Cooking without smoke

Local (im)possibilities for indoor air pollution reduction in Arba Minch, Ethiopia

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Abstract

Relevance: Indoor air pollution related to biomass fuel cooking habits in Arba Minch, Ethiopia, results in exposure to daily Black Carbon (BC) and Nitrogen Dioxide (NO2) concentrations during cooking of about 150 and 700 µg/m3 respectively for 75% of the population. As it will take some time still before cleaner fuels become widely available and accepted, it is relevant to study what inhabitants of Arba Minch can do themselves at this moment. | **Methods:** This study searches such solutions in three steps: (1) a study of the variations across different households, (2) a review of the possibilities to shift within these variations according to the reasons for those variations, and (3) a quantification of the influence on accumulated exposure of such a shift. Methods from different disciplines are used to take these steps: semi-structured interviews on cooking habits and measurements of CO_2, BC, NO_2, temperature and wind are taken at 42 households. The Theory of Planned Behaviour is used to categorize the reasons for variations. Several statistical tests are used to investigate the relation between these variations and BC and NO_2 concentrations. | **Results:** For exposure to BC and NO_2 concentrations, variations are encountered regarding fuel material, fuel state, fire place specifics, kitchen openings and materials, the place of cooking and cooking times. Shifts possible for everyone (e.g. fire place depth and material), generally have no influence, while quite some shifts with substantial influence are not possible (e.g. shifts toward charcoal or kerosene, 74% decrease of accumulated exposure, or an increase in amount of people cooking, 31% decrease). Possibilities increase when only looked to some inhabitants (e.g. those in the ability to increase the amount of openings, 43%) or assuming that support by governments or NGOs can be given (e.g. implementing chimney structures, 49%).

Keywords:
Indoor air pollution; biomass fuel; Black Carbon; Nitrogen Dioxide; accumulated exposure; Theory of Planned Behaviour

Table of contents

Glossary

Concepts defined in the glossary are in *italic* throughout the chapters 1, 5, 6 and 7.

Accumulated household exposure: the *concentration* a particular person is exposed to within a household, summed over a time period. Unit used: hour μg/m^3
Capacities: see *local capacities*.
Changeability of a variable: whether a change of the variable is possible, given the *reasons* for different *variable settings*
Concentration: mass of a particle in a volume of air. Unit used: μg/m^3.
Concentration variable: a *variable* that is expected to have *influence* on the *concentration*.
Emission: mass of a particle produced by a source per time unit. Unit used: μg/s.
Emission variable: A *variable* that is expected to influence BC and NO_2 concentrations via the *emission* of particles.
Exposure to a particle: being in space where the air breathed contains some amount of a particle.
Exposure variable: a *variable* that is expected to have *influence* on the *exposure*.
Household concentration: the *concentration* within a household.
Influence of a variable on x: the change in x caused by a change of a *variable*.
Injera: big 'pancake', used for many Ethiopian dishes. The preparation of injera requires a high fire.
Locality: a group of people, seen as one group because they live at one place. For this research, Arba Minch, Ethiopia, is the locality of interest.
Local capacities: all options within the *variations among households*.
Local possibilities: things that are possible within a *locality*, given their *capacities* and their *reasons*.
Local reason: explanation given by a household for a particular *variable setting*.
Location variable: A *variable* that is expected to influence BC and NO_2 concentrations via the location of the *emission* source.
Reasons: see *local reasons*.
Variable: something found to have *variation among households*.
Variable setting: the choice of a particular household made with respect to a *variable*.
Variation among households: differences found at different households in the *locality* Arba Minch.
Ventilation: the amount of air transported per time unit. Unit used: m^3/s
Ventilation variable: A *variable* that is expected to influence BC and NO_2 concentrations via the *ventilation* of BC and NO_2 particles.

List of abbreviations

BC	Black Carbon
CO_2	Carbon Dioxide
IAP	Indoor Air Pollution
NGO	Non-Governmental Organization
NO_2	Nitrogen Dioxide
HHX	household number X

1. Introduction

1.1. Problem statement

This study investigates ways to reduce indoor air pollution (IAP). It is evident that exposure to air pollutants is related to different respiratory and cardiovascular diseases (Banerjee et al., 2012; Behera & Aggarwal, 2010; Burki, 2011; Edelstein et al., 2008; D. Fullerton et al., 2011; Mordukhovich et al., 2009; Perez-Padilla et al., 2010). Adverse health aspects are especially present in relation to IAP; yearly about 4.3 million deaths worldwide can be attributed to household air pollution (WHO, 2014). This is primarily due to cooking with biomass fuels.

Up to 3 billion people depend on biomass fuels (such as firewood, charcoal, dung) as primary cooking fuel source (WHO, 2014). These cooking habits convey exposure to high concentrations of air pollutants that are related to primary combustion, such as black carbon and nitrogen dioxide (Begum et al., 2009; D. G. Fullerton et al., 2009). NGOs and governments intervene to reduce IAP, for example by promoting new fuel materials or new stove-types, but it takes a long time to develop the infrastructure needed for a widespread implementation of these cooking tools and methods (Ezatti, 2005).

Arba Minch, Ethiopia, reflects this picture. Some inhabitants use 'new', cleaner fuels such as biogas, electricity or kerosene. There are also stoves that are created for the preparation of *injera*[a] in order to minimize the wood consumption. However, a substantial amount of the population uses traditional cooking habits. As reported by the 2007 census about 75% of the inhabitants of Arba Minch, Ethiopia, use biomass as primary cooking fuel source (CSA, 2010), and are exposed to high concentrations of black carbon (BC) and nitrogen dioxide (NO_2) accordingly. As the speed of government and NGO interventions does not seem to match with the urgency of the problem, it is relevant to review the things that the inhabitants of Arba Minch can do themselves to reduce IAP.

1.2. Theorizing the problem

Ezzati (2005) mentions two important research directions for effective interventions on IAP. The first is to study and develop accessible clean energy sources. This is a solution in the long run. While this research into long run solutions is on-going, the second research direction he mentions is a short run solution: "we need interventions that lower emissions by modifying specific aspects of current fuel stove combinations and energy-use behaviours. (...) Such interventions will almost certainly have to be designed for specific local conditions" (Ezzati, 2005, p. 106). In other words, while in the long run access to clean fuel is needed, people have to know what they can do themselves to lower exposure in the short run.

For this they can only use the assets and access they have right now: the *local capacities*. Studies suggest that differences in cooking circumstances show such solutions (Dasgupta et al., 2006; Torres-Duque et al., 2008). Variations in IAP are partly because of differences in household-specific *variable settings*, for example the design of the kitchen, the type of wood they use etc. If household variation influences exposure, a different choice on these variables might lead to a reduction in exposure. "As these arrangements are already within the means of poor families, the scope for cost-effective improvements may be larger than is commonly believed." (Dasgupta et al., 2006, p. 426) In other words: in order to find local solutions for Arba Minch, it is necessary to study the *local capacities* (i.e. the household specific *variable settings*) and their relation with the pollutant *concentrations*, and the *exposure* to these concentrations.

[a] See Glossary. All words from the glossary are in *italic* in chapters 1, 5, 6 and 7.

The hypothesis of this study is:

Local possibilities to reduce exposure to BC and NO_2 household concentrations can be found in the *local capacities*

In order to investigate this hypothesis it has to be checked whether there are *local possibilities* to reduce exposure to pollutant concentrations that are available within the *local capacities.* For this I will go through three steps:

1. Firstly a set of relevant variables that can be found within the ***local capacities*** need to be distinguished. These variables can be grouped into two categories: the *concentrations variables*, (i.e. the things expected to be related to the pollutant concentrations) and the *exposure variables* (i.e. the things that expected to be related to the exposure to the pollutant concentrations).

   Selection of concentration variables
   The two selection criteria for a *concentration variable* are (1) is there a relation between the variable and concentrations according to theory (including common sense) or already existing literature? And (2) is there any *variation* in this variable in the *locality* Arba Minch? If there is *variation* in Arba Minch, it means that all values that the variable takes are *local capacities:* things that are possible in Arba Minch. The *concentration variables* can be grouped in three types of variables: emission (outcome of burning), location (location within the household) and ventilation (related to air-movements). The reasoning behind this grouping will be explained in the conceptual framework. An example of a *concentration variable* is the fuel material used.

   Selection of exposure variables
   The two similar selection criteria for an *exposure variable* are (1) is there a relation between the variable and exposure according to theory (including common sense) or already existing literature? And, again, (2) is there any *variation* in this variable in the locality Arba Minch? The *exposure variables* can be grouped in three types of variables: cooking habits, kitchen specifics and other polluting activities. The reasoning behind this grouping will be explained in the conceptual framework. An example of these variables is the number of persons that are involved in cooking.

2. Besides the *local capacities* there is a second notion that determines whether a change can be made: the ability and willingness of people to change. This will be called the ***changeability*** of a variable. Within the field of sociology, the issue of 'change' and choice of certain behaviour has been studied a lot. Azjen and Fishbein (Ajzen, 1985) developed the Theory of Planned Behaviour. They explain the intentions behind volitional behaviour with three influences: attitude (ones attitude with respect to the behaviour), norm (what the people around think about that behaviour) and control (whether one believes to control the capacities needed to conduct that behaviour) (Hale, Householder, & Greene, 2002). This makes clear why a possible change for which the capacities are present is not necessarily conducted. It might be that one's attitude towards that behaviour is not (yet) positive, or that it is a problem for someone that others around are not (yet) conducting that behaviour, or simply that that person itself thinks he is not able to conduct that behaviour. The everyday-life perspective recognizes this barrier of intervention. It advocates to study the everyday life of people and the attitudes they hold, in order to help "people to design and perform the activities on the base of attitudes that they already

hold." (van Woerkum & Bouwman, 2012, p. 2) In other words: in order to get to know which *local capacities* provide *local possibilities* to reduce IAP in the short run, the researcher should also understand the *reasons* that people have for particular choices. These reasons may lie in volitional behavior, as discussed in the theory of planned behavior, but the behavior can also be habitual or externally influenced determined (Hale et al., 2002). These categories of behavior can be used in order to translate *reasons* into *changeability*.

3. The third step to determine whether a *local capacity* is a *local possibility* is to analyze the ***influence*** of a variable on pollutant concentrations and exposure to these concentrations. There should be a statistically significant relation between a variable and (exposure to) pollutant concentrations in order to see it as a viable option to reduce IAP in the short run.

The requirements for a *local capacity* to be a *local possibility* to reduce exposure to polluted air are summarized in Table 1.1.

Table 1.1: Steps to take in finding local possibilities to exposure to pollutants

Items to check		**Measurable by**
Local capacity		Variation of a variable within Arba Minch
Changeability		Reasons
Influence +		Statistical relation between variable and (exposure to) concentrations
= Local possibility to reduce accumulated exposure to BC and CO_2 concentrations		

1.3. Research questions

Considering all this, with this study I aim to answer the following research question:

What are the local possibilities to reduce accumulated household exposure to black carbon (BC) and nitrogen dioxide (NO_2) in Arba Minch?

Sub-questions:

1. What are *local possibilities* to reduce BC and NO_2 *household concentrations* in Arba Minch?
    a. What are the BC and NO_2 *household concentrations* and their indicators?
    b. What are the *variations* of the *concentration variables*?
        i. Outside the reach of the households
        ii. Inside the reach of the households
    c. What are *reasons* for *variation* in the *concentration variables* within the households reach*?* Are they *changeable*?
    d. What is the relation between these *variables* and BC and NO_2 *household concentrations*?
2. What are *local possibilities* to reduce the *accumulated household exposure* to these BC and NO_2 concentrations in Arba Minch?
    a. What are the *variations* of the *exposure variables*?
    b. What are *reasons* for *variation* in the *exposure variables?* Are they *changeable*?
    c. What is the relation between these variables and exposure to BC and NO_2 *household concentrations*?

The research objective is to test the hypothesis:

Local possibilities to reduce *exposure* to BC and NO_2 *household concentrations* can be found in the *local capacities*

For this I will get insight in *local possibilities* to reduce *accumulated household exposure* to BC and NO_2 concentrations by analysing variables (*local capacities*) on their *changeability* and *influence* on the *accumulated household exposure* to BC and NO_2 concentrations.

1.4. Conceptual framework

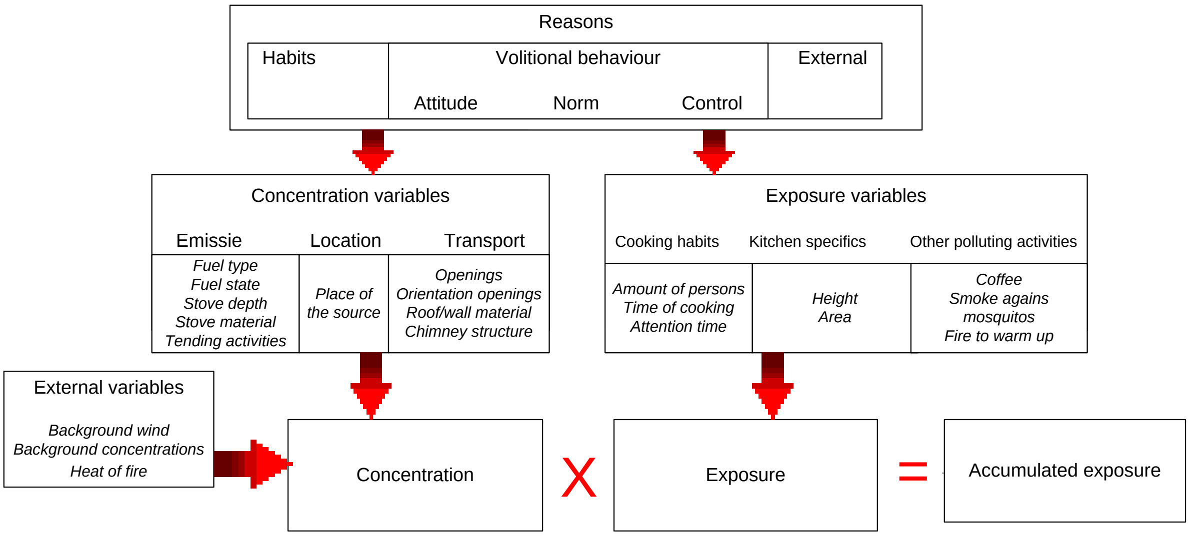


Figure 1.1: Overview of reasoning

This section will introduce the structure of this thesis and the terms that will be used. All italic words are defined in the glossary (page vi).

Figure 1.1 gives an overview of the steps to take in order to answer the main question: how to reduce the accumulated exposure in households in Arba Minch? For this the following aspects have to be considered: (1) the *reasons*, (2) the *variation* in *concentration-* and *exposure variables* and (3) their effects on concentrations and exposure respectively. In the following sections each part will be explained in more detail.

1.4.1. Reasons

The reasons for behavior can be grouped into habitual, volitional and external behavior. Habitual behavior I define as behavior decided by necessity, rather than own choice (volitional) or decided by an external party. An example of a habitual reason is to choose an amount of wood based on what is needed for the dish. Volitional behavior can be analyzed by the theory of planned behavior (Ajzen, 1985). External behavior is behavior decided by an external party. An example of an external reason is if the government introduces the law that it is no longer allowed to collect fuel wood in the forest: that is possibly a reasons for less use of wood.

By reviewing these *reasons* I will indicate the *changeability* of *variable settings*. The specific classification and valuation of *changeability* is further explained in the methodology chapter, section 2.4.3.

1.4.2. External variables

There are some variables that are relevant to take into account, but which *variable setting* are not a result of household choice. They will be described in this section.

Background wind: The background wind is influencing transport of BC and NO2 particles. It will be taken into account as control variable in some analyses. The background wind is measured by Minda (2014).

Background BC and NO2 concentrations: The background concentrations are a result of several emission sources throughout Arba Minch, such as garbage burning and all other households cooking. It is not in the reach of one household to change these activities. The background concentrations are measured by Minda (2014). They will be used by calculating the aggregate exposure to BC and NO2.

Heat of the fire: Warm air rises. Therefore, BC and NO_2 concentrations are most likely higher close to the roof. These dispersion patterns are also out of the reach of households.

1.4.3. Concentration variables

The *concentration variables* are the variables that will be tested on three aspects:

1. whether there is *variation* in the *variable setting* within Arba Minch.
2. whether the variable is *changeable* given the *reasons* for particular *variable settings*
3. whether the variable is significantly related to BC and/or NO_2 concentrations

If a variable fulfills all three criteria, it is a *local possibility* to reduce BC and NO_2 concentrations. In this section I will make a classification of the *concentration variables* and a first selection, based on theory, common sense and literature.

Classification of concentration variables

A particular BC or NO2 concentration is based on the emission from the source, the transport of the particles (ventilation) and the place where the concentration is measured. All variables to be investigated are grouped in these three categories.

Box 1: The effect of stove material on concentrations:

Let us assume for example that the variable stove material can take tree values (no, clay, stone).

To analyse the effect of stove material on BC concentration we can simply estimate the model:

$$C=\alpha+\beta 1*clay+\beta 2*stone+\varepsilon$$

C=predicted BC concentration
Clay=1 if clay stove, 0 if no clay stove
Stone=1 if stone stove, 0 if no stone stove
α, β1, β2 are the parameters to estimate
ε=error

The disadvantage of this model is that a lot of the variation in C can be explained by many other variables, that are not included in the model. The effect of the variation in these variables is in ε. If we include all variables that we collected in the data collection, there will be many βs, resulting in modelling problems caused by multicollinearity.

We know, however, that C is related to Emission. We can estimate a new model, in which only variables that affect emission are included.

$$E'=\alpha+\beta_i'*X_i'+\varepsilon'$$

E=vector of all predicted emissions
i=number of variables within emission
β_i'= vector of all parameters that are related to a variable
X_i'= matrix with all household variable settings per

There are two reasons to categorize the *concentration variables*. Firstly it gives us a helpful structure to see which variables have a similar effect on both BC and NO2 concentrations[a] (variables from the 'ventilation' and 'location' group) and which variables have a different effect on BC and NO2 concentrations (variables from the 'emission' group).

