascular diseases: a hospital-based study in Taiwan. *Public Health,* 127**,** 828-33.

LIN, H.-H., EZZATI, M. & MURRAY, M. 2007. Tobacco Smoke, Indoor Air Pollution and Tuberculosis: A Systematic Review and Meta-Analysis. *PLoS Med,* 4**,** e20.

LIN, H.-H., MURRAY, M., COHEN, T., COLIJN, C. & EZZATI, M. 2008. Effects of smoking and solid-fuel use on COPD, lung cancer, and tuberculosis in China: a time-based, multiple risk factor, modelling study. *Lancet,* 372**,** 1473-1483.

LING, S. H. & VAN EEDEN, S. F. 2009. Particulate matter air pollution exposure: role in the development and exacerbation of chronic obstructive pulmonary disease. *Int J Chron Obstruct Pulmon Dis,* 4**,** 233-43.

LITTON, C. D., SMITH, K. R., EDWARDS, R. & ALLEN, T. 2004. Combined optical and ionization measurement techniques for inexpensive characterization of micrometer and submicrometer aerosols. *Aerosol Science and Technology,* 38**,** 1054-1062.

LIU, S., ZHOU, Y., WANG, X., WANG, D., LU, J., ZHENG, J., ZHONG, N. & RAN, P. 2007. Biomass fuels are the probable risk factor for chronic obstructive pulmonary disease in rural South China. *Thorax,* 62**,** 889-897.

LIU, Y., DING, J., BUSH, T. L., LONGENECKER, J. C., NIETO, F. J., GOLDEN, S. H. & SZKLO, M. 2001. Relative Androgen Excess and Increased Cardiovascular Risk after Menopause: A Hypothesized Relation. *Am J Epidemiol,* 154**,** 489-494.

LONDAHL, J., SWIETLICKI, E., RISSLER, J., BENGTSSON, A., BOMAN, C., BLOMBERG, A. & SANDSTROM, T. 2012. Experimental determination of the respiratory tract deposition of diesel combustion particles in patients with chronic obstructive pulmonary disease. *Part Fibre Toxicol,* 9**,** 30.

LOPEZ BERNAL, J. A., UPTON, M. N., HENDERSON, A. J., DEDMAN, D., MCCARTHY, A., DAVEY SMITH, G. & BEN-SHLOMO, Y. 2013. Lower respiratory tract infection in the first year of life is associated with worse lung function in adult life: prospective results from the Barry Caerphilly Growth study. *Ann Epidemiol,* 23**,** 422-427.

MACHISA, M., WICHMANN, J. & NYASULU, P. S. 2013. Biomass fuel use for household cooking in Swaziland: is there an association with anaemia and stunting in children aged 6-36 months? *Trans R Soc Trop Med Hyg,* 107**,** 535-44.

MADRIGANO, J., KLOOG, I., GOLDBERG, R., COULL, B. A., MITTLEMAN, M. A. & SCHWARTZ, J. 2013. Long-term exposure to PM2.5 and incidence of acute myocardial infarction. *Environ Health Perspect,* 121**,** 192-6.

MALLA, S. 2013. Household energy consumption patterns and its environmental implications: Assessment of energy access and poverty in Nepal. *Energy Policy,* 61**,** 990-1002.

MANDOLESI, G., POMODERI, L., KHANAL, S., SAPKOTA, A., SHRESTHA, S. & COGO, A. 2011. Prevalence of airflow obstruction in Nepal rural population exposed to indoor but not outdoor pollution. 17th International Hypoxia Symposium, 2011 Lake Louise. Canada.

MANNINO, D. M. & BUIST, A. S. 2007. Global burden of COPD: risk factors, prevalence, and future trends. *Lancet,* 370**,** 765-773.

MCCRACKEN, J. P., SMITH, K. R., DIAZ, A., MITTLEMAN, M. A. & SCHWARTZ, J. 2007. Chimney stove intervention to reduce long-term wood smoke exposure lowers blood pressure among Guatemalan women. *Environ Health Perspect,* 115**,** 996-1001.

MCKENZIE, D. J. 2005. Measuring inequality with asset indicators. *Journal of Population Economics,* 18**,** 229-260.

MILLER, K. A., SISCOVICK, D. S., SHEPPARD, L., SHEPHERD, K., SULLIVAN, J. H., ANDERSON, G. L. & KAUFMAN, J. D. 2007. Long-term exposure to air pollution and incidence of cardiovascular events in women. *N Engl J Med,* 356**,** 447-458.

MILLER, M. R., HANKINSON, J., BRUSASCO, V., BURGOS, F., CASABURI, R., COATES, A., CRAPO, R., ENRIGHT, P., VAN DER GRINTEN, C. & GUSTAFSSON, P. 2005. Standardisation of spirometry. *Eur Respir J,* 26**,** 319-38.

MILLER, M. R., PEDERSEN, O. F., PELLEGRINO, R. & BRUSASCO, V. 2009. Debating the definition of airflow obstruction: time to move on? *Eur Respir J,* 34**,** 527-8.

MINISTRY OF HEALTH AND POPULATION, G. O. N., SOCIETY FOR LOCAL INTEGRATED DEVELOPMENT NEPAL (SOLID NEPAL) AND WHO, 2008. WHO Steps Surveillance Noncommunicable disease risk factors survey. Nepal. Kathmandu, Nepal: Ministry of Health and Population, Government of Nepal, Society for Local Integrated Development Nepal (SOLID Nepal) and WHO.

MISHRA, V. 2003. Indoor air pollution from biomass combustion and acute respiratory illness in preschool age children in Zimbabwe. *Int J Epidemiol,* 32**,** 847-853.

MISHRA, V. & RETHERFORD, R. D. 2007. Does biofuel smoke contribute to anaemia and stunting in early childhood? *Int J Epidemiol,* 36**,** 117-29.

NAEHER, L., LEADERER, B. & SMITH, K. 2000. Particulate matter and carbon monoxide in highland Guatemala: indoor and outdoor levels from traditional and improved wood stoves and gas stoves. *Indoor air,* 10**,** 200.

NAEHER, L., SMITH, K., LEADERER, B., NEUFELD, L. & MAGE, D. 2001. Carbon monoxide as a tracer for assessing exposures to particulate matter in wood and gas cookstove households of highland Guatemala. *Environ Sci Technol,* 35**,** 575-581.

NAEHER, L. P., BRAUER, M., LIPSETT, M., ZELIKOFF, J. T., SIMPSON, C. D., KOENIG, J. Q. & SMITH, K. R. 2007. Woodsmoke health effects: a review. *Inhalation toxicology,* 19**,** 67-106.

NBPA. 2014. *Major contributors in the development of the Nepalese Biogas Sector* [Online]. Kathmandu: Nepal Biogas Promotion Association (NBPA). Available: https://sites.google.com/site/nepalbiogas/biogas/history-of-biogas [Accessed February 13 2014].

NEA 2013. A year in review-fiscal year 2012/13. Kathmandu: Nepal Electricty Authority (NEA).

NETHERLANDS DEVELOPMENT ORGANISATION. 2014. *Biogas* [Online]. Netherlands Development Organisation. Available: http://www.snvworld.org/en/sectors/renewable-energy/about-us/snv-energy/domestic-biogas/snv-and-domestic-biogas [Accessed Sep 1 2014].

NIESSEN, L. W., TEN HOVE, A., HILDERINK, H., WEBER, M., MULHOLLAND, K. & EZZATI, M. 2009. Comparative impact assessment of child pneumonia interventions. *Bull World Health Organ,* 87**,** 472-80.

PANDEY, M. 1984a. Domestic smoke pollution and chronic bronchitis in a rural community of the Hill Region of Nepal. *Thorax,* 39**,** 337-339.