The second reason to categorize the variables is to ease the analysis. Emission, for example, is a.o. determined by the fuel material, the fire stage and characteristics of the stove. In

[a] I assume that ventilation and location mechanisms are similar for BC and NO_2. Lifetimes are respectively 6 days and 1 hour (Freitas et al., 2005; Spicer, Kenny, Ward, & Billick, 1993); the transport times within the household distances are well smaller than 1 hour (e.g. lowest ventilation rate (0.05 m^3/s) measured combined with highest volume encountered (60 m^3) still results in a total air refreshment time of 20 minutes - three times as low as the lifetime of NO_2).

order to see whether there is a relation between concentration values and the fuel material, the researcher has to take into account all other variables from all other categories that may have *influence* on concentration. Since many variables are categorical and not continuous (yes/no, multiple options), a large multiple-ANOVA or multiple regression model, with all variables included, will result in perfect multi-collinearity. In that case it is impossible to estimate a full model, with all variables included.

Since the sub-groups (emission, location and ventilation) have an impact on concentration, it is possible to take the sub-group value as dependent variable in some analyses (see example in box 1). In order to cross-check the validity of emission values, some of the analyses will be repeated using proxies for emission as dependent variables. The two best proxies are CO2 and (relative) fire temperature, since it is shown that if the temperature of the fire increases, BC emission and CO2 emission are also increasing (Begum et al., 2009). To see whether this is also true for the data from Arba Minch, I will test this in section 3.1.3.

You will find in the result-section that it was still not possible to include all relevant variables in the model each time, but taking emission (and related proxies CO2 and fire temperature) or ventilation as dependent variable, already improves the prediction of the effect of a *concentration variable* on the concentration. The calculation of emission and ventilation rates are will further be explained in the methodology chapter, section 2.3.

Selection of concentration variables: emission

Firstly, **fuel material** "has been the most common choice of indicator, typically as a dichotomous variable (using wood or not using wood) and sometimes as a categorical variable with multiple values" (Brauer & Saksena, 2002, p. 1156).

Typically it is found that wood, coal and other biomass result in higher concentrations than charcoal, kerosene or LPG. Difficulties that run across this variable are the use of more than one fuel, and also differences across days or seasons. The **state of the fuel** might also affect the BC and NO2 emissions. An important characteristic of vegetation burning is the presence of water. The vaporization of this water extracts energy from the process, leading to a lower burning efficiency. BC is a product of incomplete burning, so the BC emission might be higher if burning with wet wood instead of dry wood (Simoneit, 2002).

Secondly, Brauer & Saksena (2002) mention the stove type. "While many studies have shown that improved stoves are associated with reduced exposure, some have indicated that the degree of reduction is not as high as desired, and some have even found no influence of stove type" (ibid., p. 1157). It might also be difficult to transform the variety of stoves into a few variables to measure. Two *concentration variables* resulting from differences in stoves are **stove material** and **stove depth**.

Lobert and Warnatz (1993) give an extensive overview of the different stages for the combustion process when burning vegetation. The two most important stages for emission are: flaming (hot) combustion and smouldering. During the flaming combustion stage there is more oxygen needed than during the smouldering stage. The flame is the result of a 'cloud' of flammable particles above the fuel. Most people use **tending activities** (like blowing) to sustain this stage, as it both adds oxygen, as well as mixes additional small (flammable) particles with air.

Selection of concentration variables: ventilation

Besides the variables that *influence* emission of BC and NO2, (Brauer & Saksena, 2002, p. 1156) mention ventilation as an indicator of the BC and NO2 concentrations. Ventilation is influenced by many elements such as the place of cooking (inside or outside), the **kitchen openings**, specific openings like a **chimney structure** but also the **material of the roof and walls** of the kitchen. Besides that, ventilation is affected by weather circumstances (the external variables wind direction and wind speed), which makes the **direction of the openings** another *concentration variable*.

<u>Selection of concentration variables: location</u>
A concentration at a particular place is influenced by the **place of the emission source**. The location of the source might be outside or inside, in or not in a separate kitchen. In case of a separate kitchen it might be important whether the kitchen is close to or far away from the living area.

1.4.4. Exposure variables

The *exposure variables* are the variables that will be tested on three aspects:

1. whether there is *variation* in the *variable setting* within Arba Minch.
2. whether the variable is *changeable* given the *reasons* for particular *variable settings*
3. whether the variable is significantly related to exposure to BC and/or NO2 concentrations

If a variable fulfills all three criteria, it is a *local possibility* to reduce exposure to BC and NO2 concentrations. In this section I will make a classification of the exposure a first selection, based on theory, common sense and literature.

The *exposure variables* are categorized in three groups: cooking habits, kitchen specifics and other polluting activities. Unlike the concentration categorizations, this categorization does not support a methodological aim; it merely helps to structure all information.

<u>Selection of the exposure variable: cooking habits</u>
"In order to understand an individual's exposure to combustion products it is essential to gather information about their activity patterns" (Freeman & De Tejada, 2002, p. 980). As most exposure is experienced when close to cooking fires, epidemiological studies often use **cooking time** as prime indicator for exposure (Brauer & Saksena, 2002). This is hence for this study also the most important information. According to Freeman and De Tejada there are five different methods used for the collection of data to construct these 'time/activity-budgets': groups discussion, surveys, questionnaires, diaries, and observations.
The cooking time per person is dependent on the **number of people** involved in cooking. Further it also matters how much **attention time** is needed to prepare the dish. This is not only dependent on the dish type, but also on the stove type.

<u>Selection of the exposure variable: kitchen specifics</u>
The kitchen specifics **area** and **height** are also *exposure variables* that have to be taken into account, as they determine where the pollutants are and where the person can be. For example, within a kitchen with large area there are possibly more places to be with low concentrations. Also, based on the external variable fire heat it is known that pollutants will accumulate under the roof. Hence, if the roof is lower, pollutants accumulate closer to the person.

<u>Selection of the exposure variable: other polluting activities</u>
There can be additional usages of fire such that people are exposed, besides the daily cooking habits. Burning garbage is already mentioned under the external variable background concentration. Households may use burning for other purposes. Households can use a charcoal pot for having a **coffee ceremony**, make **smoke against mosquitos** and

make **fire for heating**. All these activities add to the exposure to BC and NO2 concentrations.

1.4.5. From concentrations and exposure to accumulated exposure

If I found a variable (1) to be a *local capacity*, (2) to be related with BC and NO2 concentrations or exposure to BC and NO2 concentrations and (3) I found that variable to be changeable, it provides a *local possibility* to reduce accumulated exposure to BC and NO2 concentrations. The sum of all concentrations (μg/m^3) times the time spend in the areas with these concentrations will be used to illustrate examples of common accumulated exposures to BC and NO2 concentrations of different people in Arba Minch.

1.5. Structure

The aim of the study is to answer the research questions. In order to give insight in data collection and analyses methods, the methodology will be discussed in chapter two. Chapter three and four will describe the findings on research question one and two respectively. The last section of chapter four will give an overview of the *changeability* and *influence* of each variable, followed by a discussion in chapter five. Chapter six will give the concluding answer on the main question, followed by some recommendations for further research and policy makers in chapter 7.

2. Methodology

For this research, I used three types of methods: measurements, observations and interviews. In the introduction, I have structured what needs to be studied. Table 2.1 summarizes the topics to study and the methodology (collection, processing and analysis) to use. Section 2.1 discusses the instruments used, section 2.2 discusses the measurement setups, section 2.3 describes how the data is processed and finally it is described how the data is analyzed in section 2.4.

Table 2.1: Overview of research methodology

From the research questions		**Data to collect**	**Instru-ment 2.1**	**Set-up 2.2**	**Processing data 2.3**	**Analysis method 2.4**	**Outcome/description**
1a	Concentration	BC	1	A	Correct negative values		Concentrations throughout households
		NO_2	2	B	Correct sampling time with cooking time		
1b	Variations in concentration variables	Which variables, and which settings	6,7,8	A			List of concentration variables and their variations
1c	Reasons for variations	What are explanations for variable settings	6,9	A,D		Theory of Planned Behaviour	Changeability of concentration variables
1d	Relation between concentration variables and concentration	BC&wind at openings	1,4	A	Emission calculation	Regression analysis Comparison analysis	Influence of concentration variables on concentration
		Increase in BC with no ventilation	1	C	Emission calculation		
		BC and CO_2 at end of fire	1,3	A	Ventilation calculation		
		Wind at openings	4	A	Ventilation calculation		
		CO_2, T_{fire} and height of flames	1,5,8	A	Translation of T_{fire} into relative T_{fire}		
		Background BC	10	E			
		Background wind (direction)	10	E	Average wind (direction) calculation		
2	Exposure	When are people under which concentrations	6,7,8	A			The exposure to concentrations
2a	Variations in exposure variables	Which variables, and which settings	6,7,8	A			List of exposure variables and their variability
2b	Reasons for variations	What are explanations for variable settings	6,9	A,D		Theory of Planned Behaviour	Changeability of exposure variables
2c	Relation between exposure variables and					Combine with concentration to explain differences in	Influence of exposure variables on exposure in terms of accumulated exposure

	exposure					exposure	
Main	Accumulated exposure				Combine concentration influences with exposure		Influence of concentration and exposure variables on accumulated exposure
Instruments: BC sensor (1), NO_2 passive sampling (2), CO_2 sensor (3), Wind sensor (4), Fire temperature (5), Semi structured interview (6), Diary (7), Observation (8), Group discussion (9), Data from Thomas Minda (Minda, 2014) (10) Set-up: Household visit (A), NO_2 sample days (B), Experiment under controlled circumstances (C), Group discussion (D), See Minda (2014) (E)							

The research was an iterative process: for example information from interview showed me extra variables to include in the measurements, as well as what to include in the next interviews. Also, intermediate analyses showed on which variables I collected enough data and which variables needed more attention. Hence, both what to ask as well as what to measure changed throughout the process.

Box 2.1: Introducing research assistant Tekalign Torora
Throughout the whole research, I have been assisted by Tekalign Torora (see Figure 2.1). He was a helpful translator during the interviews. He was also involved as co-worker in making sense of findings, finding the necessary new households, distinguishing relevant new questions, etcetera: his assistance was of great importance for the iterative process. Additionally, he assisted in all measurements (writing, operating instruments). Tekalign Torora is a habitant of Limat, the region of Arba Minch with the highest percentage of households using biomass fuel. Also, he is fifth year student of BSc Architecture, and as such had expertise with respect to household set-up and building materials.

Figure 2.1: Tekalign assisted me a.o. in operating instruments.

2.1. Measurement instruments

2.1.1. Instrument 1: Black carbon sensor

For the measurement of Black Carbon concentrations, I used two Aethalometers (microAeth Model AE51) with PM 2.5 size selective inlet. The operating principle of this instrument is the optical attenuation of a light beam transmitted through a filter due to a change in number of black carbon particles on the filter (Park, Hansen, & Cho, 2010). Table 2.2 shows its technical specifications.

Table 2.2: Technical specifications of microAeth Model AE51

Optical source	880 nm wavelength (IR) LED
Measmnt. range	•avg. 5 µg BC/m^3 for 24 hours @ 100 mL/min •avg. 100 µg BC/m^3 for 3 hours @ 50 mL/min •avg. 1 mg BC/m^3 for 15 min @ 50 mL/min
Measmnt. resolution	0.001 µg BC/ m^3
Measmnt. precision	±0.1 µg BC/m^3 At 1 min avg., 150 mL/min flow rate
Measmnt. time base	1 second, 1 minute or 5 minute
Flow rate	50, 100 or 150 mL/min

2.1.2. Instrument 2: NO_2 passive sampling

The Nitrogen Dioxide concentrations were measured with the use of free hanging filter badges as passive samplers. “The filters are impregnated with triethanolamine to bind NO_2.

With standard colorimetrical analysis, the amount of NO_2 on the filters is determined." (Heeres, Setiawan, Krol, & Adema, 2009, abstract). Standard analysis protocol was followed. The following three instruments were used in the laboratory analysis:

- Micro Refrigerated Centrifuge, model no. RSE-025;
- Double Beam Spectrophotometer, series no. AQ1111006;
- Citizen weighing scale, model no. CY220.

2.1.3. Instrument 3: CO2 sensor

For the measurement of Carbon Dioxide concentrations, I used the CO2mini CO2 Monitor (model RAD-0301). **Table 2.3** shows the technical specifications.

Table 2.3: Technical specification of CO2mini CO2 Monitor model RAD-0301.

Measmnt. range	0-3000 PPM display;
Measmnt. resolution	1 PPM at 0-1000 PPM; 10 PPM at 1001-3000 ppm;
Measmnt. precision	0-2000 PPM: ± 7%; >2000 PPM: ± 10%
Measmnt. time base	3 second
Response time	2 min for 63% step change

2.1.4. Instrument 4: Wind sensor

A simple cup anemometer was used to measure the wind speed in window, door and other openings. The sensor only showed values from 0.4 m/s. At the first couple of households I used the values of the display, but from HH04 on I guessed a value below 0.4 m/s by eye – only taking zero when there was indeed no turning of the cups at all.

2.1.5. Instrument 5: IR thermometer

From HH07 on I included a relative indication of the fire temperature in my measurements. For this, I placed a small sheet of iron close to the fire place, and regularly measured the temperature of this plate with help of the portable Infrared Thermometer Raytek Minitemp MT2. See **Table 2.4** for the technical specifications.

Table 2.4: Technical specification of portable Infrared Thermometer Raytek Minitemp MT2

Measmnt. Range	-18-375 °C
Measmnt. Resolution	0.2 °C
Measmnt. Precision	± 2 °C or 2 %
Response time	500 mSec

2.1.6. Instrument 6: Semi Structured Interview

In the interviews I questioned the following topics:

- (Specifics of) place of fire;
- Fuel material;
- Cooking habits;
- Things influencing smoke;
- Other moments of exposure;
- Attitude towards smoke;
- Possible solutions;

Throughout the research period I developed new questions or improved the way of asking. The questions were quite structured, but there was an option to ask for deeper reasons and to take a side path in the conversation (semi-structured). Appendix B shows the interview guide and its development throughout the research project.

2.1.7. Instrument 7: Diary

From HH03 on some of the items on the interview were moved to a kind of diary (Freeman & De Tejada, 2002). Participating households were given a sheet, on which they could fill in for each day for a week the cooking times, time of cooking close to the fire, who was cooking, the fuel used and a relative indication of the amount of fuel. The sheets were in Amharic, with also an explanation in Amharic above it. This approach obtains better answers than a single time of asking about cooking times. Appendix C shows the week diary.

2.1.8. Instrument 8: Observation

Per household me and my assistant did the following observations:
- Presence of participants;
- Household specifics (building size, fuel material used, openings etcetera.);
- Height of flames;

I tried to standardize the observations, to make sure that the particular aspect was observed, and to synchronize the observation of me and my research assistant. For example, I developed a fire coding system regarding the fire stage: whether or not flames where present, and whether or not smoke was present. Appendix D shows the observation sheets.

2.1.9. Instrument 9: Group discussion

In order to get a deeper insight in reasons for particular variable settings, I organized a group discussion with the following topic list:
-Dishes, cooking and attention time
-Wood types
-Dry wood during rainy season
-Kitchen preferences
-Outside cooking
-Kitchen changes
-Reasons for fuel materials

Appendix E shows the transcript of the group discussion.

2.2. Measurement set-up

All measurements in this study are conducted in Arba Minch. Arba Minch can be divided into three parts. North of the river is the region Limat, where the poorest households live. In that region, mostly wood and charcoal is used as fuel. Sikela is the region with the center of the town. The richer households are located closer to the center, which also translates into use of other fuels, such as kerosene. To the south-west of this is the region Shecha, which is somewhat more uphill. The households within this region are not necessarily different from the households in Sikela.

2.2.1. Set-up A: Household visit

Sample selection

In total, we visited 42 households (see Figure 2.2). 26 of these households were situated in the region Limat (upper detail), and the other 16 in Sikela (lower detail). Households were selected based on the goal to obtain as much as possible knowledge on the different variables (deliberate sampling, (Blankertz, 1998)). For example, within wood cooking more diversity is possible than within biogas cooking, hence much more wood cooking houses were selected. This was also an iterative process: household characteristics that were underrepresented in the first half of the data collection were extra selected in the second half of the data collection period. For example, initially quite some households were selected with kitchens with clearly distinguishable openings, so later on we picked some households with kitchens of a more open structure. Appendix A shows a table with specifications of the different households.

Figure 2.2: Map of Arba Minch, indicating visited households. Upper detail: 26 households in Limat region. Lower detail: 16 households in Sikela region.

A household was visited during a cooking period: 12 households during dinner preparations, 26 households during lunch preparations and 4 households during other moments (such as injera preparation early in the morning or during the afternoon). The following sections deal with the different measurements and interviews conducted at the households. Figure 2.3 shows the general measurements. A detailed overview of the measurements taken at the distinct households can be found under Appendix A.

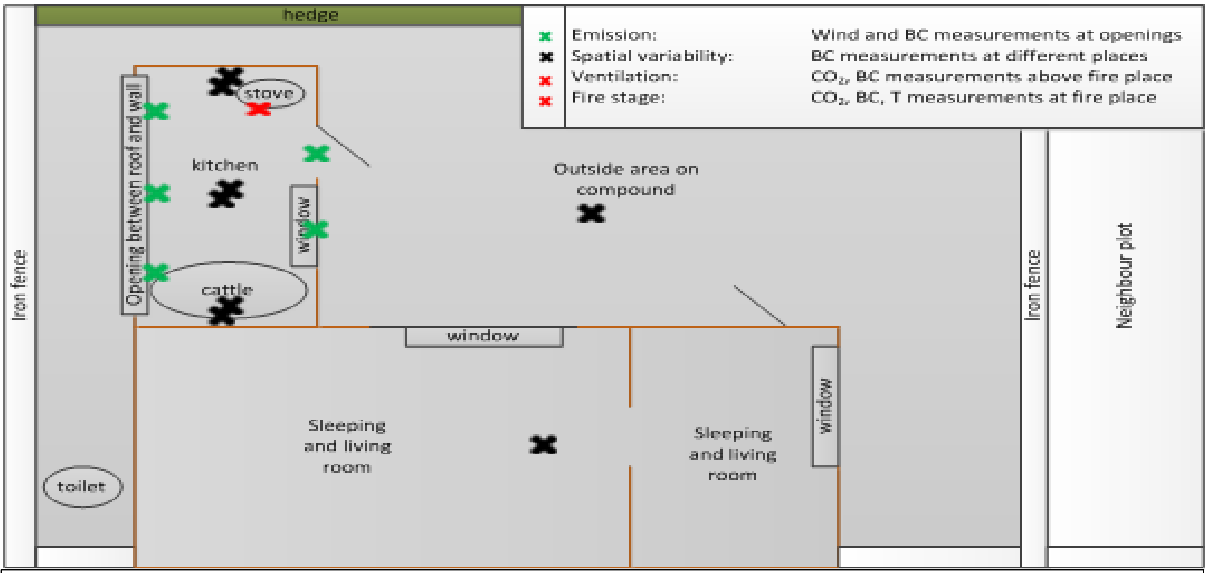


Figure 2.3: Within a household, several measurements were taken

Execution: Black carbon and wind measurements

Table 2.5 describes the places where I measured BC and the purpose of the measurements. From HH28 on we could use two black carbon sensors at the same time: from that moment on several simultaneous measurements were taken (for example close to the roof and at lower height, or in the left and in the right corner, etcetera).

I also did BC measurements during non-cooking events, such as the coffee ceremony.

Table 2.5: Different measurements and their purposes

Place	**Purpose**
At each opening, three times one minute BC measurements together with 5 wind measurements	Calculate emission and ventilation with the box-model (see section 2.3.3)
Above the fire place	Indicate fire stages, and decay in concentration at the end of the fire
Where cooking people are	Indicate exposure of cooking person
Outside	Indicate exposure person being outside
In other room/building on the compound	Indicate exposure person in other room/building
Different heights in kitchen (roof, middle height, sometimes close to the ground)	Indicate spatial variability
Different sides in kitchen (in the middle, at different walls, at different corners)	Indicate spatial variability

Execution: CO2 measurements

The CO_2 instrument was fixed during the whole household visit at one place. The first six household visits the CO_2 instrument was connected close to a wall. From HH06 on I decided to fix it somewhere between the fire and an opening, in order to get a better picture of the ventilation rate.

Execution: temperature measurements

From HH07 on I included a relative indication of the fire temperature in my measurements. Since the fire was too hot to measure, I measured a small sheet of iron that was placed close to the fire place. In the time that I was not busy with arranging other measurements, I measured the temperature of the iron plate each five á ten minutes with an infrared thermometer.

Execution: Semi structured interviews

Mostly after cooking, the interview was conducted with the person cooking. At most households we could find enough time – at some households the participant was in a hurry,

or there was some disturbance through the presence of others. While questions were made on beforehand, at the moment itself the conversation went somewhat flexible – skipping some questions and giving more attention for others, or adding some questions that appeared useful for the situation.
Tekalign as much as possible literally translated what the participant answered. Of course, still much more was said than could be put into English. Throughout the process I started to distinguish Amharic and Gamunia words, which helped me better to ask additional things.

Execution: Diary
The diary that the households had to keep was translated and digitalized by Tekalign. Because we were absent, not all households completed the diary properly. The households in Limat were regularly visited by Tekalign, so those sheets are best completed. In total I collected 31 completed week diaries.

Execution: Observations
The household specifics, like a map of the building and the fuel material used, were observed once for each household. Other observations were done regularly. If I was not too busy with other measurements (eg for the box-model) I regularly took the following fire state observation: fire code[a], whether the participant was in the kitchen or not, and any special remarks (such as pan on fire, participant blowing or adding fuel, etcetera).

2.2.2. Set-up B: NO_2 sampling days

The measurement method of NO_2 requires analysis in the laboratory. It was therefore not possible to measure NO_2 during each of the household visits. Apart from some test measurements, I confined the NO_2 measurements to two days. For these days, a tight schedule was made, given the number of badges available and the information I wanted to retrieve. Appendix F shows the full measurement set-up for the NO_2 sampling days.

Sample selection
I wanted to measure NO_2 at households during the same preparation period (lunch). Due to this time restriction I could only focus on one area of Arba Minch. This reduced my options, so I had to use convenience sampling (Marshall, 1996), i.e. that the researcher accepts each option that fulfills the requirements. We went through Limat, to find the needed number of kitchens at which lunch was prepared and at which the required measurements could be taken. A prerequisite was that either we would still visit that kitchen, or that we already had visited it, as one of the household visits, so that information obtained through the household visit could be combined with obtained NO_2 data.

Execution
The NO_2 badges were placed at different places in the kitchens, according to the following interests:
-Spatial variability across the kitchen (different heights and different sides of the kitchen);
-Spatial variability throughout the household (kitchen versus living room);
-Differences for different fuels (wood, biogas, electricity)

[a] The fire code consisted of two parts: 1) flames rating (no, low, medium or high), and 2) smoke rating (no, low, medium or high). For dinner measurements it was difficult to see the amount of smoke, so possibly the smoke is underestimated. Also, especially in case of a big radius, I observed flames on only one side of the fire place.

Up to the moment of sampling, and after retrieval, the badges were kept in individual airtight bags. They were analyzed in the laboratory of Arba Minch University.

2.2.3. Set-up C: Experiment under controlled circumstances

To obtain more insight in different emission rates for different fuel materials, I burned different materials (coffee, plastic, rubber, wood, charcoal, chad, animal waste, grass) under controlled circumstances.

Sample selection

A room was picked which could be fully closed, such that an increase in concentration is linearly related to the emission rate. The fuel materials were selected deliberately by Tekalign, based on the using frequency.

Execution

In the room, I placed a ventilator and installed the CO_2-sensor and both BC-sensors. Outside, the material was set on fire, and then carried inside and left there for 3-4 minutes. After that, it was removed from the room, and window and door were left open for 15 minutes before the next material was brought in. The ventilator made sure that air was mixed within the room. Emission rates can be obtained from the linear increase in concentration within that room during the burning – assuming no loss or transport to outside. To check this latter assumption, after one experiment I removed the source but kept window and door closed, to see whether there was any decline in the concentration. This decline was negligible.

2.2.4. Set-up D: Group discussion

At the end of my stay I used a group discussion to fill some gaps of knowledge I still had, and to see what answers would be given if there was discussion on the subject.

Sample selection

Six women from a church in Limat were invited by Tekalign. No further specifications were made in the selection, based on the assumption that the combined knowledge of six women from Arba Minch on the different topics would be sufficient, no matter their background.

Execution

The group discussion was held at the house of Tekalign's family. Each of the topics was posed to the group of women. Tekalign led the discussion, and translated at the end of each discussion part the different arguments made. The full discussion was recorded; later on based on the recordings Tekalign could tell me the information that I missed during the group discussion itself. Appendix E is a transcript of this group discussion.

2.3. Processing data

2.3.1. Black carbon concentrations: negative values

For the black carbon sensor, sometimes (high) positive values were followed by negative values. Negative concentrations physically make no sense; rather they reflect the operation of the instrument, and are resolved for when averages are taken. In some cases, however, I encountered continuous negative concentrations. To solve this, I have set all values during a measurement period (this is: a period of time at which I was measuring at the same place) with a negative average to 0 $\mu g/m^3$.

2.3.2. Nitrogen Dioxide concentrations: correction for cooking time

The passive sampling method gives an amount of NO_2 accumulated during the whole sampling time. I assume that the NO_2 found on the badges is due to a background concentration and emission during reported cooking times, i.e. that the concentration during *not cooking* equals the background concentration. From the average concentration over the sampling time C_S the background concentration C_B is subtracted and the remaining concentration C_S-C_B is divided by sampling time and multiplied by the time of cooking during the sampling time, giving the concentration during cooking C_C.

2.3.3. Emission rates

I have used two methods to approach emission rates: the box model, and linear increase.

<u>Emission rates based on the box model</u>

The kitchen can be considered as a box with in- and outfluxes of pollutants. Let us consider the change in amount of black carbon within a box with volume V. The change of mass within that box is given by emission E, loss by deposition L, transport in F_{in} and transport out F_{out}:

$$\frac{d\rho}{dt} = \frac{E - L + F_{in} - F_{out}}{V} \quad [kg \cdot m^{-3} \cdot s^{-1}]$$

The fluxes are given by the area A_x of the opening through which they come in (door, window, chimney, ...), the respective wind speeds u_x, and the concentrations c of the air the flux originates from. For example, a house with only a door with area A_1 through which air enters and a room with area A_2 through which air leaves, gives us:

$$F_{in} = A_1 \cdot u_1 \cdot c_{outside} \quad [kg \cdot s^{-1}]$$

$$F_{out} = A_2 \cdot u_2 \cdot c_{inside} \quad [kg \cdot s^{-1}]$$

In the case of indoor biomass fuel use it can be expected $c_{outside} << c_{inside}$, hence $F_{in} \cong 0 kg \cdot s^{-1}$. Likewise, I assume that loss by deposition L is negligible compared to F_{out}. F_{out} can be measured, and under circumstances of a stable concentration ($\frac{d\rho}{dt} = 0 \; kg \cdot m^{-3} \cdot s^{-1}$) $F_{out} \equiv E$. Hence, based on measurement of the concentration and wind at the different openings, combined with the area of the openings, I can calculate an approximation of the emission rate.

At the openings where concentrations were low, I considered the flux as F_{in} – all the other fluxes I took as F_{out}. However, each emission rate calculation needed individual attention, due to measurement errors and changes during the box model measurement round. For example, when the sum of all outgoing air Σf_{out} did not fit with all ingoing air Σf_{out}, I had to weigh which of the measurements were most trustworthy. Such arguments were based on the kitchen set-up (e.g. an opening with a big area is more likely to cause wind speed measurement errors than with a small area, or at the right side of the kitchen we clearly caught strong outgoing wind, so the high concentration at the left side should not be considered as F_{out}). Furthermore, there are certain indicators of whether a calculated emission rate is trustworthy or not. I used the following indicators as three validation methods:

- The ventilation budget closes, i.e. the sum of all incoming measured air is comparable to the sum of all outgoing measured air: $\Sigma f_{in} \approx \Sigma f_{out}$.
- The sum of all outgoing air during one emission rate calculation is comparable to another in the same household: $\Sigma f_{out,1} \approx \Sigma f_{out,2}$;
- The sum of all outgoing air is comparable with calculated ventilation rates based on CO_2 and/or BC (see section 2.3.4): $\Sigma f_{out} \approx f_{CO2}$ / f_{BC}.

I rated 'comparability' as follows: with one star if the highest value is within 50% range of the lowest value, and with two stars if the highest value is within 10% range of the lowest value. In analyses, only emission rates with at least one star on any of the validations are incorporated.

Appendix G1 shows all calculated emission rates, combined with comments on individual corrections, and validation ratings.

<u>Emission rates based on a linear increase</u>
From the concentrations measured in the experiment under controlled circumstances, I estimate the emission rates from the linear increase in concentration. Under the controlled circumstances of a source in a room with no ventilation but still mixing, and considering loss L as negligible, emission E equals the increase of a concentration times the volume of the room ($\frac{d\rho}{dt} * V = E$).

2.3.4. Ventilation rates

I have used two methods to approach ventilation rates: the box model, and the decrease of concentrations.

<u>Ventilation rates based on the box model</u>
The ventilation rate based on wind measurements f_W (m^3/s) is part of the calculation of emission as done in the box model method: $E=F_{out}=f_{out}*c$. The eventual Σf_{out} used in the emission rate calculation I took as f_W.

<u>Ventilation rates based on a decrease in concentrations</u>
Rather than measuring all different $F_{x,in}$ and $F_{x,out}$, I can also measure the air exchange rate to indicate the total ventilation, with use of an initial concentration C_0 of the pollutant and the final concentration C(t) after some time t (assuming no loss other than due to ventilation):

$$C(t) = C(0) \cdot \exp(-\frac{f}{V} \cdot t)$$ (Xu et al., 2010)

With ventilation rate f (m^3/s) and volume of the room V (m^3). As the method is based on the assumption that eventually the concentration will go to zero, C(0) and C(t) should be corrected for a background concentration (if present). The difficulty with this approach is that theoretically between C(0) and C(t) there should be an immediate instead of a gradual decline, for example a stop in emission or from a constant to a lower constant emission.

With this method, ventilation rates based on the decay in concentrations of CO_2 and BC f_{CO2} and f_{BC} can be obtained. For these calculations, individual attention was required. I used graphs of 30-second averaged concentrations to choose the period over which the calculation was taken (i.e. which concentrations to take as c(0) and c(t)), and to determine a background concentration if present. For f_{CO2}, the response time of the sensor has to be taken into account: 2 minutes for 63% step change (see Table 2.3). A particular response time implies a certain maximum of ventilation rates that can be captured. For example, there can be very high ventilation, resulting in a high decay when emission stops – too high to capture with the given response time. Therefore, I have removed the ventilation rates f_{CO2} that are within 50% range or greater than $f_{CO2,max}$ ($f_{CO2}>0.5*f_{CO2,max}$) from the analysis.

In the same way as the emission rates I have validated all ventilation rates (see section 2.3.3). In analyses, only emission rates with at least one star on any of the validations are incorporated.

Appendix G3 shows all measured f_W and calculated f_{CO2} and f_{BC}, with comments on individual corrections, either or not removal based on $f_{CO2,max}$ and the validation ratings.

2.3.5. Fire temperature

An indication of fire temperature was given by measuring the temperature of an iron plate close to the fire. These fire temperatures cannot be compared among different households, as besides the fire, also the place of the iron plate influences the eventual temperature. Hence, I have transformed the temperature values into qualitative categories: “Lowest”, “Low”, “Medium”, “High” and “Highest”. I divided the measured values at a household linearly over these categories: I split the range (max(T)-min(T)) into five parts with equal ranges, and divided the measured temperature values over the ranges accordingly.

2.3.6. Wind direction

For the calculation of average wind direction, I use the following formulas (WebMET, 2002):

$$V_e = -\frac{1}{N}\sum u_i \sin(\theta_i)\,; \qquad V_n = -\frac{1}{N}\sum u_i \cos(\theta_i)$$

$$\overline{\theta} = \arctan(V_e / V_n) + FLOW$$

With $FLOW = +180$ for $\arctan(V_e / V_n) < 180$

$FLOW = -180$ for $\arctan(V_e / V_n) > 180$

θ_i is the measured wind direction and u_i the measured wind speed. For each box model measurement period P_i I took a corresponding $\overline{\theta}_i$.

Different average wind directions $\overline{\theta}_i$ can be compared with wind speeds measured during a particular P_i at openings with a different orientation $O_{degrees}$. For such analyses, I distinguished whether a particular opening was facing, opposite to or level with the average wind direction (respectively $O_{degrees}=\overline{\theta}_i\pm45°$; $O_{degrees}=(\overline{\theta}_i+180°)\pm45°$; $O_{degrees}=(\overline{\theta}_i-90°)\pm45°$ or $(\overline{\theta}_i+90°)\pm45°$). See Figure 2.4 for a visual explanation.

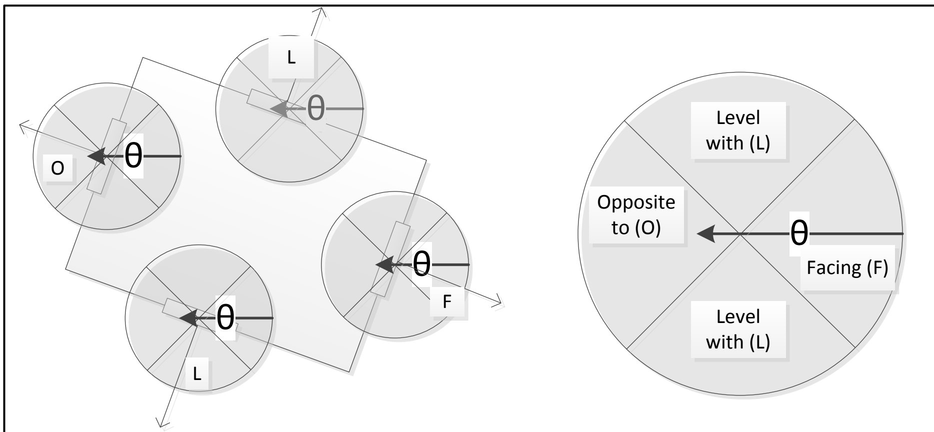


Figure 2.4: A hypothetical kitchen with an opening at each side, with respect to the particular average wind direction θ_i. As average wind direction is taken an average of the wind directions measured during the same time measurements at the openings were taken.

2.4. Analysis methods

2.4.1. Regression analysis

To check whether two variables are significantly related, the statistical tool *regression* can be used. The main idea is that one or multiple independent variables (X or multiple Xes: X_i) are (linearly) related with a dependent variable (Y). Linear regression gives the best estimates of the α and βs for the formula:

$$Y = \alpha + X_i * \beta_i$$

Where X_i is a vector of all values of the independent variables and β_i a vector with all parameter estimates. The method used to let this formula give the best estimates is the minimization of the sums of squares. The assumptions of running such models and the tests to perform its validity and performance can be found in Ott and Longnecker (2008).

In this thesis I will report (1) the estimate for β, (2) the corresponding p-values that indicate the performance of the inclusion of one variable (X) in the model. If a p-value is 0.05, it means that the data shows with 95% security that, within the model, the variable X is relevant in predicting the dependent variable Y. This significance will also be reported with '>90% security, *>95% security, **>99% or ***>99.9% security. After reporting these values I will describe the practical interpretation of the outcome.

In case X is categorical (for example with three categories), there is no linear relation between Y and X, but the model has to calculate the group differences and their significance. For that, X has to be transformed into dummy variables; variables that can take only two values (0 or 1). The number of dummy variables needed is the number of categories minus 1 (reference group). The model then, performs similar as an *independent sample t-test* (in case of two categories) or as an *(multiple-way) ANOVA*.

In case X is continuous, the relation between Y and X is expected to be linear. A one unit increase of X means that Y increases by β. It might be that the model includes both categorical and continuous variables. The estimation of such a model can also be called *ANCOVA*.

2.4.2. Comparison analysis

In comparison analysis I review the relation between one categorical (2 groups) and one continuous variable (similar to t-test) but I will not test its significance due to absence of sufficient data to do so. Usually the reason is that the number of observations is too low to run a model. For example:

X: cooking in living room vs. cooking in separate kitchen

Y: BC concentrations in living room

Since I only observed one household where cooking appeared inside the main building, running a formal t-test is not possible, but the difference in BC concentrations in the main building is so large that I can conclude there is a relation between X and Y. In case of comparison I will report the average value of the dependent variable per group, and the corresponding standard errors.

2.4.3. From reasons to changeability

In analyzing the reasons that people give for specific variable settings within a household I went through five steps.

1. Digitalizing the interviews. This allowed me to overthink the given answers and to form possible new questions for coming households and new variables to study.
2. Putting all answers together in one document to get familiarized with the data.
3. Categorizing answers into concentrations- and exposure variables.