PANDEY, M. R. 1984b. Prevalence of chronic bronchitis in a rural community of the Hill Region of Nepal. *Thorax,* 39**,** 331-6.

PANDEY, M. R., REGMI, H. N., NEUPANE, R. P., GAUTAM, A. & BHANDARI, D. P. 1985. Domestic smoke pollution and respiratory function in rural Nepal. *The Tokai journal of experimental and clinical medicine,* 10**,** 471-481.

PARAJULI, R. 2011. Access to energy in Mid/Far west region-Nepal from the perspective of energy poverty. *Renewable Energy,* 36**,** 2299-2304.

PELLEGRINO, R., BRUSASCO, V., VIEGI, G., CRAPO, R. O., BURGOS, F., CASABURI, R., COATES, A., VAN DER GRINTEN, C. P., GUSTAFSSON, P., HANKINSON, J., JENSEN, R., JOHNSON, D. C., MACINTYRE, N., MCKAY, R., MILLER, M. R., NAVAJAS, D., PEDERSEN, O. F. & WANGER, J. 2008. Definition of COPD: based on evidence or opinion? *Eur Respir J,* 31**,** 681-2.

PELLEGRINO, R., VIEGI, G., BRUSASCO, V., CRAPO, R., BURGOS, F., CASABURI, R., COATES, A., VAN DER GRINTEN, C., GUSTAFSSON, P. & HANKINSON, J. 2005. Interpretative strategies for lung function tests. *Eur Respir J,* 26**,** 948-968.

PEREZ-PADILLA, R., SCHILMANN, A. & RIOJAS-RODRIGUEZ, H. 2010. Respiratory health effects of indoor air pollution [Review article]. *The International Journal of Tuberculosis and Lung Disease,* 14**,** 1079-1086.

PO, J. Y., FITZGERALD, J. M. & CARLSTEN, C. 2011. Respiratory disease associated with solid biomass fuel exposure in rural women and children: systematic review and meta-analysis. *Thorax,* 66**,** 232-239.

POKHREL, A. K., BATES, M. N., VERMA, S. C., JOSHI, H. S., SREERAMAREDDY, C. T. & SMITH, K. R. 2010. Tuberculosis and indoor biomass and kerosene use in Nepal: a case-control study. *Environ Health Perspect,* 118**,** 558-64.

POKHREL, A. K., SMITH, K. R., KHALAKDINA, A., DEUJA, A. & BATES, M. N. 2005. Case–control study of indoor cooking smoke exposure and cataract in Nepal and India. *Int J Epidemiol,* 34**,** 702-708.

POPE, D. P., MISHRA, V., THOMPSON, L., SIDDIQUI, A. R., REHFUESS, E. A., WEBER, M. & BRUCE, N. G. 2010. Risk of low birth weight and stillbirth associated with indoor air pollution from solid fuel use in developing countries. *Epidemiol Rev,* 32**,** 70-81.

POPE III, C. A. & DOCKERY, D. W. 2006. Health effects of fine particulate air pollution: lines that connect. *Journal of the Air & Waste Management Association,* 56**,** 709-742.

POULTER, N. 2003. Global risk of cardiovascular disease. *Heart,* 89**,** ii2-ii5.

PRACTICAL ACTION 2013. Annual Report 2012/13. Kathmandu, Nepal: Practical Action.

PROCKOP, L. D. & CHICHKOVA, R. I. 2007. Carbon monoxide intoxication: an updated review. *J Neurol Sci,* 262**,** 122-30.

PUZZOLO, E., STANISTREET, D., POPE, D., BRUCE, N. & REHFUESS, E. 2013. Factors influencing the large-scale uptake by households of cleaner and more efficient household energy technologies. London: EPPI-Centre, Social Science Research Unit, Institute of Education, University of London.

QUANJER, P., STAM, H., MERTENS, F. W., DE JONGSTE, J. C., CHAVANNES, N. H. & HOOGSTEDEN, H. C. 2014. [Contemporary interpretation of lung function test results]. *Ned Tijdschr Geneeskd,* 158**,** A7031.

QUANJER, P. H. *Recognizing correct and incorrect maneuvers during spirometry* [Online]. Available: http://www.spirxpert.com/performing7.htm#top [Accessed April 27 2014].

QUANJER, P. H., BRAZZALE, D. J., BOROS, P. W. & PRETTO, J. J. 2013. Implications of adopting the Global Lungs Initiative 2012 all-age reference equations for spirometry. *Eur Respir J,* 42**,** 1046-54.

QUANJER, P. H., ENRIGHT, P. L., MILLER, M. R., STOCKS, J., RUPPEL, G., SWANNEY, M. P., CRAPO, R. O., PEDERSEN, O. F., FALASCHETTI, E. & SCHOUTEN, J. P. 2010. Open letter: the need to change the method for defining mild airway obstruction. *Prim Care Respir J,* 19**,** 288-91.

QUANJER, P. H., HALL, G. L., STANOJEVIC, S., COLE, T. J. & STOCKS, J. 2012a. Age-and height-based prediction bias in spirometry reference equations. *Eur Respir J,* 40**,** 190-197.

QUANJER, P. H., STANOJEVIC, S., COLE, T. J., BAUR, X., HALL, G. L., CULVER, B. H., ENRIGHT, P. L., HANKINSON, J. L., IP, M. S. M., ZHENG, J., STOCKS, J. & INITIATIVE, T. E. G. L. F. 2012b. Multi-ethnic reference values for spirometry for the 3–95-yr age range: the global lung function 2012 equations. *Eur Respir J,* 40**,** 1324-1343.

QUANJER, P. H., TAMMELING, G. J., COTES, J. E., PEDERSEN, O. F., PESLIN, R. & YERNAULT, J. C. 1993. Lung volumes and forced ventilatory flows. Report Working Party Standardization of Lung Function Tests, European Community for Steel and Coal. Official Statement of the European Respiratory Society. *Eur Respir J Suppl,* 16**,** 5-40.

R CORE TEAM 2013. R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing.

RAI, S. 2013. *Background Paper For Clean Cooking Market Place 2013, Nepal* [Online]. Kathmandu: Alternative Energy Promotion Centre (AEPC). Available: http://www.nepalcookstoves.org/downloads/background_paper_on_clean_cooking_market_place_2013_nepal.pdf [Accessed April 22 2014].

RAJU, P. S., PRASAD, K., RAMANA, Y. V., BALAKRISHNA, N. & MURTHY, K. 2005. Influence of socioeconomic status on lung function and prediction equations in Indian children. *Pediatric pulmonology,* 39**,** 528-536.

RAUB, J. 1999. Health effects of exposure to ambient carbon monoxide. *Chemosphere-Global Change Science,* 1**,** 331-351.

RAUB, J. A., MATHIEU-NOLF, M., HAMPSON, N. B. & THOM, S. R. 2000. Carbon monoxide poisoning — a public health perspective. *Toxicology,* 145**,** 1-14.

REGALADO, J., PÉREZ-PADILLA, R., SANSORES, R., PARAMO RAMIREZ, J. I., BRAUER, M., PARÉ, P. & VEDAL, S. 2006. The effect of biomass burning on respiratory symptoms and lung function in rural Mexican women. *Am J Respir Crit Care Med,* 174**,** 901-905.

REGIONAL COPD WORKING GROUP 2003. COPD prevalence in 12 Asia-Pacific countries and regions: projections based on the COPD prevalence estimation model. *Respirology,* 8**,** 192-8.

REHFUESS, E. 2006. *Fuel for life: household energy and health,* Geneva, World Health Organization.

REHFUESS, E. A., PUZZOLO, E., STANISTREET, D., POPE, D. & BRUCE, N. G. 2014. Enablers and barriers to large-scale uptake of improved solid fuel stoves: a systematic review. *Environ Health Perspect,* 122**,** 120-30.