4. Coding the reasons for particular variable settings. Each of the reasons are translated into simple codes:
   - reasons for a particular variable setting. (+)
   - reasons against a particular variable setting. (-)
   - reasons that simply play a role (X), not necessarily being negative or positive.
   - and eventual additions: reasons that only count in some situations (addition S), or reasons that are only true for some persons (addition P) or reasons – the ones related to costs and efforts – that can possibly be overcome with support, for example help from the government or an NGO (addition H).

Each of the variables will be rated with these codes in the result sections.

5. Classifying the codes into changeability, using the behavioural categories as mentioned in the conceptual framework (section 1.4.1). The changeability of a particular variable can be described as follows:
   - **Changeable** if: attitude + or nothing, norm + or nothing, control no -, habitual no X, external no – or X; everything with extension S does not count;
   - **Changeable for some**: similar to above, but everything with extension P does not count;
   - **Changeable with support**: similar to the first, but everything with extension H does not count;
   - **Not changeable**: none of the above.

Each of the variables will get one of the four above values in the result section.

3. Household concentrations

What are local possibilities to reduce BC and NO2 concentrations in Arba Minch?

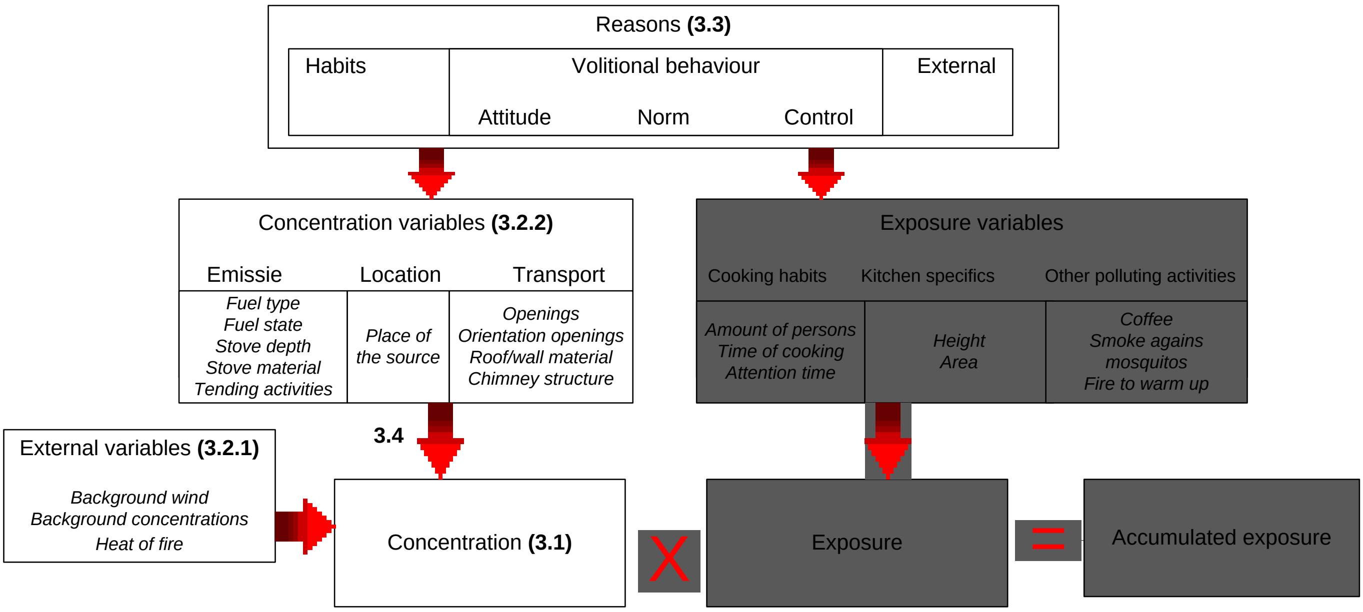


Figure 3.1: Overview of reasoning, the white areas are discussed in this chapter

This chapter will present the results of the concentration section. The white areas of the flow-chard are covered by this chapter. Section 3.1 discusses the household concentrations and 'indicators' for household concentration: emission, ventilation, C02 and fire temperature. Section 3.2 describes concentration variables: the ones that are expected to be related with concentration, and their variation in Arba Minch. Both the variables that are outside (3.2.1) and inside (3.2.2) the reach of the households, are discussed.

Section 3.3 reports the changeability of the variables, by reviewing the reasons for the variations, and section 3.4 discusses the relation between the concentration variables and the BC and NO2 concentrations. Based on the findings in section 3.3 and 3.4, the question 'What are local possibilities to reduce BC and NO2 concentrations in Arba Minch?' will be answered in section 3.5.

3.1. Concentrations and indicators

What are the BC and NO_2 household concentrations and their indicators?

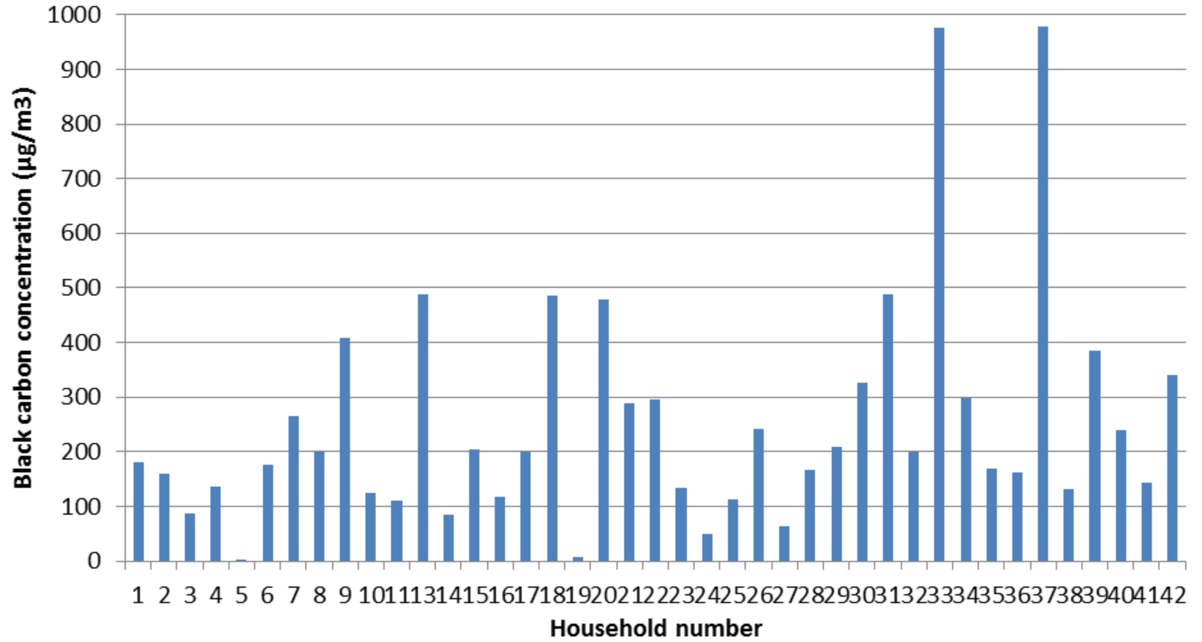
3.1.1. BC concentrations

Measured black carbon concentrations in kitchens during cooking practices were on average 248±2.2 μg/m^3. At twelve households I measured average concentrations of more than 500 μg/m^3 at the place where people are during cooking, close to the fire.

Box 3.1: European guidelines on NO2 and PM10 as reference

European guidelines limit NO_2-concentrations to 32 μg/m^3 as yearly average, with hourly averages of 140 μg/m^3. There is no individual guideline for BC; with respect to PM_{10} the yearly average is limited to 28 μg/m^3, with 24-hour averages of 35 μg/m^3 (EU, 2008). Concentrations encountered in Arba Minch households exceed these limits often by far.

Concentrations varied greatly between different households, with average cooking kitchen values ranging from 3 up to 1000 µg/m^3 (see Graph 3.1).



Graph 3.1: average kitchen BC concentrations during cooking. Concentrations vary significantly from house to house.

Also, within a household concentrations differed (see **Table 3.1**). Highest concentrations are found in the same room as the source; within that room there is horizontal and vertical variability, amongst other things depending on the place of the fire and the place of openings. For example, At one household (HH40) I measured simultaneously for three minutes close to the fire – where people stood when busy with the dish – and two meters away – where the sauce was prepared. Average concentrations were respectively 70±7 and 20±0.4 µg/m^3. Besides higher *concentrations*, *variability* is also higher closer to the fire; further away the plumes are already better mixed with their environment.

Table 3.1: Average concentrations at different places within the household. Concentration varied within the household, vertically and horizontally

Place	BC±se (µg/m^3)	Place (kitchen)	BC±se (µg/m^3)	Place (near kitchen roof)	BC±se (µg/m^3)
Kitchen	248±2.2	Near roof	156±1	Near opening	289±5
Outside	61±10	Not near roof	323±5	Not near opening	376±11
Living room	12±0.7[a]				

3.1.2. NO_2 concentrations

Nitrogen dioxide concentrations in kitchens during cooking were on average 763±92 µg/m^3. All NO_2 samples near the roof gave an average of 1006±231 µg/m^3, while at middle height (1.5-2 meters) the concentrations were 680±120 µg/m^3.

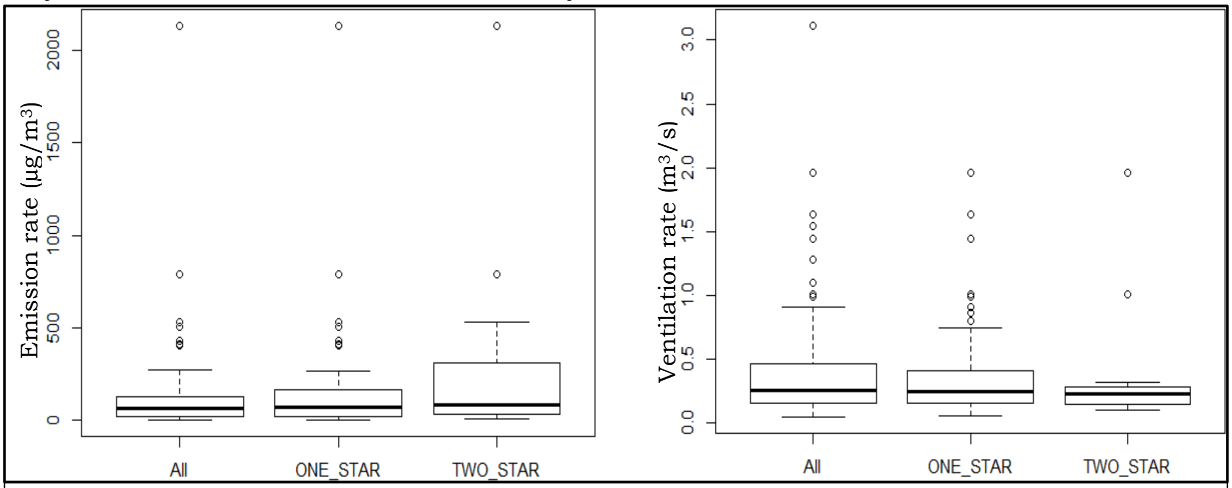
3.1.3. Indicators of BC concentration

The indicators of BC concentrations will be used as dependent variable in some of the analyses.

[a] Excluded from this is the living room measurement at HH07, average 389±27 µg/m^3. Within this household cooking and living was within the same room; at some point concentrations in the living room even gave a two minute average of 1368±20 µg/m^3.

Emission and ventilation rates

The measured emission rates for BC ranged from 1 up to 2133 μg/s, with an average of 147 μg/s. Ventilation rates ranged from 0.05 up to 3 m^3/s, with an average of 0.4 m^3/s. After validation (see section 2.3.3), the range for the emission rates becomes 9-2133 μg/m3 and for ventilation rates 0.06-1.96 m^3/s (see Graph 3.2). Average emission and ventilation rate with at least one star validation is respectively 170 μg/s and 0.35 m^3/s. In the analyses, only the values with at least one star on any of the validation methods will be used.



Graph 3.2: emission (left panel) and ventilation (right panel) rates, ordered according to validation: all values, at least one star in any of the validation methods, or two stars in any of the validation methods (see sections 2.3.3 and 2.3.4). Also after validation a wide range remains.

Fire temperature and CO2

Theory suggests a positive relation between fire temperature and both CO_2 and BC emission (see section 1.4.3). Table 3.2 shows the relation between fire temperature, CO2-concentrations and BC-concentrations. My measurements confirm the expectations especially for the relation between CO_2 and the fire temperature. For BC, this is in the same, but the individual categories are less well distinguished; the relation with fire temperature is less clear-cut than for CO_2. Concluding, both fire temperatures as well as CO_2-concentrations can be used as dependent variable in the analyses, to crosscheck for relations between BC emission and a *concentration variable*.

Figure 3.2: To give an indication of fire temperature, the temperature of an iron plate was measured.

Table 3.2: CO_2 and BC concentrations (during cooking in the kitchen) are related to the relative fire temperature categories. P-values mentioned are from a regression with "Highest" as reference group.

Relative fire temperature	**CO_2-concentration (PPM)**	**BC-concentration (μg/m^3)**
"Highest"	959±4 (*Intercept; p<<0.001*)	317±6 (*Intercept; p<<0.001*)
"High"	949±4 (p=0.05)	332±9 (p=0.1)
"Medium"	850±3 (p<<0.001)	256±3 (p<<0.001)
"Low"	844±3 (p<<0.001)	223±4 (p<<0.001)
"Lowest"	653±2 (p<<0.001)	228±6 (p<<0.001)

3.2. Variations of the concentration variables

What are the variations of the concentration variables?

Of all variables that influence concentration there are two broad categories: *variables* that are not influenced by individual household choices, and *variables* that are. Eventually, this studies interest is in the latter: those present possible reductions. Still, insight in the first category helps our understanding of the full picture. Variables of both categories will be shown in this section.

3.2.1. Outside the reach of the households

Table 3.3 shows the variation in external variables background wind and concentration, fire temperature and tending activities. Tending activities are observed as an external variable, as they are by nature linked to 'having a cooking fire', i.e. there is no choice.

Table 3.3: Variation of the variables that are outside the reach of the households

Variable	**Variation in Arba Minch?**
Background wind	10:00-14:00: 1.2±0.01 m/s; 116° (N=13545) 19:00-23:00: 0.6±0.01 m/s; 92° (N=13680)
Background concentration	Black Carbon: On average about 2 μg/m³, with morning and evening peaks of 5-25 μg/m³ NO^2: 5-25 μg/m³ (Minda, 2014)
Fire temperature	Absolute values unknown. Temperatures of the temperature plate ranged from 50 up to and above 300 ˚C
Tending activities	Blowing, adding fuel

3.2.2. Inside the reach of the households

The concentration variables inside the reach of the households can be grouped in three categories (as explained in section 1.4.3). The variation of these variables that I found in Arba Minch is described in Table 3.4.

Table 3.4: Variation of the variables that are inside the reach of the households

	Variable	**Variation in Arba Minch?**
Emission variables	Fuel material	A high variety of fuel materials can be found in Arba Minch <u>Main materials:</u> Wood, charcoal, biogas, kerosene, electricity, dung. <u>Start-up materials:</u> Plastic, paper, rubber, grass
	Fuel state	<u>Variation is found in:</u> Amount: Little or much Dryness: Wet or dry Wood type: Wood from highland or lowland
	Fire place	Traditional/injerra/biogas/electricity/kerosine/charcoalpot stove Fire place materials: stone, a piece of pottery, some shattered pieces of pottery iron, nothing Fire place depth: 0-30 cm
Ventilation variables	Number of openings	1-24 m²
	Height of openings	Attached to the roof or not
	Type of openings	Chimney structure, opening between roof and wall, window, door
	Orientation	At any side of the kitchen
	Roof material	Iron, bamboo, plastic, grass; sealed or partially open.
	Wall material	Wood, plaster, bamboo; sealed, partially open or very open.
Location variables	Chimney injera stove	Injera stove with chimney vs. injera stove without chimney
	Separate kitchen room	Kitchen vs. no kitchen (and cooking in main building)
	Kitchen attached to	y/n

	main building	
	Outside cooking	y/n

3.3. Reasons for the variations

What are reasons for variation in the concentration variables within the households reach? Are they changeable?

3.3.1. Emission rates

The emission rates depend on the fuel material, fuel state and fire place.

Fuel material

We mostly visited households that use ***wood***. In most cases, the reason for using wood was economical: it is very good available, as well as the cheapest option. Wood is basically the only (primary) fuel that can even be obtained for free: the poorest households will collect the fuel themselves and thus save on fuel costs. Some intrinsic benefits of wood cooking are the speed and that it can be left alone safely. Even the households that do have the capacity to cook electrical or with biogas, have not fully switched away from wood cooking. For electricity cooking, wood is still a second option for the cases there is no electricity. For the biogas households, wood cooking is still used for preparation of bigger dishes such as bread or injera. Reasons why people would like to switch away from using wood, is the time it takes to collect it, the effort needed to tend the wood fire, and the smoke release related to wood fire.

Basically each household, except for the very poor ones, owns a ***charcoal*** pot (see Figure 3.3) for charcoal food preparation. Once burning, the coals retain heat for a long period, and no flames nor barely any smoke is produced. Most often it is used for the preparation of coffee, but some households also use it to prepare small dishes. Because of the long heat retention it is handy for dishes that need long heating. For example, a meat dish can be put on the charcoal pot in the evening, and then will be prepared throughout the whole night without attention needed. In comparison to wood, charcoal is more difficult to start-up, and the speed is also lower because of less heat production. Further, charcoal is not suitable for bigger dishes, such as bread or injera. Also, charcoal is considered expensive for some households, and hence often not possible as primary fuel.

Figure 3.3: Charcoal pot at HH02

Lately there has been quite some promotion as well as funding for the use of ***biogas*** systems in different African countries. We encountered two households (HH05, HH19) that had obtained such a system. There are some obvious positive points related to cooking with biogas, besides a decreased amount of smoke emission. The households themselves mentioned the speed, both in start-up as the whole cooking process, and the fact that the fuel is free or does not have to be collected (as faeces of their cattle is used). Also, the fire is adjustable, and only a small place is needed for the cooking stove itself. The two main reasons why people do *not* have a biogas system, is 1) costs and 2) space. Firstly, while biogas systems are heavily funded, still the two households spent about 10.000 ETB on it. For many households this is a too high investment. Secondly, the installation itself needs quite some space (specifically, the storage in which the animal waste goes). And of course, enough cattle is needed for the necessary animal waste – which both takes costs as well as costs space. One interviewee (HH10) said that, in the light of city population growth, she did not dare to take the risk: in the future there might not be enough space anymore for the cattle needed.

Kerosene is especially suitable for single persons, such as students, as it is small, moveable and easy to start. It is however expensive, and you also depend on the distributor.

With the grid expanding, an increasing amount of people switch to the use of ***electricity*** as primary cooking fuel. Of course, with respect to the emission of pollutants, this is a large improvement. Besides this point, electricity is liked because no labor is required to start or tend the 'fire'. The users relate electricity to decreased costs[a]. Also, it is constant in its heat production, and no flames are produced. The latter is related to an increased safety. Some others saw in electric cooking safety dangers – they were afraid for electrical shocks. Yet the primary reason not to use electricity: the investment and effort needed to obtain individual electricity access[b]. Also electricity users still used charcoal or wood once in a while – for example when there was no power, or for the making of injera. One household (HH42) even used wood more often, while having an electric stove; nobody had shown her the problems of wood, wood was faster than electricity, and a wood fire can be left alone without dangers.

Animal waste is especially used for dishes that need a somewhat longer preparation, because it stays warm for a long time. Besides, of course, for cattle owners it is a free fuel. It is generally used complementary to wood: the initial fire with wood, and then some animal waste added for heat retention.

Grass, paper, plastic, and ***rubber*** are used as start-up materials, due to their inflammability. For grass, as a downside was mentioned that quite some smoke is produced. Only at two households (HH06, HH31) we encountered the use of rubber. Of course, it is also highly inflammable, and keeps burning nicely for quite some time, so it serves an easy start-up of the fire. Yet, in the group discussion it was mentioned as a bad example: 'such people' are not aware of the negative side of its high emission of pollutants.

Table 3.5 sums up all arguments made pro and contra the use of the different fuel materials, ordered into the types of reasons that are distinguished under section 1.4.1.

Table 3.5: Reasons for fuel materials

Choice at hand	**Attitude reasons**	**Norm reasons**	**Control reasons**	**Habitual reasons**	**External reasons**	**Changeability rating**
Wood instead of another material	+Speed +Can be left alone -Tending -Smoke -Time collecting		+available +cheapest option	When no electricity (*S*) For bigger dishes (*S*)		YES
Charcoal vs wood	-Low speed		-Difficult start-up -Expensive (*H*)	Coffee preparation Heat retention	-Not for big dishes (S)	NO
Biogas vs wood	+Speed +Space in kitchen +lower		+Free fuel +No collection time		+Funding	SOME,SUPPORT

[a] Interestingly, this was never mentioned by those that did not use electricity. It seems that those not yet using electricity, are not aware of possible cost reductions with respect to other fuel materials.

[b] Many households have shared access to electricity, in which case they are not allowed to cook with electricity, as their enhanced usage would not be fair with respect to other users. To obtain an own line takes money and paperwork

	smoke		- investment (*H*) -cattle needed (*P*) -space on compound (P)			
	+moveable +easy +small		-expensive (*H*) -depending on distributor			NO
Electricity vs wood	±safety +constant +no tending -slower than wood +lower smoke		- investment for own line (*H*) +cheaper		-own line difficult (*H*) -not for big dishes (S)	SUPPORT
Dung complementary or not			+free fuel	Heat retention		NO
Start-up materials or not				flammability		NO
Other start-up material than rubber	+bad emissions from rubber					YES
Other start-up material than grass	+lot of smoke from grass					YES

Fuel state

The total ***amount*** of wood used differs according to the dish requirements: when a high fire is needed, more wood is used. For example, a typical Ethiopian dish is injera, which is somewhat like a big pancake. The preparation of injera needs a constant high fire. Hence, much more wood is used during injera preparation than during other dish preparations.

Several respondents mentioned to check which fuel they select. Firstly, they pay attention whether it is dried enough. As ***wet fuel*** not only produces more smoke, but also is more difficult to fire, people try to select dry fuel, or otherwise let it dry themselves. Most of the people have some place to keep the wood dry. In the rainy season it is difficult to obtain dry wood; in such a case some flammable material is added. Secondly, people pay attention to the ***wood type***. There is a general distinction between wood from the highland or the lowland. Wood from the highland is more expensive, but (or: because) it releases less smoke and has a higher density resulting in longer burning.

Table 3.6: Reasons for fuel state

Choice at hand	**Attitude reasons**	**Norm reasons**	**Control reasons**	**Habitual reasons**	**External reasons**	**Changeability rating**
Amount				According to dish requirements		NO
Dry fuel vs wet	+Less release of smoke +Easier to burn				-Difficult during rainy season	NO

Highland/lowland (H/L)	+H more dense +H releases less smoke		-H more expensive (*H*)			SUPPORT

<u>Fire place</u>

Within wood cooking, we encounter much variation in stoves. Most of these differences are related to the material, size or state of the fire place – all varying around the same 'theme', namely a hole to put wood in and a pan on. One exception to this is the ***injera stove***, a stove specifically produced for injera preparation. An injera stove saves fuel (due to more efficient use of heat) and is safer, because it confines the flames to a closed space. For these reasons, it has been developed and promoted by organizations. A reason not to have a fixed fire place is cattle. At one household (HH41), they used to have a fixed injera stove, but their cattle destroyed it. Another reason not to have a fixed injera stove: simply because it is not used often enough. Injeras can also be bought and for festivals once in a while they can be prepared on the normal fire place.

I encountered five different ***materials*** for the normal wood cooking fire places: simply the soil, a piece of pottery, some shattered pieces of pottery, stones or iron. In general, most people 'made something' of their fire place, by either stones, pottery or iron. For the piece of pottery as explicit reasons were give that it helped to save the lifespan of the fire (HH29, HH39), and that it helped to prevent soil moisture to enter (HH32, HH39). Furthermore, the wall material makes sure that the hole stays a hole.

As for the size of the fire place, there was substantial variability in the ***depth*** – ranging from 0 (i.e. a pile of wood on the ground) up to even 30 centimeters. The participants agree on the fact that a fire place of some depth helps to preserve the heat of the fire, which is generally considered as positive. However, for one household (HH30) this attribute is a reason not to have a very deep fire place, as that saves the consumption of wood. Also, another participant (HH38) sees this attribute as a danger; it might explode. The same person prefers a fire place with little depth because then the fire is closer to the pan. However, it might well be that the main reasons for a particular depth are rather mundane. As one participant puts it: 'it is only to have wood in it' (HH33), or another, 'only for the ash' (HH36).

Table 3.7: Reasons for stove types

Choice at hand	**Attitude reasons**	**Norm reasons**	**Control reasons**	**Habitual reasons**	**External reasons**	**Changeability rating**
Having an injera stove	+Less fuel consumption +Safety		-Cattle can destroy it (*n_p*)	-Not needed so much (P)	+Promoted by organizations	SOME
Using some material or not	+Prevent soil moisture +Preservation of heat			+To retain a hole		YES
Increased depth of fire place	+Preservation of heat -Danger of heat preservation -Fire closer to pan -Consumption of wood			Just to have wood or ash in (P)		SOME

3.3.2. Ventilation

The ventilation that transports the BC and NO_2 particles are expected to depend on openings (amount, height, type, orientations) and the roof and wall material.

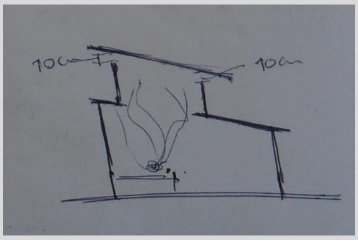
<u>Openings</u>

There are four common types of openings: a door, a window frame, lower openings in plaster and an opening between roof and wall. Generally, the people are aware that ***openings*** are important with respect to ventilation. Ten respondents mention to have provided the openings as a remedy of the amount of smoke, four others mention their openings as the thing they like about their kitchen. A participant from a house with biogas (HH19) regrets the low ventilation because of the low number of openings, resulting in a lot of heat. However, there can also be a thing as 'too much openings'. Some are glad that their kitchen is also enclosed enough to counter wind. Another (HH20) mentions that through the openings and wind direction smoke enters the kitchen. At HH34 the complaint was that the kitchen was not enclosed enough, and hence that smoke could freely disperse in the direction of the renting living rooms. Some were aware that because of the ***orientation*** of openings with respect to the main building, wind was blown into their main building. Others mentioned the aspect of cross-ventilation: ventilation would increase if cross-ventilation is possible. At one household was mentioned that for cross-ventilation to be possible, a window at the neighbors side of the compound was needed, which was not allowed. Also, both the orientation and number of openings is related to what comes in convenient: a couple of openings at the sides of the kitchen where it is suitable.

I encountered some kitchens that had a kind of ***chimney-structure*** (HH13, 14, 36; see Box 3.2). At HH36, they were glad with this structure, as it transported the smoke away. A reason not to have such a structure is a combination of capacity and unawareness: it is more difficult to implement such a structure, and as long as people do not see the additional worth of such a structure, they will not do it.

Box 3.2: Chimney structures

With a hole in the roof, rain will enter the kitchen. At some households, a small 'small roof on the roof' is made to create a chimney structure. Left: measurements by Tekalign at such a chimney structure. Right: sketch of a kitchen with chimney structure.



<u>Roof and wall materials</u>

Concerning the ***roof material***, people are more considered with a well-closed roof with respect to rain, than a roof type that provides hidden openings. One participant that owned a kitchen with bamboo roof, mentioned the wish to rebuild the kitchen, and then to put an iron roof on it. As for the ***wall material***, people prefer to have a wall that is protecting the fire place from wind and rain as well.

Table 3.8: Reasons for ventilation variable settings

Choice at hand	**Attitude reasons**	**Norm reasons**	**Control reasons**	**Habitual reasons**	**External reasons**	**Changeability rating**
Increased number of openings	-Rain entering +Ventilation -Smoke entering or dispersing			What is convenient (*P*)		SOME

Chimney	-not aware +less smoke		-costs (*H*)			SUPPORT
Orientation: wind direction	Decides where the smoke goes			What is convenient (*P*)		SOME
Orientation: cross-ventilation	+better ventilation			What is convenient (*P*)	-Not towards neighbors side (*P*)	SOME
Roof material partially open	-Protect from rain					NO
Wall material partially open	-Protect from wind and rain					NO

3.3.3. Location

The location of the emission source influences concentrations via the following variables: chimney for injera stove (y/n), separate kitchen room (y/n), kitchen attached to main building (y/n) and outside cooking (y/n).

Figure 3.4: injera stove with chimney structure, HH37.

Injera stove chimney[a]

At one household (HH37), we found an interesting addition to an injera stove: a ***chimney*** made from iron plates, connected to the pan outlet (see Figure 3.4). This 'inventor' did it purely to get rid of the smoke.

Separate kitchen room

Small stoves such as biogas or electricity generally were used within a small room of the main building. The charcoal pot was often used in front of the main building, for example at a veranda. However, it was also used regularly inside the main building, for example for the coffee ceremony, or simple when one was tired and the kitchen was a bit far away. For wood cooking, in most of the cases we encountered a ***separate kitchen***, either attached or de-attached from the main building. The only two cases in which wood cooking was conducted within the same room as living, was when they were obliged to do so because of rain: one (HH07) would cook outside as soon as possible, and the other (HH09) would switch as soon as possible to the kitchen building – one that was not properly water-proof.

Kitchen attached to main building

In the group discussion the women said they wanted the ***kitchen de-attached*** – primarily because then smoke from the kitchen would not influence the color of the main building. However, for other households it was also a pre if the kitchen was attached to the main building, or bridged by some corridor, so that it was useable at all times: one could come dry into the kitchen during the rainy season. Furthermore, it depends on what is convenient: for example how the set-up of the compound arranged, deciding whether it is possible to attach the kitchen to the main building or not.

Outside cooking

[a] The injera stove chimney is placed under 'location' variables, as it does not influence emission or ventilation rates: it alters the place of the source (the pollutants enter the kitchen at a higher point)

Outside cooking was done only for dishes that required quite some space, and if that space was not available in the kitchen area. Especially for festivals big breads were prepared, which was often done outside. However, outside cooking in general was not preferred. Not only is then not your cooking gear at hand, but also the wind disturbs the fire and things from outside might enter the dish. And, with certain dishes (when using butter, oil or other fatty ingredients), a phenomenon called 'mitch' could occur: wounds around the mouth. All the participants of the group discussion said to have experienced it.

Table 3.9: Reasons for location variable settings

Choice at hand	**Attitude reasons**	**Norm reasons**	**Control reasons**	**Habitual reasons**	**External reasons**	**Changeability rating**
Chimney attached to injera stove	+Less smoke			-Only for injera stoves (*P*)		SOME
A separate kitchen room or not	+things by the hand +no smoke in living room				-not useable if not water-proof (*H*)	SUPPORT
Kitchen attached to main building or not	-color of main building +walking dry to the kitchen			What is convenient (*P*)		SOME
Outside cooking or not	-'mitch' -distortion by wind -dirt can enter dish			+For big dishes (S)		NO

3.4. The influence of the concentration variables on concentration

What is the relation between these variables and BC and NO2 household concentrations?

As explained in footnote a (page 1) it is assumed that the *concentration variables* that are related to ventilation and location have the same effect on BC and NO_2 concentrations. In these analyses BC concentrations or BC emissions will be used as dependent variables, but the result will be comparable if you test it with NO_2 concentrations. The emission variables may have a different effect on the NO_2 concentrations. I was not able to collect data on all these variables, but I was able to measure the effect of three different fuel materials on NO_2 concentrations.

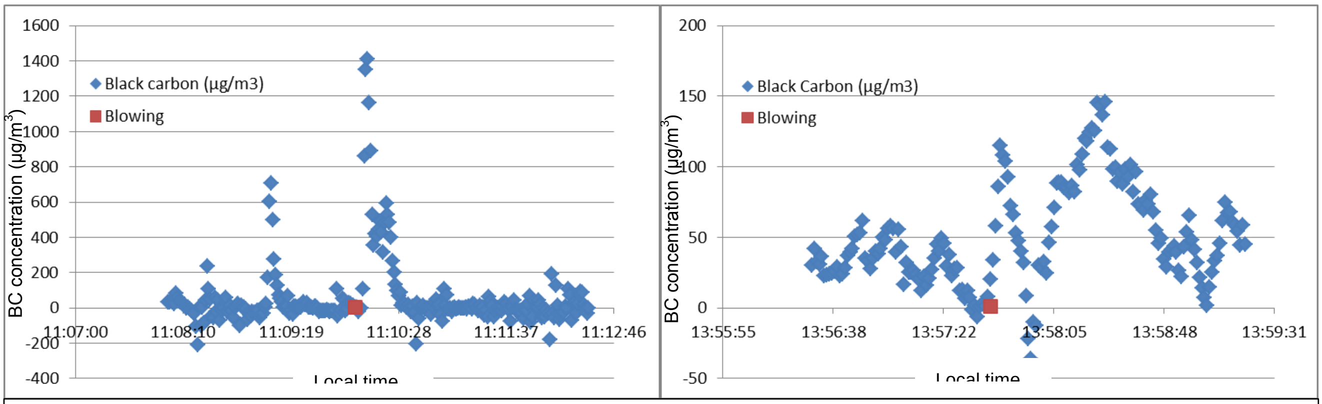
This section reports the relations between concentrations and concentration variables. Section 3.4.1 discusses the variables that are external and section 3.4.2 discusses the variables of our main interest: the ones that might be *local capacities* to reduce exposure to pollutants.

3.4.1. Variables outside the reach of the household (external variables)

The variables discussed in section 3.2.1 are all tested on their relation with BC concentrations, or other variables that have an effect on BC concentrations (such as ventilation).

In Table 3.10 the results are summarized. Background wind speed and direction indeed influence household concentrations, and hence are important to incorporate in the analyses. Background concentrations are negligible during cooking times, and hence do not have to be taken into account during the analyses of the other variables. However, knowledge of the background variables is needed in the eventual calculation of accumulated exposure. Fire temperature explains the vertical stratification; a difference in fire temperatures however will most likely not result in a different vertical stratification. Lastly, tending activities cause for great irregularities. It shows that after taking into account all other circumstances, still substantial variability is expected.

Table 3.10: Impact of external variables on BC concentrations		
Variable	**Hypothesis**	**Test result**
Background wind	Both background wind speed and direction are expected to influence household compound wind speed and direction.	Wind speeds measured at the households are positively correlated with the background wind speeds measured (0.17 m/s increase for each m/s increase in background wind speed, p=0.003, R-squared=4%). Validated ventilation values increase with 0.26 m^3/s for each m/s background wind increase (p=0.004, R-squared=11%). Also the background wind *direction* has a significant influence: wind speeds measured at openings facing the wind direction are on average significantly (p=0.01) higher than those measured at the opposite side of the wind direction (0.26 m/s vs 0.17 m/s).
Background concentrations	when there is no cooking conducted at the household, values within the household compound are determined by the background concentration.	From my own data-set I have background concentration values from measurements during our measurement-periods outside, while the household not was cooking. These were on average 12±13 $\mu g/m^3$. This is in the same order of magnitude as the background concentrations measured during morning and evening peaks (5-25 $\mu g/m^3$), respectively. Indeed, when there is no cooking, background concentration determines household concentration.
Fire temperature	Fire temperatures result in vertical transport.	Significant higher concentrations near the roof than at lower height (see section 3.1.1). It is not possible to test for differences in this effect with different fire temperatures (i.e. faster vertical transport with higher fire temperatures).
Tending activities	Tending activities, like blowing in the fire, add to the irregularities in concentrations during the cooking period.	The blowing disperses the ash particles into the air. **Error! Reference source not found.** shows this effect. The eventual result of blowing, however, is that emissions decline. The blowing results in a return of flames, which help decomposing the particles. In other words: not blowing also increases concentrations – especially when fuel is added. Box 3.3 shows two examples of this.