RICE, M. B., LJUNGMAN, P. L., WILKER, E. H., GOLD, D. R., SCHWARTZ, J. D., KOUTRAKIS, P., WASHKO, G. R., O'CONNOR, G. T. & MITTLEMAN, M. A. 2013. Short-Term Exposure to Air Pollution and Lung Function in the Framingham Heart Study. *Am J Respir Crit Care Med,* 188**,** 1351-1357.

RINNE, S. T., RODAS, E. J., BENDER, B. S., RINNE, M. L., SIMPSON, J. M., GALER-UNTI, R. & GLICKMAN, L. T. 2006. Relationship of pulmonary function among women and children to indoor air pollution from biomass use in rural Ecuador. *Respiratory medicine,* 100**,** 1208-1215.

ROBERTS, S. D., FARBER, M. O., KNOX, K. S., PHILLIPS, G. S., BHATT, N. Y., MASTRONARDE, J. G. & WOOD, K. L. 2006. FEV1/FVC ratio of 70% misclassifies patients with obstruction at the extremes of age. *CHEST Journal,* 130**,** 200-206.

ROMIEU, I., RIOJAS-RODRIGUEZ, H., MARRON-MARES, A. T., SCHILMANN, A., PEREZ-PADILLA, R. & MASERA, O. 2009. Improved biomass stove intervention in rural Mexico: impact on the respiratory health of women. *Am J Respir Crit Care Med,* 180**,** 649-56.

ROSENBAUM, P. R. 1984. The consquences of adjustment for a concomitant variable that has been affected by the treatment. *Journal of the Royal Statistical Society. Series A (General)***,** 656-666.

ROSENBAUM, P. R. 1991. A characterization of optimal designs for observational studies. *Journal of the Royal Statistical Society. Series B (Methodological)***,** 597-610.

ROSENBAUM, P. R. & RUBIN, D. B. 1983. The central role of the propensity score in observational studies for causal effects. *Biometrika,* 70**,** 41-55.

SAHA, A., RAO, N. M., KULKARNI, P., MAJUMDAR, P. & SAIYED, H. 2005. Pulmonary function and fuel use: a population survey. *Respiratory research,* 6**,** 127.

SAHN, D. E. & STIFEL, D. 2003. Exploring alternative measures of welfare in the absence of expenditure data. *Review of income and wealth,* 49**,** 463-489.

SALVI, S. & BARNES, P. J. 2010. Is exposure to biomass smoke the biggest risk factor for COPD globally? *Chest,* 138**,** 3-6.

SALVI, S. S. & BARNES, P. J. 2009. Chronic obstructive pulmonary disease in non-smokers. *Lancet,* 374**,** 733-743.

SAMET, J. M. & TIELSCH, J. 2007. Commentary: Could biomass fuel smoke cause anaemia and stunting in early childhood? *Int J Epidemiol,* 36**,** 130-131.

SAWYER, K., MUNDANDHARA, S., GHIO, A. J. & MADDEN, M. C. 2010. The effects of ambient particulate matter on human alveolar macrophage oxidative and inflammatory responses. *J Toxicol Environ Health A,* 73**,** 41-57.

SCHAFER, J. L. & KANG, J. 2008. Average causal effects from nonrandomized studies: a practical guide and simulated example. *Psychological Methods,* 13**,** 279.

SCHWARTZ, J. & MORRIS, R. 1995. Air Pollution and Hospital Admissions for Cardiovascular Disease in Detroit, Michigan. *Am J Epidemiol,* 142**,** 23-35.

SEMPLE, S., APSLEY, A., WUSHISHI, A. & SMITH, J. 2014. Commentary: Switching to biogas – What effect could it have on indoor air quality and human health? *Biomass and Bioenergy*.

SEZER, H., AKKURT, İ., GULER, N., MARAKOĞLU, K. & BERK, S. 2006. A case-control study on the effect of exposure to different substances on the development of COPD. *Ann Epidemiol,* 16**,** 59-62.

SHAHAB, L., JARVIS, M. J., BRITTON, J. & WEST, R. 2006. Prevalence, diagnosis and relation to tobacco dependence of chronic obstructive pulmonary disease in a nationally representative population sample. *Thorax,* 61**,** 1043-7.

SHARMA, S. K., GHIMIRE, A., RADHAKRISHNAN, J., THAPA, L., SHRESTHA, N. R., PAUDEL, N., GURUNG, K., BUDATHOKI, A., BARAL, N. & BRODIE, D. 2011. Prevalence of hypertension, obesity, diabetes, and metabolic syndrome in Nepal. *International journal of hypertension,* 2011.

SINGH, A., TULADHAR, B., BAJRACHARYA, K. & PILLARISETTI, A. 2012. Assessment of effectiveness of improved cook stoves in reducing indoor air pollution and improving health in Nepal. *Energy for Sustainable Development,* 16**,** 406-414.

SMITH-SIVERTSEN, T., DIAZ, E., POPE, D., LIE, R. T., DIAZ, A., MCCRACKEN, J., BAKKE, P., ARANA, B., SMITH, K. R. & BRUCE, N. 2009. Effect of reducing indoor air pollution on women's respiratory symptoms and lung function: the RESPIRE Randomized Trial, Guatemala. *Am J Epidemiol,* 170**,** 211-20.

SMITH K, UMA R, KISHORE V, ZHANG J, JOSHI V & M, K. 2000. *Greenhouse gases from small scale combustion devices in developing countries-Household stoves in India,* India.

SMITH, K. R. 1987. *Biofuels, air pollution, and health: a global review*, Plenum Press.

SMITH, K. R., APTE, M. G., YUQING, M., WONGSEKIARTTIRAT, W. & KULKARNI, A. 1994. Air pollution and the energy ladder in Asian cities. *Energy,* 19**,** 587-600.

SMITH, K. R., BRUCE, N., BALAKRISHNAN, K., ADAIR-ROHANI, H., BALMES, J., CHAFE, Z., DHERANI, M., HOSGOOD, H. D., MEHTA, S., POPE, D. & REHFUESS, E. 2014. Millions dead: how do we know and what does it mean? Methods used in the comparative risk assessment of household air pollution. *Annu Rev Public Health,* 35**,** 185-206.

SMITH, K. R., MCCRACKEN, J. P., THOMPSON, L., EDWARDS, R., SHIELDS, K. N., CANUZ, E. & BRUCE, N. 2010. Personal child and mother carbon monoxide exposures and kitchen levels: methods and results from a randomized trial of woodfired chimney cookstoves in Guatemala (RESPIRE). *J Expo Sci Environ Epidemiol,* 20**,** 406-16.

SMITH, K. R., MCCRACKEN, J. P., WEBER, M. W., HUBBARD, A., JENNY, A., THOMPSON, L. M., BALMES, J., DIAZ, A., ARANA, B. & BRUCE, N. 2011. Effect of reduction in household air pollution on childhood pneumonia in Guatemala (RESPIRE): a randomised controlled trial. *Lancet,* 378**,** 1717-26.

SMITH, K. R., SAMET, J. M., ROMIEU, I. & BRUCE, N. 2000a. Indoor air pollution in developing countries and acute lower respiratory infections in children. *Thorax,* 55**,** 518-532.

SMITH, K. R., UMA, R., KISHORE, V. V. N., LATA, K., JOSHI, V., ZHANG, J., RASMUSSEN, R. A. & KHALIL, M. A. K. 2000b. Greenhouse gases from small-scale combustion devices in developing countries. Phase IIa: household stoves in India. Prepared for: United States Environmental Protection Agency / Office of Research and Development / Office of Air and Radiation. Prepared by: National Risk Management Research Laboratory. Washington, DC.