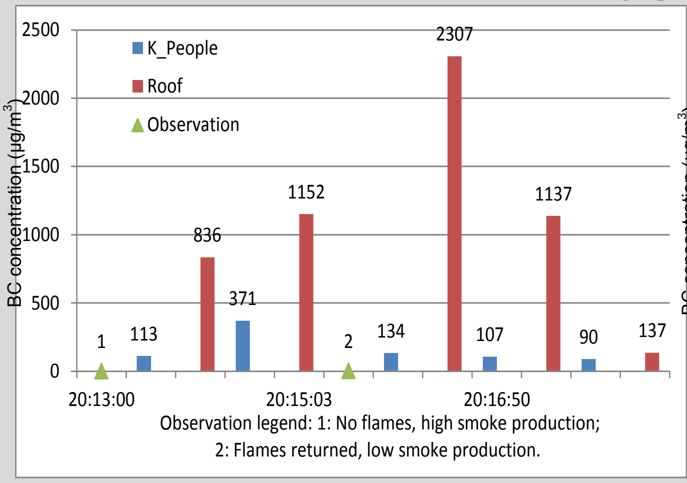


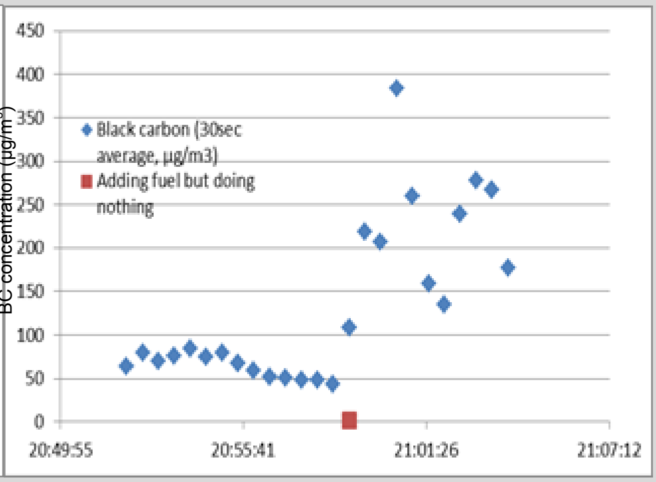
Graph 3.3: BC concentrations around the event of blowing at HH17(left) and HH18(right), close to the fire

Box 3.3: Tending the fire or not?

At HH28 we conducted *shifting measurements*: for five times subsequently 30 seconds close to the fire (K_People) and near the roof. One such a sequence was during the moment flames went away and a lot of smoke was produced, after which the participant blew in the fire such that flames came back and smoke production decreased. The below bar graph shows averages of the measurement periods in µg/m3. Logically, at K_People the concentration reacts faster to the event than near the roof. The difference in concentration is considerable: at K_People the concentration is four times as high, while near the roof concentrations pass the 2000 µg/m3 at its highest point, sixteen times as high as when smoke production is reduced again.

About half an hour later, I measured at a fixed point above the fire for about twenty minutes. Initially, the fire was in smouldering stage. At some point, some fuel was added, but there was no further tending conducted. This resulted in increased concentrations – see the graph to the right.





3.3.2 *Variables inside the reach of the household*

Emission variables

The concentration variables under emission are fuel material, fuel state and fire place characteristics. As explained in section 1.4.3 the effects of ventilation and location will be filtered out by making emission the dependent variable (instead of BC concentrations directly). The BC emission is calculated based on the box-model and the linear increase method. I used two methods to cross-check my findings:

1. A controlled experiment for the fuel materials (see section 2.2.3)
2. I took indicators of emission as dependent variable: BC concentrations and CO_2 concentrations (as explained in section 3.1.3).

The emission outcomes per different ***fuel material*** are displayed in Table 3.11 and compared with calculated emissions under non-controlled circumstances.

Table 3.11: The influence of fuel material on BC emission and NO2 concentration			
Material	**BC emission controlled experiment (µg/s)**	**BC emission not controlled (µg/s)**	**NO_2 concentrations close to the roof (µg/m^3)**
Wood	124-131	117±21 (N=56)	987
Charcoal	0.003-0.06	1.3	n.a.
Kerosene	94-112 µg/m^3 during start-up; 1.5-3 µg/s during further use	n.a.	n.a.
Animal waste	14-42	n.a.	n.a.
Plastic	2.5-4.2	n.a.	n.a.
Rubber (shoe)	1136-3081	2133	n.a.
Grass	178-181	n.a.	n.a.
Biogas	n.a.	0	1615
Electricity	n.a.	0	14

The BC emission of biogas and electricity were not measured in the controlled experiment, since the emission of these fuel materials is negligible. The emission of animal waste, grass and plastic was not calculated for the not-controlled circumstances, since they were used combined with other fuel materials or for a short time only: too short to find a proper emission value. The use of kerosene was not encountered under non-controlled circumstances. Charcoal emissions were only measured while it was already started. Generally charcoal is started with burning coals from a wood fire. Starting a charcoal fire without such help is more difficult and releases more smoke. One measurement period close to a charcoal pot that was being started outside gave an average concentration of 60 µg/m^3.

Unfortunately I could not obtain NO_2 concentrations for all fuel materials. Remarkable is the high NO_2 concentration in the biogas kitchens. This, however, is due to the low ventilation in the kitchen: biogas stoves are placed inside the main building in a small room, generally badly ventilated, because it is convenient to have the stove closeby, and because there does not seem to be a problem with having low ventilation (as there is no visible smoke).

Box 3.4: Injera preparation as indicator of fuel amount.

We asked 19 participants how much money they spent on fuel wood. Two of them were sellers of injera, and thus daily prepared injera (HH20&HH30) – a dish normally not prepared often. Their monthly expense on wood was about four times as high as other households: 400 and 480 Ethiopian Birr (ETB), respectively, while the other households on average spent 112±15 ETB monthly on wood.

This difference partly is due to the longer cooking time, as not only food is prepared for their own family, but also for selling purposes. Total cooking time daily (eg. breakfast+lunch+dinner) for all households using wood on average is 4.3 hours. One injera preparation sequence we witnessed took about two hours. Let us assume that expenses and time spent on all cooking besides injera preparation is the same for all households. In that case, 440-112≈320 ET remains for the injera preparation, which takes two hours a day. With a simple calculation this shows that an injera cooking hour is about 6 times as expensive as a normal cooking hour (320/2=160 ETB versus 112/4.3≈25 ETB), implying that about six times as much fuel is used for injera preparation. In other words: either or not injera preparation is a good indicator for using a high or low amount of fuel.

Besides the fuel material, there are the ***fuel state*** and ***fire place*** that might affect BC emission. Table 3.12 shows their relation with emission, BC concentration (indicator for emission) and/or CO_2 concentration (indicator for emission). As indicator for amount, preparation of injera versus other dishes was chosen, as for injera much more wood is used (Box 3.4).

Since the stove type is highly related with the fuel material used, it does not make sense to compare all stoves. It would have been interesting to see the emission if injera was prepared on a traditional stove (not injera stove) but unfortunately I could not collect data on that. The effects of the material of the fire place present themselves through 1) dryness and 2) depth. 1) Material is used to counter soil moisture. As I have not measured this, I cannot test for this. 2) The use of some material was directly related to the depth of the fire place: fire places made with some material generally were deeper than those without. Hence, what remains to test is fire place depth. The practical depth of a particular fire place is varying, in relation to the amount of ash remaining in the fire place. Hence, the only sensible comparison is that between a not-deep and a deep fire place.

Table 3.12: The influence of fuel state and fire place on BC emission and BC and CO_2 concentration

	dependent variable→ / **independent variables↓**	**Emission**	**BC-concentration**	**CO_2 concentrations in the kitchen**	**Implications/practical meaning**
Fuel state	Amount of fuel: injera preparation vs no injera preparation	362 μg/s 80 μg/s (p=0.03)* [t-test]		1246 PPM vs. 824 PPM (p=0.003)*** [t-test]	A higher amount of fuel results in higher emission rates.
	Dry vs. wet wood		208 μg/m³ 1368 μg/m³ [comparison of two living room measurement periods at HH07]		The use of wet fuel results in higher black carbon concentrations
	Highland vs. lowland				No data available
Fire place	Injera stove y/n				No data available
	Fire place depth >3cm vs ≤3cm	99 μg/s vs. 50 μg/s (p=0.08)’ [t-test]		717 PPM vs. 964 PPM (p=0.16) [t-test]	There is no significant relation between fire place depth and BC emission: the weak relation is falsified by the non-correlation with CO_2.

Ventilation variables

In order to find the effect of the ventilation variables on BC and NO_2 concentrations, I can take ventilation or wind as indicator for BC concentrations (see Box 3.5 for an example in which BC concentrations are used directly). By that the effects of emission and location are filtered out. Two regression models are run, one with ventilation as dependent variable, one with wind as dependent variable.

Box 3.5: A relation between wind direction and black carbon concentration?
In order to ease the analysis, ventilation and wind have been used as indicators of concentration, rather than concentration itself. Is it possible to trace back a relation between wind direction and black carbon directly?

I applied three data corrections. Firstly, BC values at openings are weighted with the average of all values measured in the corresponding household kitchen to correct for household concentration differences. Secondly, dependence on wind direction will not be the case for low wind speeds. Hence, measurements corresponding to household wind speeds below 0.05 m/s (1st quadrant) were excluded from the analysis. Thirdly, to correct for differences due to differences in area of openings, total area is included in the regression model. With this model, I find that BC concentrations at openings facing the wind direction are 308 µg/m³ lower (p=0.03) than at openings opposite of the wind direction. Indeed, black carbon concentration ventilation is related to background wind direction. However, quite some corrections are needed. Hence, it is easier to use an indicator like wind speed.

The effect of the variables ***area of openings*** and ***chimney*** on ventilation, controlled for the background wind is highly significant (see Table 3.13). The ***type of openings*** and the ***material of the roof/wall*** is closely related to the area of openings, so these are not included in the regression model.

Table 3.13: Regression analysis to show influence of variables on ventilation		
Dependent variable → **Independent variables ↓**	**Ventilation (Avg: 0.35 m³/s) (Rsq: 0.39, N=85)**	**Implications/practical meaning**
Opening total area (1-16 m²)	0.12 (p<0.001)***	For each m² increase in total area of openings, ventilation rates increase with 0.12 m³/s.
Chimney structure (y/n)	0.55 (p<0.001)***	Ventilation rates at households with a chimney structure are 0.55 m³/s higher than at households without a chimney structure.
Type of openings	Taken into account via openings	
Roof and wall materials	Taken into account via openings	
Background wind (0.15-2.5 m/s)	0.14 (p=0.08)’	For each m/s increase in background wind, ventilation rates increase with 0.14 m³/s.
Significance codes: 0 *** 0.001 ** 0.01 * 0.05 ’ 0.1 ‘ ’ 1 Excluded: ventilation rates without at least one star in one of the validation methods.		

The effect of the variable ***height of* openings** is checked by comparing openings connected to the roof with other openings. According to the second model of this section (Table 3.14) wind speeds are significantly higher at roof openings. Also, the ***orientation of the openings*** has significant influence: at openings facing the wind direction or level with the wind direction higher wind speeds are measured. The implication of the variable ***orientation of the openings*** is difficult. According to the model there is significant difference in wind speeds either measured at openings facing the wind direction, level with the wind direction or opposite to the wind direction. The households however generally have openings at more sides of the kitchen – a translation of this effect into a concentration difference hence is not possible with the data I have. Within this model ***cross-ventilation*** did not seem to have a significant effect. The R^2 of the model is very low, only 3% of the variation in wind is explained by the model.

Table 3.14: Regression analysis to show influence of variables on wind		
Dependent variable → **Independent variables ↓**	**Wind (Avg: 0.25 m/s) (Rsq:0.03, N=191)**	**Implications/practical meaning**
Roof openings (y/n)	0.09 (p=0.04)*	Wind speeds at openings connected to the roof are 0.1 m/s higher than lower openings.

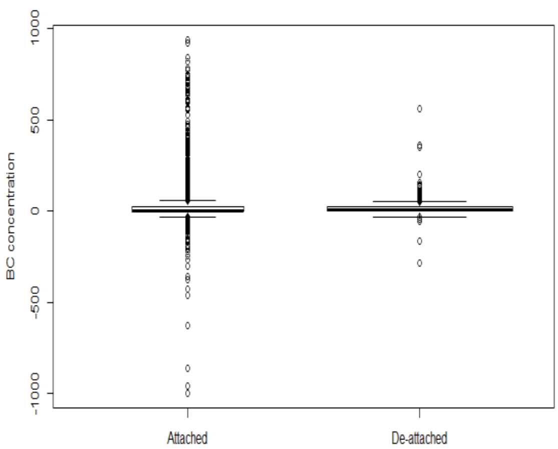
Opening direction (facing/opposite to wind direction)	0.09 (p=0.09)’	Wind speeds at openings facing wind direction are 0.1 m/s higher than those opposite of wind direction.
Opening direction (level with/opposite to wind direction)	0.23 (p<0.001)***	Wind speeds at openings level with wind direction are 0.23 m/s higher than those opposite of wind direction.
Cross-ventilation possibility (y/n)	0.03 (p=0.5)	No relation
Background wind (0.2-2 m/s)	0.10 (p=0.06)’	For each m/s increase in background wind, there is 0.1 increase in wind speeds at openings.
Significance codes: 0 *** 0.001 ** 0.01 * 0.05 ’ 0.1 ‘ ’ 1		

<u>Location variables</u>

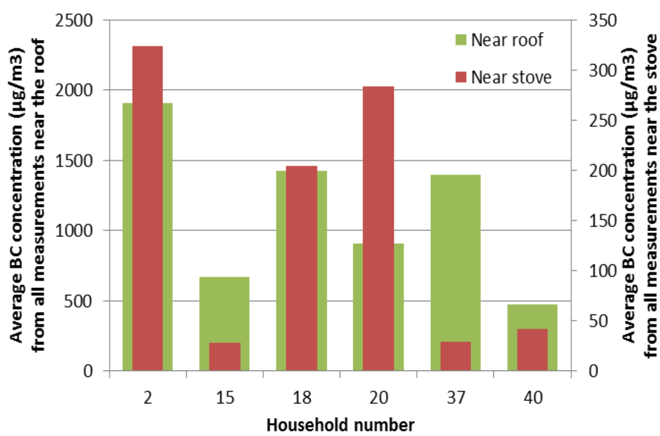
For location variables there is no indicator of BC concentrations to eliminate the effects of emission and ventilation on BC concentrations. Therefore the dependent variable in the analyses is BC concentrations. For the variables ***injera stove chimney*** and ***main building de-attached*** I control for BC concentrations near the kitchen roof to represent emission and ventilation variables (see Box 3.6). For the variable ***distinct kitchen*** such a correction is not possible, as there are no kitchen roof values for both groups (because, for one group, there is no kitchen). Table 3.15 shows the findings. Furthermore, for the analysis of ***main building de-attached*** four households are excluded: two households that had no distinct kitchen (HH07 and HH09), and two households that had their main building attached to the kitchen even with a window opening (HH35 and HH40). The latter two are excluded because I only want to test for how close the kitchen is to the main building, not whether they also give a direct pathway into the main building (in that case, the position of the fire place within the kitchen becomes important, see Box 3.7).

Table 3.15: Influence of location variables on BC concentration

Variable	BC-concentration	Implications/practical meaning
Injera stove with chimney vs. stove without chimney [t-test of: near to stove values weighted with roof values]	36 μg/m³ 237 μg/m³ (p<<0.001)***	A chimney on the injera stove reduces concentrations at breathing level (see Graph 3.5)
Main building de-attached y/n [t-test of: main building values weighted with kitchen roof values]	24 μg/m³ 49 μg/m³ (p<<0.001)***	Concentrations in the main bulding are higher if the kitchen is attached to the main building. The concentrations are also more variable (see Graph 3.4)
Distinct kitchen y/n [t-test of: living room values]	12 μg/m³ 210 μg/m³ (p<<0.001)***	Concentrations in the living room are much higher when cooking is conducted in that same area, instead of in a distinct kitchen.
Cooking outside y/n	n.a.	



Graph 3.4: BC concentrations are more variable if the kitchen is attached to the main building



Graph 3.5: Average black carbon concentrations (μg/m³) near the roof and near the stove while injera is prepared on a stove. At HH37 a chimney was implemented on the stove: concentrations near the stove relative to roof concentrations are lowest there.

Box 3.6: Correction with kitchen roof values

For each kitchen it is the case that due to the heat of the fire initially BC and NO_2 accumulate under the roof. Hence, I assume that differences in average concentrations near the roof are a best possible indicator for differences in emission, with least possible influence from ventilation. Therefore, concentrations at other places than the kitchen roof (e.g. near the injera stove or in the main building) are weighted with average kitchen roof concentrations: each value is divided by the average of all roof values of the corresponding household, and multiplied by the average of all roof values.

Box 3.7: Main building and kitchen attached with a window

At HH35 and HH40 between the main building and the kitchen there was a window. Average black carbon concentration measured in the main building was respectively 4±0.8 and 221±6.5 μg/m^3. This big difference is especially due to the fact that at HH40 the fire place was directly under the window. The kitchen of HH35 was relatively big and well ventilated, and the fire place was at the other side of the kitchen.

3.5. Possibilities to reduce BC and NO_2 concentrations

What are local possibilities to reduce BC and NO_2 concentrations in Arba Minch?

We found a lot of variation among households. There is variation in the concentration values (plus their indicators) and in the concentration variables. However, changing within this variability is not always possible, and also the influence of a certain change varies substantially. Table 3.16 reports the changeability for each of the variables, as well as whether the variable has a significant influence on BC and/or NO_2 concentrations. A review of exposure in the next chapter will add some additional variables, and will help to translate the relations of the variables found in this chapter into an influence on accumulated exposure.