SOMOGYI, E., BALOGH, I., RUBÁNYI, G., SÓTONYI, P. & SZEGEDI, L. 1981. New findings concerning the pathogenesis of acute carbon monoxide (CO) poisoning. *The American Journal of Forensic Medicine and Pathology,* 2**,** 31-39.

STANOJEVIC, S., QUANJER, P., MILLER, M. R. & STOCKS, J. 2013. The Global Lung Function Initiative: dispelling some myths of lung function test interpretation. *Breathe,* 9**,** 462-474.

STEINBERG, M. & BECKLAKE, M. R. 1986. Socio-environmental factors and lung function. *S Afr Med J,* 70**,** 270-4.

STEINER, P. M. 2011. Propensity Score Methods for Causal Inference: On the Relative Importance of Covariate Selection, Reliable Measurement, and Choice of Propensity Score Technique.

STUART, E. A. 2008. Developing practical recommendations for the use of propensity scores: Discussion of 'A critical appraisal of propensity score matching in the medical literature between 1996 and 2003'by Peter Austin, Statistics in Medicine. *Stat Med,* 27**,** 2062-2065.

STUART, E. A. & GREEN, K. M. 2008. Using full matching to estimate causal effects in nonexperimental studies: examining the relationship between adolescent marijuana use and adult outcomes. *Developmental Psychology,* 44**,** 395.

SWANNEY, M. P. & MILLER, M. R. 2013. Adopting universal lung function reference equations. *Eur Respir J,* 42**,** 901-903.

TRAISSAC, P. & MARTIN-PREVEL, Y. 2012. Alternatives to principal components analysis to derive asset-based indices to measure socio-economic position in low-and middle-income countries: the case for multiple correspondence analysis. *International journal of epidemiology,* 41**,** 1207-1208.

TREVOR, J., ANTONY, V. & JINDAL, S. K. 2014. The effect of biomass fuel exposure on the prevalence of asthma in adults in India - review of current evidence. *J Asthma,* 51**,** 136-41.

VAIDYA, A., PATHAK, R. P. & PANDEY, M. R. 2012. Prevalence of hypertension in Nepalese community triples in 25 years: a repeat cross-sectional study in rural Kathmandu. *Indian heart journal,* 64**,** 128-131.

VAN RIJT, S. H., BEIN, T. & MEINERS, S. 2014. Medical nanoparticles for next generation drug delivery to the lungs. *Eur Respir J,* 44**,** 765-774.

VESTBO, J., HURD, S. S., AGUSTI, A. G., JONES, P. W., VOGELMEIER, C., ANZUETO, A., BARNES, P. J., FABBRI, L. M., MARTINEZ, F. J., NISHIMURA, M., STOCKLEY, R. A., SIN, D. D. & RODRIGUEZ-ROISIN, R. 2013. Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease: GOLD executive summary. *Am J Respir Crit Care Med,* 187**,** 347-65.

VYAS, S. & KUMARANAYAKE, L. 2006. Constructing socio-economic status indices: how to use principal components analysis. *Health policy and planning,* 21**,** 459-468.

WHO 2006. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: global update 2005: summary of risk assessment. Geneva: World Health Organization (WHO).

WHO 2009. *Global health risks: mortality and burden of disease attributable to selected major risks*, World Health Organization (WHO).

WHO 2010. *WHO guidelines for indoor air quality: selected pollutants*, World Health Organization (WHO).

WHO 2014. Burden of disease from Household Air Pollution for 2012. Geneva, Switzerland: World Health Organization (WHO),.

WILLEMSE, B., POSTMA, D., TIMENS, W. & TEN HACKEN, N. 2004. The impact of smoking cessation on respiratory symptoms, lung function, airway hyperresponsiveness and inflammation. *Eur Respir J,* 23**,** 464-476.

WILLIAMSON, E., MORLEY, R., LUCAS, A. & CARPENTER, J. 2012. Propensity scores: from naive enthusiasm to intuitive understanding. *Statistical methods in medical research,* 21**,** 273-293.

WONG, G. W., BRUNEKREEF, B., ELLWOOD, P., ANDERSON, H. R., ASHER, M. I., CRANE, J. & LAI, C. K. 2013. Cooking fuels and prevalence of asthma: a global analysis of phase three of the International Study of Asthma and Allergies in Childhood (ISAAC). *Lancet Respir Med,* 1**,** 386-94.

WORNAT, M. J., LEDESMA, E. B., SANDROWITZ, A. K., ROTH, M. J., DAWSEY, S. M., QIAO, Y.-L. & CHEN, W. 2001. Polycyclic Aromatic Hydrocarbons Identified in Soot Extracts from Domestic Coal-Burning Stoves of Henan Province, China. *Environmental Science & Technology,* 35**,** 1943-1952.

YANAI, M., SEKIZAWA, K., OHRUI, T., SASAKI, H. & TAKISHIMA, T. 1992. Site of airway obstruction in pulmonary disease: direct measurement of intrabronchial pressure. *J Appl Physiol (1985),* 72**,** 1016-23.

YERNAULT, J. C. 1997. The birth and development of the forced expiratory manoeuvre: a tribute to Robert Tiffeneau (1910-1961). *Eur Respir J,* 10**,** 2704-10.

YIN, P., ZHANG, M., LI, Y., JIANG, Y. & ZHAO, W. 2011. Prevalence of COPD and its association with socioeconomic status in China: findings from China Chronic Disease Risk Factor Surveillance 2007. *BMC Public Health,* 11**,** 586.

ZHANG, J. J. & SMITH, K. R. 2007. Household air pollution from coal and biomass fuels in China: measurements, health impacts, and interventions. *Environ Health Perspect,* 115**,** 848.

ZHAO, Z. 2008. Sensitivity of propensity score methods to the specifications. *Economics Letters,* 98**,** 309-319.

ZHOU, M., LIU, Y., WANG, L., KUANG, X., XU, X. & KAN, H. 2014. Particulate air pollution and mortality in a cohort of Chinese men. *Environ Pollut,* 186**,** 1-6.

ZHOU, Y., WANG, C., YAO, W., CHEN, P., KANG, J., HUANG, S., CHEN, B., WANG, C., NI, D., WANG, X., WANG, D., LIU, S., LU, J., ZHENG, J., ZHONG, N. & RAN, P. 2009. COPD in Chinese nonsmokers. *Eur Respir J,* 33**,** 509-18.

OxTREC Clearance

Oxford Tropical Research Ethics Committee

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UNIVERSITY OF OXFORD

Professor B Basnyat
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Nepal International Clinic
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Kathmandu
Nepal

6th March 2012

- Dear Professor Basynat

Full Title of Study: Cardio-respiratory health of women exposed to indoor air pollution in rural Nepal: A cross sectional comparative study among traditional stove users and biogas users

OXTREC Reference: 16-12

In addition to your application, the documents reviewed were:

Documentation:	**Version:**	**Date:**
Protocol	V4.2	15.02.2012
ICF	V1.2	22.02.2012
Health Questionnaire	V1.0	
Eligibility Criteria Checklist	V1.0	31.12.2011
Peer review		03.01.2012

The OXTREC executive team reviewed the above application at the meeting held on Tuesday 6th March 2012 and were happy to give approval to this study, approval is for the first 5 years.

This will be fully implemented upon final approval of the full committee at the meeting on Thursday 22nd March 2012.

Yours sincerely

Richard Mayon-White

Dr Richard

OXTREC Chair

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NHRC clearance

Nepal Health Research Council
Estd. 1991

NHRC

Ref. No. 498

Executive Committee

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National Planning Commission
Ministry of Health & Population
Chief, Research Committee, IOM
Chairman, Nepal Medical Council

29 February 2012

Dr. Buddha Basnyat
Principal Investigator
University of Munich, Germany

Ref: Approval of Research Proposal entitled **Cardiorespiratory Health of Women exposed to indoor air pollution in rural Nepal: A cross sectional comparative study among traditional stove users and biogas users**

Dear Dr. Basnyat,

It is my pleasure to inform you that the above-mentioned proposal submitted on 20 January 2012 (**Reg. no. 10/2012** please use this Reg. No. during further correspondence) has been approved by NHRC Ethical Review Board on 23 February 2012 (2068-11-11).

As per NHRC rules and regulations, the investigator has to strictly follow the protocol stipulated in the proposal. Any change in objective(s), problem statement, research question or hypothesis, methodology, implementation procedure, data management and budget that may be necessary in course of the implementation of the research proposal can only be made so and implemented after prior approval from this council. Thus, it is compulsory to submit the detail of such changes intended or desired with justification prior to actual change in the protocol.

If the researcher requires transfer of the bio samples to other countries, the investigator should apply to the NHRC for the permission.

Further, the researchers are directed to strictly abide by the National Ethical Guidelines published by NHRC during the implementation of their research proposal and submit progress report and full or summary report upon completion.

As per your research proposal, total research amount is NRs. 50,000.00 and NHRC processing fee is US$ 100.00.

If you have any questions, please contact the research section of NHRC.

Thanking you.

Sincerely Yours,

Dr. Shanker Pratap Singh
Member Secretary

Tel. +977-1-4254220, 4227460, Fax: +977-1-4262469, Ramshah Path, P.O. Box 7626, Kathmandu, Nepal.
Website: http://www.nhrc.org.np, Email: nhrc@nhrc.org.np

Consent form

Comparing heart and lung health in women using traditional stoves and biogas stoves
Information and Consent sheet

You are being asked to participate in a research study assessing the cardiorespiratory health of adult women exposed to indoor air pollution in Nepal. You are invited because you are the main cook of the family and is 30 years or older.

Researchers from Nepal International Clinic-Kathmandu, Oxford University Clinical Research Unit-Nepal and Ludwig Maximilian University-Germany are conducting this study along with members from the Mountain Medicine Society of Nepal.

The purpose of this research is to quantify the exposure to indoor air pollutants and explore the impacts in cardiorespiratory health by cooking daily in biogas fuel for last 10 years in adult female cooks and compare it to those cooking in traditional firewood stoves.

More than 80% of Nepali population still cooks with biomass fuel. When these biomass fuels are burned in inefficient open stoves inside houses with poor ventilation, they emit a complex mixture of hundred of pollutants, including fine particulate matter, carbon monoxide and several carcinogenic compounds. These pollutants are proved to cause chronic obstructive lung disease, acute respiratory tract infections and even cancer. It is also thought that they cause high blood pressure, tuberculosis, cataract etc.

The Biogas Support Program of Nepal (BSPN), which promotes cleaner biogas plant fuels, is expanded now. More than 200,000 biogas plants are running nationally. However, whether there is reduction in pollutant levels in the kitchens of these biogas users is not known. Many houses use biogas together with other traditional fire-stoves. We also do not know if there are any health benefits when biogas is used together with other fuel source. So, we want to find out the same by doing spirometry and measuring your blood pressure and oxygen saturation coupled with pollutants level quantification.

If you agree to take part in this research, we will ask you to do the following things. We will ask some questions to know what fuel you use for cooking, where you cook and etc. We will also ask you if you have any respiratory symptoms. We will also perform some procedures to measure your respiratory and cardiac health. All of these procedures are painless and noninvasive. We will ask you to blow your breath out in a small device the size of a radio to measure your lung functions. We will also shine a special light through your fingertip to measure the amount of oxygen in your blood. We will also measure your blood pressure. We will explain what it means to your health and give you a report of these. We will also measure the indoor air quality in your kitchen by keeping two devices for 24 hours. They measure these compounds automatically by themselves.

By participating in this study, you and the other women in your area will help us learn if cooking in the biogas for long time is helpful to reduce the indoor air pollution and improve the cardiorespiratory functions than cooking with the traditional woodstoves. We hope we will learn what the women and doctors here can do to help women be healthy and have good indoor air quality.

You will not receive any money for the time that you spend with us. However, we will give you a report that includes details on your blood pressure, oxygen saturation, heart rate and lung functions. We will also explain what does that mean to you and can provide advice if you wish.

We would also like to ask if you would allow us to share your information after we prepare it so that it cannot be linked to you. The information in this study will only be used in ways that will not reveal who you are. You will not be identified in any publication from this study or in any information shared with other researchers. Your participation in this study is confidential.

Your participation is voluntary. If you choose not to participate, it will not affect your current or future relations with us or our universities or the Nepal International Clinic. If you choose to participate and then change your mind in between, that is okay. There is no penalty for not participating or for discontinuing your participation.

The researchers conducting this study are Buddha Basnyat, Maniraj Neupane, Eva Rehfuess, Rainald Fischer, Guenter Froeschl and Jeremy Farrar from Nepal, Germany and UK. Other Nepalese citizens who are from your area are helping with this study. Please ask any questions you have now or later. If you have any additional questions, concerns or complaints about the study after you talk with them, you may again contact them at
Maniraj Neupane: +977-9841625 295
Buddha Basnyat: +977-14434642 or +977-14435 357

If the researchers cannot be reached, or if you would like to talk to someone else about; (1) questions, concerns or complaints regarding this study, (2) research participant rights, (3) research-related injuries, or (4) other human subjects issues, please contact Nepal Health Research Council's Institutional Review Board at +977 1 425 4220 or write: Nepal Health Research Council, Institutional Review Board, Kathmandu, Nepal.

Statement of Consent

I have heard or read the above information. I have received answers to the questions I have asked. I am at least 18 years of age.
I consent to participate in this research. Yes ☐

Print name of participant: ____

Signature or mark or thumbprint of participant: ___________________________________

Signature of a witness (in case of illiterate patients): ______________________________

Signature of person obtaining the consent: _________________________
Date: _________________________

Short version of consent form in Nepali

घरभित्र हुने वायु प्रदुषणले वयस्क महिलाको मुटु र फोक्सोमा पार्ने स्वास्थ्य प्रभाव

अध्ययन सहभागी पत्र

मैले यस अनुसन्धानको बारेमा जानकारी पाएँ । आफूले सोधेका प्रश्नहरुको उत्तरहरु पाएँ । म कम्तिमा १८ वर्षको छु ।

म यो अध्ययनमा सहभागी हुन सहमत छु ।   हुन्छ   ☐

सहभागीको नाम : ....

सहभागीको हस्ताक्षर अथवा छाप वा चिन्ह : ....

साक्षीको हस्ताक्षर : ....

मञ्जुरीनामा लिने व्यक्तिको हस्ताक्षर : ....

मिति : ....

....

Questionnaire

Interviewer: .... Recruitment no: .... Master HH ID: ....

सहभागीता सहमतिपत्र

मैले यस अनुसन्धानको बारेमा जानकारी पाएँ। जानकारी पत्रमा लेखिएका कुराहरु सुने अथवा पढें र आफूले सोधेका प्रश्नहरुको उत्तरहरु पाएँ। म कम्तिमा १८ वर्षको छु र म यो अध्ययनमा सहभागी हुन सहमत छु। हुन्छ ☐

सहभागीको नाम: ....

सहभागीको हस्ताक्षर अथवा छाप वा चिन्ह : ....

साक्षीको हस्ताक्षर: ....

सहमति लिने व्यक्तिको हस्ताक्षर: ....

मिति: ....