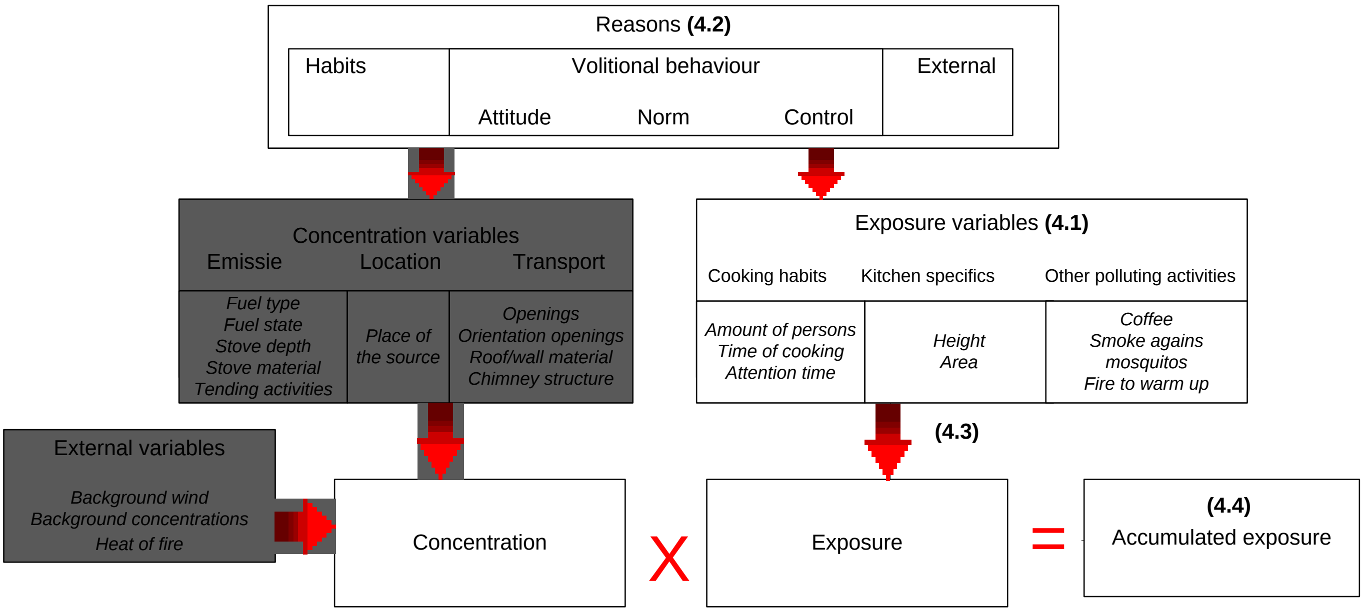
Table 3.16: Overview of local possibilities to reduce BC and NO2 concentrations in Arba Minch

		Variable description	Changeable	Significant influence? On BC conc.	Significant influence? On NO_2 conc.
Emission variables	fuel material	Wood vs. biogas	SOME/ SUPPORT	Yes	Yes
		Wood vs. electricity	SUPPORT	Yes	Yes
		Wood vs. kerosene	NOT	Yes	No data
		Wood vs. charcoal	NOT	Yes	No data
		Complementary dung vs. no dung	NOT	Yes	No data
		Start-up materials vs. no start-up materials	NOT	No	No data
		Rubber as start-up vs. other start-up materials	YES	Yes	No data
	Fuel state	Lowland vs. highland	SUPPORT	No data	No data
		Wet wood vs. dry wood	NOT	Yes	No data
		Much wood vs. little wood (much is needed for injera preparation)	NOT	Yes	No data
	Fire place	Injera stove vs. no injera stove	SOME	No data	No data
		Fire place material	YES	No	No data
		Fire place depth	YES	No	No data
		Fire place dry vs. wet	NOT	No data	No data
Ventilation variables	openings	Low vs. high openings	SOME	Yes	
		Mean opening vs. 3rd quintile opening	SOME	Yes	
		Chimney structure vs. no chimney structure	SUPPORT	Yes	
	orientation	Cross ventilation possible vs. not possible	SOME	No	
		Opening in vs. not in wind direction	SOME	No data	

	Construction material	Roof material sealed vs. partially open	SOME	No
		Wall material sealed vs. partially open	SOME	No
Location variables		Chimney on injera stove vs. no chimney on injera stove	SOME	Yes
		Kitchen attached vs. de-attached from main building	SOME	Yes
		Distinct kitchen vs. no distinct kitchen	SUPPORT	Yes
		Outside cooking vs. inside cooking	NOT	No data

4. Household exposure

What are local possibilities to reduce the accumulated household exposure to these BC and NO2 concentrations in Arba Minch?



In this chapter I will discuss the exposure variables, i.e. variables that influence the exposure to the concentrations shown in the previous chapter. Firstly, this will add exposure variables to the total list of potential local possibilities to reduce accumulated exposure to the pollutants. Secondly, this will help to translate the influence of concentration variables, as discussed in the previous chapter, into accumulated exposure. In section 4.1 I will present the exposure variables with their variations, section 4.2 reports the reasons for these variations, i.e. the changeability. In section 4.3 the relation between the variables and exposure will be discussed. This gives me enough tools to present the total list of all exposure- and concentration variables, their variation, their changeability with respect to the reasons and their influence on accumulated household exposure, in section 4.4.

4.1. Variations of the exposure variables

What are the variations of the exposure variables?

As mentioned in section 1.4.4, the exposure variables can be categorized in three groups: cooking habits, kitchen specifics and other polluting activities. **Table 4.1** shows the exposure variables and their variations.

Table 4.1: The exposure variables and their variations

Group	Variable name	Variation in Arba Minch?
Cooking habits		
	Number of persons	1 up to 4 persons responsible for cooking, so they cook less time per person
	Cooking time	15 minutes up to 8 hours
	Attention time	10% up to 100% of the cooking time
Kitchen specifics	Kitchen height	1.75 meter up to 3.75 meter
	Kitchen area	4 m^2 up to 24 m^2

Other polluting activities	Coffee preparation	Coffee consumption as a social activity or not
	Use of smoke	Countering mosquito's with smoke, or heating a room

4.2. Reasons for the variations

What are reasons for variation in the exposure variables? Are they changeable?

4.2.1. Cooking habits

The ***number of persons*** that is involved in cooking depends on the family composition. Whether a particular person is involved in the cooking, depends on:

- Gender: typically women are expected to cook, and men are not. Some respondents mentioned – somewhat joking – that men are even not allowed in the kitchen or near the fire place. When asking for the reason, no clearer answer than 'cultural' can be given by the respondents. However, practical circumstances can overrule this cultural habit. When there are only sons, often they are expected to help their mother in cooking. We encountered one household where the father was cooking (HH31)[a], because the mother was absent due to work. Also, there were single men (mostly students) cooking for themselves – having no woman to do so for them. Some men, when asked directly, claimed to help when possible. Nevertheless, mostly women are responsible to cook.
- Age: at HH17 there was a girl of about 5 years that was cooking, but mostly young girls are not yet expected to cook. They might be helping though.
- Other responsibilities: work or study can be reasons not to cook. One mother (HH25) said that only she was responsible for cooking, despite having two daughters that were old enough. The daughters, in their own words, "work daytime, study night".

In general, the number of persons involved in cooking simply equals the number of women available in the household[b].

Differences in ***cooking time*** can be explained with:

- Moment of cooking. From the diaries we find that cooking for breakfast takes on average 58±1.6 minutes, lunch 80±2.3 minutes and dinner 84±3.1 minutes. Moments in between (such as coffee preparation) take 42±2.4 minutes. Often, for breakfast already prepared food is heated and for lunch and dinner more extensive cooking is conducted.
- Fuel material. Different fuel materials have different temperatures, resulting in different cooking speeds. Cooking times with biogas are significantly ($p<<0.001$) shorter than cooking with wood (43±2.1 versus 72±1.6 minutes), while cooking with electricity takes longer than both (80±5.8 minutes; difference with wood is not significant).
- Dish type. For example, boiling meat takes a long time (a couple of hours), while a traditional dish of dough and vegetables ('Posose') can be prepared within half an hour.

Cooking times do not equal exposure time: the ***attention time*** is usually shorter than the cooking time. Attention time depends on:

- Fuel material. The positive aspect 'speed' mentioned by respondents in relation to biogas and electricity is by them also related to the negative aspect 'that it cannot be left alone'. According to them, a wood fire can be safely left alone as it will go out at some point by

[a] He did however say that as soon as his wife was home, he would stay away from the kitchen – and that she was a much better cook. He excused himself for the quality of the dish; if she would prepare a posose of this quality, he himself would not eat it. Frankly, indeed this might have been one of the lowest quality dishes we encountered on all the lunch or dinner invitations.

[b] They are also expected to be involved in cooking and other household tasks when they visit other households. It is nicely put in an Amharic saying: "Yessit ing'da jillem"; there are no female guests.

itself. Also, a charcoal pot can be left alone, as it is simply heating on a constant and not too hot way. Biogas or electricity, however, due to their speed require attention and hence presence. For biogas and electricity, the person cooking is on average respectively 97±1% and 82±3% near the 'fire place'. In case of wood cooking this is 75±1%.

- Dish type. For example, boiling meat can be left alone for most of the time. A 'wot' (something sauce-like) on the other hand needs continuous attention: the person is close to the fire, adding ingredients and stirring the *wot*.

The summary of the reasons for cooking habit variables is reported in Table 4.2.

Table 4.2: Reasons for cooking habits variable settings						
Choice at hand	**Attitude reasons**	**Norm reasons**	**Control reasons**	**Habitual reasons**	**External reasons**	**Changeability rating**
Cooking time				(x) According to moment, fuel and dish needs		NO
Attention time				(x) According to dish and fuel needs		NO
Number of persons	-not when too young (S) +practice rules over norm (S) -study or work important (S)	-Men should not cook +all women should cook				NO

4.2.2. Kitchen specifics

Both increased ***height*** and increased ***area*** are preferred. It is a compromise between the convenience of more space, and the costs and space it takes.

Table 4.3: Reasons for kitchen specifics variable settings						
Choice at hand	**Attitude reasons**	**Norm reasons**	**Control reasons**	**Habitual reasons**	**External reasons**	**Changeability rating**
Increased kitchen height	+convenient		-costs (H) -space (P)			SOME, SUPPORT
Increased kitchen area	+convenient		-costs (H) -space (P)			SOME, SUPPORT

4.2.3. Other polluting activities

It is claimed by many that Ethiopia is the country where coffee is invented. True or not, ***coffee preparation*** indeed has a central place in households; from harvesting to consumption. A traditional coffee ceremony is one which is combined with burning incense on a small charcoal pot. As such, often people are gathered around a direct source of burning.

There are two ***other uses of fire*** within a household:

- 13 respondents said to sometimes use fire inside to heat the room. However, as a woman (HH16) pointed out smartly, this is not often needed in the Arba Minch climate – they maybe did so for about three or four times a year.
- Another often mentioned point is that smoke is effective against mosquitos: sometimes rooms are made mosquito free with use of smoke.

Table 4.4: Reasons relating other polluting activities						
Choice at hand	**Attitude reasons**	**Norm reasons**	**Control reasons**	**Habitual reasons**	**External reasons**	**Changeability rating**
No coffee		-Coffee				NO

preparation		drinking is social activity				
No other use of fire	-used against mosquitos -used for heating					NO

4.3. The influence of the exposure variables on exposure

What is the relation between these variables and exposure to BC and NO2 household concentrations?

The relation between the exposure variables and exposure can only be stated in terms of 'shorter' or 'longer' exposure to this or that air. Instead of such qualitative terms, I will express where possible the relations in terms of concentrations and exposure*concentrations (accumulated exposure).

4.3.1. Cooking habits

Table 4.5 shows a calculation of how accumulated exposure to BC for one day for a cooking person is related to ***cooking time***, ***attention time*** and the ***number of cooking persons***. This is shown for two different fuel materials: wood and biogas. Average cooking times are based on the diary results. I have assumed that once coffee is prepared on a charcoal pot (see section 4.3.3 for this concentration), and that all time is spent within the household (either cooking, or otherwise outside or in the living room on the compound).

Table 4.5: accumulated exposure depends on: fuel material, cooking time, attention time and number of persons. The values between brackets are exposure values if cooking is divided over two persons.

		Wood			**Biogas**		
Moment	*Place*	*Time [min]*	*Conc. [μg/m³]*	*Exposure [hr μg/m³]*	*Time [min]*	*Conc. [μg/m³]*	*Exposure [hr μg/m³]*
Breakfast	Kitchen	41 (20)	248	169 (83)	40 (20)	12	8 (4)
Lunch	Kitchen	60 (30)	248	248 (124)	50 (25)	12	10 (5)
Dinner	Kitchen	64 (32)	248	265 (132)	40 (20)	12	8 (4)
Rest during cooking	Outside Living room	22 (64) 22 (64)	60 12	22 (64) 4 (13)	0 (32) 0 (32)	12 12	0 (6) 0 (6)
Coffee	Around CH pot	30	20	10	30	20	10 (10)
Rest	Outside or inside	1200	3	60	1280	3	64
Accumulated exposure				778 (486)			100

Cooking time and ***attention time*** are exposure variables, but their variation is already taken into account by calculating the effect of fuel material and moment of cooking on accumulated exposure. In other words: their variations are already incorporated in other variations – individually those variables present no separate situations.

Number of persons, on the other hand, does present a separate situation according to its variation. When a large share of accumulated exposure is due to cooking activities, an increase in the number of persons decreases accumulated exposure for one person substantially.

4.3.2. *Kitchen specifics*

Table 4.6 shows with a regression model that ***kitchen height*** and ***kitchen area*** have a significant relation with the BC concentrations not near the roof, i.e. at the level of the people. Higher kitchens reduce the accumulated exposure, because particles accumulate under the roof and a higher kitchen brings the roof farther away from breathing level. Kitchens with a larger area reduce accumulated exposure, because they have more options to be in the kitchen while taking some distance from the fire.

Table 4.6: The influence of kitchen height and area on BC concentrations		
Variable	**Linear Regression** BC-concentration (Avg: 306 µg/m³) (Rsq: 0.004, N=130237)	**Implications/practical meaning**
Kitchen height (1.75-3.75)	-300 (p<<0.001)***	For each m increase in kitchen height, the average black carbon measured not near the roof in kitchens decreases with 300 µg/m³
Kitchen area	-13 (p<<0.001)***	For each m² increase in kitchen area, the average black carbon measured not near the roof in kitchens decreases with 13 µg/m³
Significance codes: 0 *** 0.001 ** 0.01 * 0.05 ' 0.1 ' ' 1 Corrected for: values near the roof Excluded: HH26, because of very low near roof values.		

4.3.3. *Other polluting activities*

The ***preparation of coffee*** as a social activity is mostly done on a charcoal pot. In two living rooms (HH23 and HH34) where such a pot was used, I measured respectively 28 and 26 µg/m³. At two other households (HH06 and HH26), where it was done outside, I measured respectively 14 and 10 µg/m³ around the charcoal pot. Hence, I estimate the concentration being exposed to on average during a coffee moment about 20 µg/m³.

For the ***other uses of fire*** I have not obtained data. I expect it to have a relatively small influence, given the daily exposure that the people already encounter.

4.4. Possibilities to reduce accumulated exposure

What are local possibilities to reduce the accumulated household exposure to these BC and NO2 concentrations in Arba Minch?

As we now know both the relation between concentration variables and the concentrations, and the relation between exposure variables and the exposure, these effects can be translated into accumulated exposure.

Table 4.7 and Table 4.8 report the results from the findings in chapter three and four: for each variable the changeability and influence. Table 4.7 shows all variables discussed in relation to Black Carbon. As said in footnote a (page 5), I assume that for the ventilation and location variables, the effects on NO_2 are the same. Table 4.8 shows two emission variables studied for NO_2. Besides, one ventilation effect has been picked out to show both for BC and NO_2: the effect of a chimney. This is, because ventilation rates in a biogas kitchen were very low (see section 3.3.2) – hence for a biogas kitchen a chimney would decline NO_2-concentrations dramatically.

I have used the following assumptions to fill gaps in the knowledge needed to calculate accumulated exposure:

- The ratio between the measured black carbon and NO2 concentrations in the kitchen is equal to the ratio between BC and NO2 in other areas of the main building during cooking.
- The living room concentration during cooking equals the background concentration during cooking. Changes in the variables can never bring concentrations below the background cooking concentrations.
- A change of kitchen concentrations due to a change in an emission variable results in the same ratio of change for concentrations in other areas of the household.
- A change of kitchen concentrations due to a change in a transportation variable does not change the concentrations in other areas of the household.

The average of all no-roof concentrations is taken as the reference household. All deviations from that reference household per variable change for a full-time cooker (preparing breakfast, lunch and dinner, remaining time 50% in main building and 50% of time outside on the compound) and for a full-time non-cooker (50% of time in main building, 50% of time outside on compound) are reported. Appendix H shows the individual calculations.

Table 4.7: The changeability and influence on exposure to BC particles of all concentration and exposure variables

			Variable description	Changeable	Accumulated exposure cooker Hour µg/m³	Accumulated exposure non-cooker Hour µg/m³
			Reference household		540	205
Concentration variables	Emission variables	fuel material	Wood vs. biogas	SOME/ SUPPORT	117 (-78%)	117 (-43%)
			Wood vs. electricity	SUPPORT	117 (-78%)	117 (-43%)
			Wood vs. kerosene	NOT	145 (-73%)	117 (-43%)
			Wood vs. charcoal	NOT	140 (-74%)	117 (-43%)
			Wood vs. wood&dung	NOT	409 (-24%)	168 (-18%)
			Start-up materials vs. no start-up materials	NOT	540 (0%)	205 (0%)
			Rubber as start-up vs. other start-up materials	YES	1156 (+114%)	205 (0%)
		Fuel state	Lowland vs. highland	SUPPORT	No data	No data
			Wet wood vs. dry wood	NOT	3147 (+483%)	941 (+360%)
			Much wood vs. little wood (much is needed for injera preparation)	NOT	1405 (+160%)	449 (+119%)
		Fire place	Injera stove vs. no injera stove	SOME	No data	No data
			Fire place material	YES	540 (0%)	205 (0%)
			Fire place depth	YES	540 (0%)	205 (0%)
			Fire place dry vs. wet	NOT	540 (0%)	205 (0%)
	Ventilation variables	openings	Low vs. (1/2)high& (1/2)low openings	SOME	630 (+17%)	205 (0%)
			Mean opening (6.8m²) vs. 3rd quintile opening (9.6m²)	SOME	952 (+76%)	205 (0%)
			Chimney structure vs. no chimney structure	SUPPORT	278 (-49%)	205 (0%)
		orientation	Cross ventilation possible vs. not possible	SOME	540 (0%)	205 (0%)
			Opening in vs. not in wind direction	SOME	No data	No data
		Construction material	Roof material sealed vs. partially open	SOME	540 (0%)	205 (0%)
			Wall material sealed vs. partially open	SOME	540 (0%)	205 (0%)

	Location variables	Chimney on injera stove vs. no chimney on injera stove	SOME	210 (-61%)	205 (0%)
		Kitchen de-attached vs. attached from main building	SOME	551 (+2%)	227 (+11%)
		Distinct kitchen vs. no distinct kitchen	SUPPORT	601 (+11%)	469 (+129%)
		Outside cooking vs. inside cooking	NOT	No data	No data
Exposure variables	Cooking habits	2 vs. 1 persons are active in cooking	NOT	375 (-31%)	205 (0%)
	Kitchen specifics	Mean area ($9.9 m^2$) vs. 3rd quintile area ($12.8\ m^2$)	SOME/ SUPPORT	436 (-19%)	205 (0%)
		Mean height(2.8m) vs. 3rd quintile height (3.2m)	SOME/ SUPPORT	210 (-61%)	205 (0%)
	Other uses of smoke	Yes vs. no coffee ceremony	NOT	532 (-2%)	196 (-4%)
		Yes vs. no heating	NOT	No data	No data
		Yes vs. no use of smoke against mosquitos	NOT	No data	No data

Table 4.8: The changeability and influence on exposure to NO2 particles of fuel material and chimney for biogas

		Variable description	Changeable	Accumulated exposure cooker Hour µg/m³	Accumulated exposure non-cooker Hour µg/m³
		Reference household		2275	813
Concentration variables	Emission variables	Wood vs. biogas	SOME/ SUPPORT	2776 (+22%)	884 (+9%)
		Wood vs. electricity	SUPPORT	429 (-81%)	429 (-47%)
	Transportation variables	Wood vs biogas kitchen with chimney	SOME	694 (-73%)	884 (+9%)

5. Discussion

What are the local possibilities to reduce accumulated household exposure to black carbon (BC) and Nitrogen Dioxide (NO_2) in Arba Minch?