ID. Identifying village and household			
ID1	VDC		
ID2	Ward		
ID3	Name of village		
ID5	Name of household head		
ID6	Name of interviewee		
ID7	Age of interviewee	***Exclude if less than 30 years or born after 2038 BS***	
ID8	Date of interview		
ID9	Ethnicity		
A. Identifying main fuel used for cooking			
A1	What is the main fuel used for cooking in this household? *Others (specify)*..................................	Biogas Wood Dung Crop or agricultural residues Straw ***LPG*** ***Kerosene/parafin*** ***Charcoal*** ***Electricity*** Others	1 2 3 4 5 6 7 8 9 10
Discontinue** completing questionnaire for those answering **LPG, kerosene/ paraffin, charcoal or electricity ***CONTINUE** completing questionnaire for those answering **biogas, wood, dung, crop or agricultural residues and straw.***			
B. Characteristics of main cook			
B1	How long have you been living in this household?	More than 10 yrs>>*include* **Less than 10 yrs>>*exclude***	1 2
B2	Do you currently smoke or have you ever smoked cigarettes in the past?	NEVER *>>include>> go to B3* In the past only>> *go to B2.1* Now as well>>*go to B2.2*	1 2 3
B2.1	**If past smoker**, when did you give up smoking?	10 or more years ago 5-10 years ago 1- 5 years ago	1 2 3
B2.2	How many cigarettes did / do you usually smoke per day?*Specify..*		

B2.3	For how many years did you/ have you been smoking cigarettes? *Specify..*		
B3	Do you currently suffer from tuberculosis?	**No** **YES >> exclude**	1 2
B4	Can you read or write?	**No** **Yes**	1 2
B4.1	If yes, what is your educational attainment? Specify…………………………………….	Incomplete primary school (1-4) Complete primary school (5) Incomplete secondary school (8) Complete secondary school (10) Higher education. (>10)	1 2 3 4 5
B5	What is the highest educational attainment of any of the members of the family? Specify…………………………………….	Incomplete primary school (1-4) Complete primary school (5) Incomplete secondary school (8) Complete secondary school (10) Higher education. (>10)	1 2 3 4 5

Observe,
- if main cook shows a gross deformity of back and chest. **If so, *exclude.***
- if main cook shows signs of current infection or fever above 38^{0}C? **If so, *ask if she is comfortable if investigators make a call back two weeks later.***

C. Characteristics of biogas installation: *For biogas users only*

C1	When was your biogas plant installed? *(for more than 10yrs, check in the log book and record date)*	**Less than 10yrs ago >>exclude** More than 10 yrs ago **………….. yrs or …………… BS**	
C2	Was your biogas plant continuously nonfunctional for more than 12 months in the last 10 years?	**No** **YES>> exclude**	1 2
C3	Is this biogas plant attached to the toilet?	**Yes** **No**	1 2

D. Socio-economic characteristics

D1	Does this household own any livestock, herds, other farm animals and poultry?		**Yes** **No**	1 2
D2	How many of the following animals does this household own?		**SCORE**	
	Milk cows or buffalo			
	Oxen/Bulls			
	Goats			
	Pigs			
	Poultry			
	Others			
D3	Does any member of the household own?		**SCORE**	
	A bicycle	1.Yes 2. No		
	A motorcycle/scooter	1.Yes 2. No		
	Animal drawn cart	1.Yes 2. No		
D4	Does your household have		**SCORE**	
	Electricity supply?	1. Yes 2. No		
	A radio?	1. Yes 2. No		
	A television?	1. Yes 2. No		
	A watch?	1. Yes 2. No		
	A mobile telephone?	1. Yes 2. No		
	A non mobile telephone?	1. Yes 2. No		
	A toilet?	1. Yes 2. No		

D5	What is the main source of drinking water for your household?		**SCORE**
	Piped into own yard	1.	
	Piped into nearby dwelling	2.	
	Tube well/Bore hole	3.	
	Dug well/*inar*	4.	
	Public tap	5.	
	Spring	6.	
	Others (*specify*)......	7.	

RB1	For house with biogas **not installed**, have you heard of Biogas (*gobargas)* fuel plant? Yes=1 No=2	
RB2	For house with biogas **not installed**, what is the reason for not installing the biogas (*gobargas*) plant? *(Do not prompt! Multiple answers possible)* Expensive first time investment; cannot afford it=1 Easy availability of firewood=2 Tedious and difficult to operate the biogas plant=3 Inadequate fuel production from the plant=4 Does not meet all household energy need=6 Leakage and bad odor from the plant=7 Happy with current household energy situation=8 Others ....=9	
RB3	For house with biogas **not installed,** what would have facilitated you to install the biogas (*gobargas*) plant? Better information on how to obtain it=1 If it were cheaper (more subsidy from the government)=2 If payment modalities were different, eg less upfront investment, micro finance scheme=3 Better training on how to use it and after sales services=4 Others..=5	
RB4	For house with biogas **plant installed**, what is the reason for installing the biogas (*gobargas*) plant? Neighbor had it and liked it=1 Advice and suggestions from the local agent=2 Subsidy from the government=3 Micro financing from the local banks=4 Problems with fuel availability (time for collection, money for purchase)=5 Smoky and dirty kitchen (egsoots on pots and pans)=6 Illnesses in the family members=7 Others ....=8	
RB5	Who made the decision regarding the biogas installation in the house? Grandfather/Husband=1 Grandmother/Wife=2 Joint decision=3	

To be filled later for matching:

Summary of matching variables: Age of the main cook (+/- five years): .... Cattle ownership: • No of Cow/Buffalo/ Ox: .... Socioeconomic status based on household asset index: ....

.... , ID no ....

is matched to

.... , ID no ....

HEALTH QUESTIONNAIRE

A. Cough			
A1	Over the last 12 months, have you usually had a **cough** first thing in the morning, or at other times of the day?	No (go to B1) Yes	1 2
A2	Do you usually **cough** like this on most days?	No Yes	1 2
A3	For how many months, in total, in the last year have you **coughed** like this?	9 or more months 5 - 8 months 3 - 4 months 1 – 2 months less than 1 month	1 2 3 4 5
A4	For how many years have you **coughed** like this?	Years:	
B. Phlegm			
B1	Over the last 12 months, have you usually brought up **phlegm** from your chest (deep down in your lungs) first thing in the morning, or at other times of the day?	No (go to C1) Yes	1 2
B2	Do you usually bring up **phlegm** like this on most days?	No Yes	1 2
B3	What colour is the **phlegm**usually?	Clear or white Yellow or green Brown or black Red (streaked)	1 2 3 4
B4	For how many months, in total, in the last year have you brought up **phlegm** like this?	9 or more months 5 - 8 months 3 - 4 months 1 – 2 months less than 1 month	1 2 3 4 5
B5	For how many years have you brought up **phlegm** like this?	Years:	
C. Episodes of cough and phlegm			
C1	Over the last 12months, have you had episodes of both (increased*) **cough**and**phlegm** together lasting for 3 weeks or more?**Increased if already have cough and/or phlegm*	No *(go to section WH1)* Yes	1 2
C2	How many such episodes did you have in the last year?	Number:	

WH. Wheezing			
WH1	Over the last 12 months, has your chest (your lungs) sounded **wheezy or whistling**	No (go to H1) Yes	1 2
WH2	Has this happened when you have a cold?	No Yes	1 2
WH3	Has this happened at other times when you do not have a cold?	No Yes	1 2
WH4	For how many years has this wheeze been present	Years	
DB. Difficulty breathing			
DB1	Have you experienced any difficulty in breathing in the last 12 months?	No (go to CP) Yes	1 2
DB2	How do you grade your difficulty in breathing? 1. *No dyspnea, except with strenous exercise* 2. *Dyspnea when walking up an incline or hurrying on the level* 3. *Walks slower than most on the level or stops after 15 minutes of walking on the level* 4. *Stops after a few minutes of walking on the level* 5. *Dyspneic at rest and too difficult to leave the house*	 mMRC 0 mMRC 1 mMRC 2 mMRC 3 mMRC 4	 1 2 3 4 5
CP. Chest pain and palpitations			
CP1	Have you experienced any attacks of chest pain in the last 12 months?	No Yes	1 2
CP2	Have you experienced any palpitations in the last 12 months?	No Yes	1 2
NC: Night time cough			
NC1	Have you experienced cough at night disturbing your sleep in the last 12 months?	No Yes	1 2
H. Headaches			
He1	Over the last 12 months, have you tended to get **headaches?**	No (go to TM) Yes	1 2
He2	How often do you have **headaches**?	Every day Most days Few days per week Once per week Less often	1 2 3 4 5
He3	How strong are the **headaches** usually?	Very strong Fairly strong Mild	1 2 3
TM. Treatment for health problems			
In the last 12 months have you visited any of the following health providers for respiratory or cardiovascular health problems?			
	Health provider (put '0' for no visits)	Number of visits in last year for **yourself**	Where?
TM1 TM2	Pharmacy/ Sub health post/ Hospital/ Ayurvedalaya/ Traditional healer/other	TM1	TM2

HOUSEHOLD IAP QUESTIONNAIRE

Family					
HH1	No of family members		HH4	No of U5 children	
HH2	No of females		HH5	No of rooms	
HH3	No of males		HH6	No of bed rooms	

For the question below, chose the fuel from below:

1. Wood 2. Biogas 3. LPG 4. Electricity 5. Dung 6. Charcoal 7. Kerosene 8. Agricultural residues 9. Batteries 10. Solar 11. Candle 12. Other................

HH7 Activities?	HH8 What is the main fuel used?	HH9 What stove type is used? 1. 3 stone fire 2. Open stove 3. Closed stove 4. Gas stove Specify stove model/name where available.	HH10 Does the stove possess? 1. Chimney 2. Smoke hood 3. Neither	HH11 Where is the stove fuel combination? 1. Kitchen 2. Open outdoor 3. Living room 4. Bedroom 5. Detached building	HH12 Is the fuel ...? 1.Mainly collected 2.Mainly purchased 3.Both 4.NA
Cooking family meals					
Making hot drinks Tea					
Milk					
Cooking animal fodder					
Heating water for bathing					
Space heating during winter					
Lighting					
Brewing alcohol					
Home based small industry					
Other purpose					

HH13 Using the fuel list above, what type of fuel do you mainly use for *cooking or heating* in **different seasons** of the year?

Cooking	***Heating***
Winter: Pri:.................... Sec:..................	Winter: Pri:.................... Sec:..................
Summer: Pri:.................... Sec:..................	Summer: Pri:.................... Sec:..................
Monsoon: Pri:.................... Sec:..................	Monsoon: Pri:.................... Sec:..................

HH14 Inquire and note about the significant change in fuel usage in last 10 years.

1. *How long have you been using the electric rice cooker?* ....
2. *How often do you use it?* ....
3. *How long have you been using the LPG?* ....
4. *How long does one LPG cylinder last for your family?* ....

HH15 ***How much time do you spend in the kitchen overall per day? .... hours***

During the time (the last 24 hours) that the monitor was working, we would like to know the way fuel was used:

A. Cooking Sessions

1. Main Meal
   - 1.1 Rice(bhaat)
   - 1.2 Pulses –lentil soups(Daal)
   - 1.3 Vegetable-spinach or other
   - 1.4 Dheedo (millet or maize porridge)
   - 1.5 Gundruk
   - 1.6 Meat items including sukuti (dried meat)

2. Snacks and regular preparations
   - 2.1 Tea
   - 2.2 Milk
   - 2.3 Roti/bread
   - 2.4 Noodles
   - 2.5 Roasted maize *(poleko makai)*
   - 2.6 Others……………………

3 Others (specify)
Eg. Animal fodder

B .Quality of fuel: Not used = 1 Very dry = 2 Dry = 3 Damp = 4 Wet = 5 'Green' = 6

C. Types of fuel

1. Wood 2. Biogas 3. LPG 4. Electricity 5. Dung 6. Charcoal 7. Kerosene
8. Agricultural residues 9. Batteries 10. Solar 11. Candle 12.Other................

Cooking sessions	What was cooked? (A)	Starting time of cooking	How long did it take?	How many person did you cook for?	What fuel did you use? (C)	How dry were they? *(for wood users)* (B)
H15. 1 First						
H15.2 Second						
H15.3 Third						
H15.4 Fourth						
H15.5 Fifth						

H16.1	Was the stove kept alight especially for heating (not cooking)?	1 = Yes 2 = No	Fuel?
H16.2	Was the stove kept alight especially for lighting (not cooking)?	1 = Yes 2 = No	
H16.3	Did you light any non-electric lamps in the kitchen?	1 = Yes 2 = No	
	If yes, what kind of lamp did you use? 1=Kerosene	*2=Candle 3=Other: ....*	
H16.4	During the last 24 hours was there any one who smoked in the kitchen?	1 = Yes 2 = No	
H16.5	Was garbage burned nearby, with the smoke entering into your kitchen? Duration, garbage was burned : ....hrs..........min	1 = Yes 2 = No	
H16.6	Did you burn any incense stick in the kitchen?	1 = Yes 2 = No	
H16.7	Did you burn any mosquito coils in the kitchen?	1 = Yes 2 = No	
H16.8	During the monitoring period, was there anything unusual about your stove use pattern?	1=Nothing unusual 2=Cooked for more people than usual 3=Cooked for less people than usual	
H16.9			

Name of the main cook:

OBSERVATION CHECK LIST:			
H10.1	Material used for the roof of the KITCHEN:		
	Thatch *(paral/khar)*	1.	
	Mud tiles *(taali)*	2.	
	Tin *(jastapata)*	3.	
	Wood planks *(takti)*	4.	
	Stone slates *(slate)*	5.	
	Cemented roof	6.	
	Others (*specify*)……	7.	
H10.2	Material used for the walls of the KITCHEN:		
	Bamboo with mud	1.	
	Stone with mud	2.	
	Bricks	3.	
	Bricks with mud	4.	
	Cemented wall	5.	
	Bamboo with cement	6.	
	Wood planks	7.	
	Others (*specify*)……	8.	
H10.3	Material used for the floor of the KITCHEN:		
	Earth / mud/ sand	1.	
	Wooden planks	2.	
	Bricks	3.	
	Cemented	4.	
	Bamboo	5.	
	Carpet	6.	
	Others (*specify*)……	7.	
Observe and record: Eaves space (space between the walls and the roof) in room with stoves			
H11.1	Depth of eaves spaces in the room with the stove (gap between roof and wall) None = 1 Less than 10cm in depth = 2 10 – 30cm in depth = 3 Greater than 30cm in depth = 4		
H11.2	Length of eaves spaces in the room with the stove All round room = 1 Along outside walls = 2 Along walls within house = 3 Other = 4		
Observe and record: Windows in the kitchen			
H12.1	How many WINDOWS are there in the room where cooking is done?		

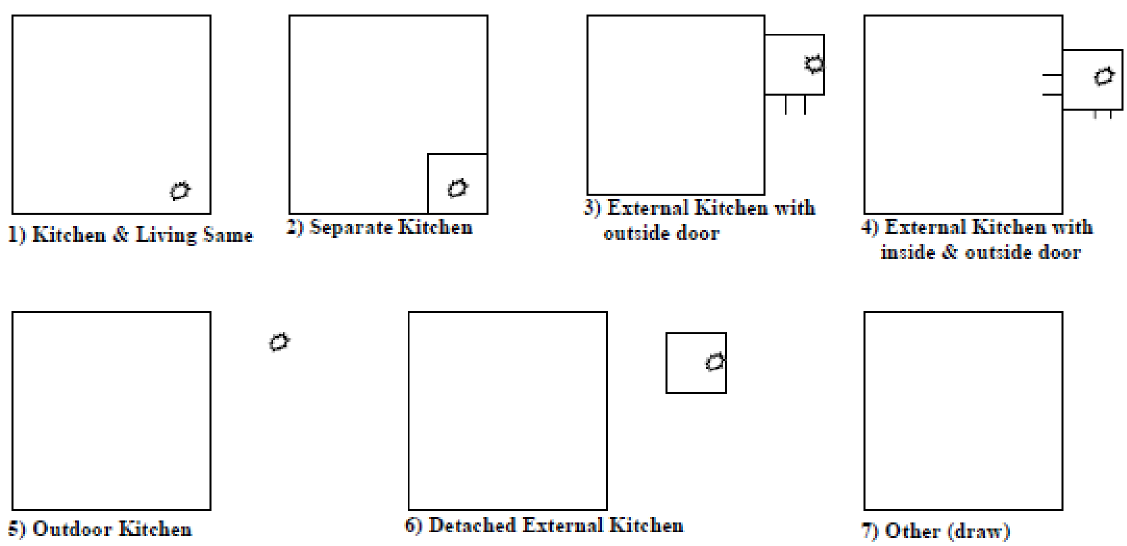
H12.2	How wide are the two largest windows in the room where cooking is done? **Measure the *l* * *b* of window in cm and record** Window 1 .... cm * .... cm Window 2 .... cm * .... cm	No window = 1 2cm – 5cm = 2 6cm –14cm = 3 15cm- 29cm=4 30cm –59cm=5 >60cm = 6	
Observe and record: Doors in the kitchen			
H13.1	How many doors are there in the kitchen?		
H13.2	How wide are the doors?		
H13.3	How high are the doors?		
H13.4	Are the doors usually open or closed?		
Measure and record: Kitchen dimensions			
H14	Height of the kitchen in meters		
	Length of the kitchen in meters		
	Breadth of the kitchen in meters		

Circle AND write in the box the appropriate kitchen type. Mark the position of the doors, windows, chimney (if present) and equipment using the symbols below.

Kitchen Location Code	

Symbols to use in your drawings

| | Doors
□ Windows
▲ Chimney
X Equipment



Master ID on HH questionnaire:					
Interviewer recruitment number:					
Name of the main cook:					
Code:	1. WW 2. BB				
Age of the main cook in years					
Weight in kgs:					
Height in cms :					
Smoker?: 1. Current 2. Past 3. Never					
Oxygen saturation DEVICE no :					
1 SpO2	%	2 SpO2	%	3 SpO2	%
1 HRp	bpm	2 HRp	bpm	3 HRp	bpm
Blood pressure DEVICE no:					
Sys 1		Dias 1		HR 1	
Sys 2		Dias 2		HR 2	
Sys 3		Dias 3		HR 3	
Spirometry DEVICE no:					
Breath	**FEV1**	**FVC**	**FEV1/FVC**	**FEF 25-75**	**Note from device**
1.					
2.					
3.					
4.					
5.					
6.					
Note on the overall Spirometry:					
Difference between two FEV1s and two FVCs should be less than 200ml					
IAP DEVICES: UCB and CO both? 1. Both 2. UCB only 3. CO only 4. None					
UCB No:	CO No:				
Removed from bag/time installed:					
Date installed:					
Time removed:					
Date removed:					
UCB file name:					
CO file name:					
Initial zeroing period:	to				
Final zeroing period:	to				

Curriculum vitae

Maniraj Neupane, MBBS, DiMM

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Professional experience

Aug 2013-present	*Mountain Medicine Society of Nepal (MMSN), Kathmandu* Secretary
Apr 2012-present	*Nepalese Diploma in Mountain Medicine Course, Kathmandu* Co-director
Nov 2012-Aug 2013	*World Young Doctor's Organization (WYDO), Netherlands* Secretary
May 2011-Nov 2013	*Nepal International Clinic Travel and Mountain Medicine Centre, Kathmandu* Medical officer
Mar 2010-Mar 2012	*Nepalese Diploma in Mountain Medicine Course, Kathmandu* Chief coordinator
Aug 2010-present	*World Young Doctor's Organization (WYDO), Netherlands* National Focal Point for Nepal

Academic qualification

Oct 2011-Sep 2014	*Center for International Health, University of Munich, Germany* Ph.D. Medical Research-International Health
May 2012-May 2014	*EURAC Institute of Mountain Emergency Medicine, Italy* International Diploma of Mountain Emergency Medicine
Nov 2012-May 2013	*UIAA/IKAR/ISMM Nepalese Diploma in Mountain Medicine Course, Nepal* Diploma in Mountain Medicine (DiMM)
Nov 2004-Apr 2011	*Maharajgunj Campus, Institute of Medicine, Tribhuvan University, Nepal* Bachelor of Medicine and Bachelor of Surgery (MBBS)

Trainings, workshops and seminars

Feb 2013	*Symposium on infectious disease, Munich* Center for International Health, University of Munich, Germany
Oct 2012	*Introduction to Biostatistics and R, Nepal* University of Oxford, Wellcome trust & Mountain Medicine Society of Nepal
Jun 2012	*Global Public Health Workshop, Munich* University of Munich, Germany
May 2011	*Spirometry and its interpretation strategy, Ferrara* University of Ferrara, Italy
Nov 2010	*Research ethics and governance workshop, Kathmandu* Oxford University Clinical Research Unit-Nepal
Apr 2010	*Jungle Medicine Training, Oxford* Wilderness Medical Training, UK
Mar 2010	*Clinical elective in acute general medicine, Oxford* *John Radcliffe Hospital, University of Oxford, UK*

Scientific presentation

NEUPANE, M. Household air pollution and airway obstruction among adult female cooks of rural Nepal. Oral presentation at the European Respiratory Society Congress, Munich, 2014

NEUPANE, M. Impact of household biogas fuel use on 24 hour kitchen concentrations of carbon monoxide in rural Nepal. Oral presentation at the International Symposium on Environment and Health, Peking University, Beijing, 2014

Peer reviewed publications

NEUPANE, M., BASNYAT, B., FISCHER, R., WOLBERS, M., FROESCHL, G., REHFUESS, EA. Sustained use of biogas fuel and blood pressure among women in rural Nepal. [**Submitted**]

THAPA, G., **NEUPANE, M**., STRAPAZZON, G., BASNYAT, B. & BRUGGER, H. 2014. Nepalese mountain rescue development project. *High Alt Med Biol.,* 15**,** 91-2.

JEONG, C., ALKORTA-ARANBURU, G., BASNYAT, B., **NEUPANE, M.**, WITONSKY, D. B., PRITCHARD, J. K., BEALL, C. M. & DI RIENZO, A. 2014. Admixture facilitates genetic adaptations to high altitude in Tibet. *Nature Communications,* 5.

GIRI, S., **NEUPANE, M.,** PANT, S., TIMALSINA, U., KOIRALA, S., TIMALSINA, S. & SHARMA, S. 2013. Quality of life among people living with Acquired Immune Deficiency Syndrome receiving anti-retroviral therapy: a study from Nepal. *HIV/AIDS (Auckland, NZ),* 5, 277.

GIRI, S., SHARMA, S., TIMALSINA, S., YADAV, V., KOIRALA, S., KUMAR, A., NEUPANE, S. & **NEUPANE, M**. 2012. Cardiovascular health risk behavior among medical students in a teaching hospital. *Journal of Nepal Health Research Council*.

MACNUTT, M. J., LAURSEN, P. B., KEDIA, S., **NEUPANE, M.**, PARAJULI, P., POKHAREL, J. & SHEEL, A. W. 2012. Acclimatisation in trekkers with and without recent exposure to high altitude. *European Journal of Applied Physiology,* 112**,** 3287-3294.