5.1. Main results

This study found much *variations* in *variable settings* of household, resulting in high variability of concentrations and accumulated exposure. However, the presence of this *variation* does not necessarily mean that there are *local possibilities* to reduce IAP.

Table 5.1 shows that there is a mismatch between *changeability* and *influence*: most variables that are changeable do not have a big *influence* on concentrations and exposure, while amongst the unchangeable variables there are a lot that have a high *influence* on the concentrations and exposure. In other words: there are no 'easy wins'[a]. This holds the positive implication that mostly, people do what they can to avoid exposure to smoke.

Table 5.1: Variables ordered by changeability. Variables with potentially large influence are not directly changeable.

YES	SOME	SUPPORT	NO
Other startup materials vs. rubber cooker: **-53%** (BC only) n-cooker: **-0%**	De-attached kitchen vs. attached kitchen cooker: **-2%** n-cooker: **-10%**	Wood vs. electricity cooker: **-78%** (BC), **-81**% (NO_2) n-cooker: **-0%** (BC), **-47%** (NO_2)	Wood vs. kerosene cooker: **-73%** (BC only) n-cooker: **-43%** (BC only)
Fire place material cooker: **-0%** (BC only) n-cooker: **-0%**	No chimney on injera stove vs. chimney on injera stove cooker: **-61%** n-cooker: **-0%**	No distinct kitchen room vs distinct kitchen room cooker: **-10**% n-cooker: **-56**%	Wood vs. charcoal cooker: **-74%** (BC only) n-cooker: **-43%** (BC only)
Fire place depth cooker: **-0%** (BC only) n-cooker: **-0%**	Low vs. (1/2)high&(1/2)low openings cooker: **-14%** n-cooker: **-0%**	No chimney structure vs. chimney structure in kitchen roof cooker: **-49%** n-cooker: **-0%**	Much vs. little wood cooker: **-62%** (BC only) n-cooker: **-54%** (BC only)
	Mean ($6.8m^2$) vs. 3th quintile ($9.6m^2$) openings cooker: **-43%** n-cooker: **-0%**		Wet vs. dry wood cooker: **-83%** (BC only) n-cooker: **-78%** (BC only)
	Cross-ventilation possible vs. not possible cooker: **-0%** n-cooker: **-0%**		Wood vs. wood & dung cooker: **-24%** (BC only) n-cooker: **-18%** (BC only)
	Roof material closed vs. Half opened cooker: **-0%** n-cooker: **-0%**		1 vs. 2 persons active in cooking cooker: **-31%** n-cooker: **-0%**
	Wall material closed vs. Half		Start-up materials vs. no start-up materials

[a] Except for the households using rubber as start-up material: stopping with that results in a 50% decrease of accumulated exposure and is possible according to the reasons.

	opened cooker: **-0%** n-cooker: **-0%**		cooker: **-0%** n-cooker: **-0%**
	Mean (9.9m^2) vs. 3rd quintile kitchen area (12.8 m^2) cooker: **-19%** n-cooker: **-0%**		Yes vs. no coffee ceremony cooker: **-2%** (BC only) n-cooker: **-4%** (BC only)
	Kitchen height 2.8m vs. 3.2m cooker: **-61%** n-cooker: **-0%**		
	Wood vs biogas without chimney cooker: **-81%** (BC), **+22%** (NO_2) n-cooker **-43%** (BC),**+9%** (NO_2)		
	Wood vs biogas with chimney cooker: **-81%** (BC), **-73%** (NO_2) n-cooker: **-43%** (BC), **+9%** (NO_2)		
Nb. The percentages mentioned are the percentages decrease in accumulated daily exposure to BC and NO_2 particles for a person. All variables on which I did not collect data are excluded from this table			

Yet, there are three areas where *local possibilities* are present:

- *Local possibilities* for some households. For example, those with an injera stove can implement an iron pipe as chimney structure (-62% in daily exposure for cooker). Or, those that not yet have openings connected to the roof, might implement some (-15%).
- *Local possibilities* if support is given by NGOs or the government. For example, support with some chimney structure where smoke can go out but rain cannot go in (-49%). Accumulated exposure for a non-cooker is reduced if the household is helped to obtain a distinct kitchen (-56%).
- *Local possibilities* for some, with support. For example, those that have enough space and cattle can be helped to obtain a biogas system (for the cooker -81% in BC, but +9% in NO_2) – best in combination with a chimney structure (-73% in NO_2).

To fill knowledge gaps in the accumulated exposure calculation, I have used assumptions. The assumption that a change in *ventilation variables* will not alter concentrations outside or in the main building, gives for a chimney on a biogas kitchen the following result: accumulated exposure is lower for the cooker than for the non-cooker. It is likely that altering *ventilation variables* will also alter the dispersion of particles across the household. A chimney structure releases pollutants at a high point, so they are probably transported away from the household faster, resulting also in a reduction for the non-cooker. Or, a change in the set of openings can alter the side where smoke leaves the kitchen, also altering the dispersion across the household.

5.2. Previous studies

Topics reviewed by this study were also studied in previous research.

Firstly, concentrations found in this study are comparable to those other studies found, such as a study in rural area of Bangladesh with average kitchen BC concentrations up to 244 µg/m^3 (Begum et al., 2009) or above one or two hours of exposure to PM2.5 concentrations above 250 µg/m^3, found inside Malawi homes (Fullerton et al., 2009). These are high concentrations – especially compared to concentrations measured in urban areas of the developed world (for example average indoor black carbon below 0.4 µg/m^3 in suburban Washington, measured during a two year study (LaRosa, Buckley, & Wallace, 2002)).

Contrarily to developed world situations, ambient concentration measurements do not reflect actual exposure (Begum et al., 2009; Tsai et al., 2000): most exposure is found within the household.

Secondly, other studies also found a high local spatial variability of the pollutant concentrations (Levy et al., 2000). Due to highly localized sources within the same room, concentration patterns are far from perfectly mixed (Drescher et al., 1995).

Thirdly, other studies are also focused on *variations* among households to look for *local possibilities* to reduce exposure to pollutant concentrations. Indicators of differences in concentrations are the household-specific *variable settings* (Dasgupta et al., 2006; Torres-Duque et al., 2008). Many studies mention the *influence* of fuel materials and stove combinations, but some studies also take into account the importance of *ventilation variables*. (Behera & Aggarwal, 2010; Dasgupta et al., 2006; Lee, Li, & Ao, 2002; Torres-Duque et al., 2008). While studies usually focus on some variables (only related to emission or ventilation) and their impact on concentrations, this study is innovative in its attempt to include all aspects that may *influence* both pollutant concentrations and the exposure to these concentrations. For better analysis, emission and ventilation rates are used as indicators of concentration. To my knowledge, this study is the first to quantify emission and ventilation rates in the context of IAP. Furthermore, the mismatch between the *changeability* of a variable and the *influence* of such a change on accumulated exposure, are not yet discussed and found in previous studies.

Fourthly, previous studies underline necessity of support from organizations and governments. Like this study shows that no easy wins can be made, Jerneck and Olsson (2013) mention that "…cleaner cooking technology will have to involve NGOs and government policy" (p. 213). According to Torres-Duque et al. (2008) solutions "involve the commitment and active participation of governments, scientific societies, nongovernmental organizations, and the general community." (p. 577) This was already evident for long run innovations such as a wide implementation of cleaner fuel materials. This study shows that support is also relevant for the changes that are already within *local capacities*. Edelstein et al. (2008) found in the Gondar region of Ethiopia that women are willing to change cooking practices, but were unable to afford cleaner fuels or improved stoves. This is the same for Arba Minch: quite some barriers can be overcome by (economic) support.

5.3. Wider implications

Tailored possibilities to reduce IAP

The complex and local nature of IAP requests an approach tailored to local conditions (Ezzati, 2005). Direct findings of this study hence only apply to Arba Minch. For example, the study by Dasgupta et al. (2006) in Bangladesh found a strong relation between kitchen and living area concentrations. For Arba Minch, this was generally not the case, as most households have a main building made from mud that conceals the living area from kitchen concentrations. It might well be that, while for Arba Minch local differences with substantial *influence* appear not very *changeable*, for other places more or other possibilities can be found. Or that changes that in Arba Minch are possible for some, are not at all possible in other places.

Methodological findings

This is not to say that this study only has practical relevance for the context of Arba Minch. With this study, I provide means to build further in different directions of research:

- In epidemiological studies, there is need of good exposure assessment tools (D. Fullerton, Bruce, & Gordon, 2008). As individual measurements are not feasible to estimate exposures of large populations, surrogate measures are required (Brauer & Saksena, 2002). Ambient concentrations do not serve as a good indication of exposure to IAP, and there is an ongoing discussion on what can be appropriate proxies (Baumgartner et al., 2011). Brauer and Saksena (2002) sum different exposure proxies, but stress that "…further validation work, including measurements of exposures in combination with measurements of surrogate variables, is needed" (p. 1159). I have evaluated different household variables combined with concentration measurements, and as such show possible proxies of household concentrations that are easy to measure. The study shows that the presence of openings close to the roof and background wind speeds are important denominators for ventilation rates. Emission rates are primarily influenced by fuel material, but the season indicates whether fuel is dry or wet. Dish type is a good indicator for the fire stage and the amount of fuel used, as well as the cooking time and the time near the fire. Additionally, concentrations within other areas of the household are determined by the place of the kitchen and the fire, and whether the main building is concealed from kitchen concentrations, or for example connected by a window. Information on each of these variables can be measured without costly instruments – most of it can even be obtained with a questionnaire.
- This study also shows the relevance of the study of everyday life practices around cooking. While the first objective was to find possible reductions that can be done *now*, these findings can also be incorporated in to the 'innovation trail' (Veen et al., 2011). The ongoing innovation process with respect to fuel and stove combinations should take into account the *local reasons*. For example, a stove might not be welcomed in Arba Minch households if it can be damaged by cattle. Also, it is not preferred if they are dependent on a distributor for some parts – for example for kerosene. Besides the lesson that reasons should be studied, this study offers a method to translate *local reasons* into *changeability,* by classifying reasons into habitual, external and volitional (attitude, norm and control) reasons.

6. Conclusion

What are the local possibilities to reduce accumulated household exposure to black carbon (BC) and Nitrogen Dioxide (NO_2) in Arba Minch?

In this chapter the main question of this study will be answered. This question was related to the following hypothesis:

Local possibilities to reduce exposure to BC and NO_2 household concentrations can be found in the *local capacities*.

The steps I followed to find an answer on the main question are as follows:

1. To find variables and their *variations*: i.e. to review the *local capacity*
2. To analyze the reasons that people have for particular *variable settings*: i.e. to test the *changeability* of these variables.
3. To test whether the variable is related with pollutant concentrations or exposure to these concentrations: i.e. by testing the *influence* of the variable on concentration or exposure.
4. These three elements: *capacity*, *changeability* and *influence* are requirements for a *local possibility* to reduce *accumulated household exposure* to BC and NO_2 concentrations.

The variables, their *changeability* and their *influence* are extensively reported in Table 4.7. Table 5.1 ordered them according to their *changeability*.

The fuel material (all 'wood vs.-variables') holds the largest *influence*, with possible reductions of 24-78% for cookers. Analysis of reasons for fuel choice, however, shows that shifting to a cleaner fuel mostly is not possible. Alike, an *exposure variable* like number of cooking persons results in substantial differences in *accumulated household exposure* (from 1 to 2 persons -31%), but is not *changeable*. On the other hand, variables in which shifts are possible, such as traditional fire place specifics, hold no significant *influence* on the concentrations.
In general it can be observed that the *changeable* variables are the ones with little *influence* and vice versa. This shows that people already do what they can, and that there are no *local possibilities* to reduce accumulated exposure for each household.

There are, however, *local possibilities* for some of the households, to reduce accumulated exposure (e.g. 43% with openings, for those that are in the ability to implement more openings, or 61% for those with an injera stove by implementing a stove chimney structure). Also, there are *local possibilities* to reduce exposure that can be achieved if an external entity, like the government or an NGO provides support (such as helping with access to electricity: -78%, or supporting with building a chimney structure on the kitchen: -49% for normal and -73% to NO_2 for biogas kitchens).

Accumulated household exposure is highest for the persons cooking. Hence, for them also most reductions can be achieved. Apart from changes in emission rates, reductions for non-cookers can be achieved by changing the place of cooking (for example -56% if the household moves the cooking from the living area to a distinct kitchen).

Our hypothesis cannot fully be falsified. There are *local possibilities* to reduce *accumulated household exposure* within the *local capacities*. However, these possibilities are only found for some of the households, or if support is provided.

7. Recommendations

In this chapter some final recommendations will be made for further research and ways to reduce local accumulated exposure to BC and NO_2 concentrations.

7.1. Further research

Due to the differences in measurement methods I was able to study BC concentrations more extensively than NO_2 concentrations. I could measure both BC and NO_2 for biogas cooking, which showed different outcomes, since the mechanisms to produce BC and NO_2 differ. Future research can study the *influence* of *concentration (especially emission) variables,* on NO_2 concentrations more extensively.

It is relevant to know the *influence* of the use of a charcoal pot on NO_2, since a charcoal pot is more often used close to non-cookers. A next step is to relate the NO_x (NO/NO_2) household concentrations to Ozone (O_3) household concentrations. Ozone is produced from a.o. NO_x[a], and hence high NO_2 concentrations might result in high O_3 production. O_3 is a particularly harmful pollutant.

In this study, the assumption is used that a change in *ventilation variables* influences the kitchen concentration, but does not change the concentrations in other parts of the household. Most likely, this assumption is not true. Further research can study how dispersion across the household is altered by changes in *ventilation variables*.

This study has been conducted in Arba Minch. IAP ultimately requires attention tailored to the *locality*. Hence, further research is needed across different countries and cultures, not only to find possible reductions for a particular *locality* at this moment, but also to acquire knowledge needed to tailor future interventions for that *locality*. Besides this, meta-research of the studies conducted in different localities can help to find the similarities in IAP amongst the diversity. Such research can work on a singular body of knowledge concerning common indicators of IAP (useful for epidemiological studies) and common reasons for household settings (useful to take into account for interventions).

7.2. Policy makers

In an earlier thesis I have developed the argument that governments according to the Human Rights Doctrine have an extensive set of duties regarding local air pollution (Dingemanse, 2012). An often used exception on these duties is the notion of *maximum of available resources*: research and implementation regarding newer fuels or stoves might exceed resource capacities. This study, however, shows measures that can be taken at this moment, with capacities already present. Besides economic support, findings from this study can also be included in house building guidelines and legislations. Findings of this study gives the local government of Arba Minch means to fulfil their duty regarding IAP.

The City Council can consider how access to electricity can be simplified. The Housing Department of Arba Minch City Council can include some IAP related guidelines in building requirements, such as openings near the kitchen roof and no connecting opening between kitchen and main building. Organizations promoting the injera stove can implement the iron pipe as chimney structure in the full package. Organizations promoting the biogas systems can include a chimney roof structure in the suggested installations. Organizations in other ways working on IAP reduction can orient their funds at helping those households that have

[a] Besides NO_x, also hydrocarbons and sunlight are needed in the production of O_3. For further information on O_3 production and health effects: see for example Brunekreef and Holgate (2002).

no distinct kitchen area to get one, and also to provide support in waterproofing kitchens and implement a chimney structure.

With this research, I have searched for reductions possible at this moment, based on the observations that fuel and stove interventions take time. I did find possibilities for this moment, especially for some households and with support of external entities like organisations or the government. However, I have also shown that people already do what they can. Hence, as a final recommendation, I wish to come back to the starting point: these long run interventions are needed nonetheless.

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Appendices

Appendix A: Household and Measurement overview. The table extending over the following two pages shows the different households visited, and the different measurements taken during these visits.

		Concerning the following measurements -->						CO_2	CO_2	BC	BC	BC	BC	BC	BC& Wind	BC& Wind	BC	BC	BC
HH	**Date**	**Measurement period**	**Diary**	**Roof**	**Wall**	**FP**	**T_{Fire}**	**Kitchen**	**Outside**	**People**	**Prep**	**Fixed**	**Main**	**Outside**	**Box model**	**Flux**	**Moving**	**Stationary**	**'One time'**
1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***
1	25-9	10:00 - 14:05	NO	I	W	H	NO	YES	YES	NO	NO	YES	YES	YES	-	-	-	R	-
2	27-9	10:15-13:00;15:50-16:20	NO	I	P	H	NO	YES	YES	YES	NO	YES	YES	YES	1	-	0	R	-
3	7-10	11:15-16:25	YES	I	PM	HI	NO	YES	YES	YES	NO	YES	YES	YES	3	-	0	-	-
4	9-10	10:30-14:00	YES	I	PM	HI	NO	YES	YES	YES	NO	YES	YES	YES	3	-	0	-	-
5	12-10	11:10-12:15	YES	I	P	B	NO	YES	YES	NO	NO	YES	YES	YES	-	-	0	-	-
6	14-10	11:05-12:40	YES	I	P	P	NO	YES	YES	YES	NO	YES	YES	YES	2	-	0	-	CH
7	16-10	10:50-15:00	YES	G	PM	H	YES	YES	YES	YES	NO	YES	YES	YES	3	-	K;O	-	CH
8	18-10	11:48-15:35	YES	I	PM	H	YES	YES	YES	YES	YES	YES	YES	YES	3	-	U	-	-
9	19-10	11:10-12:50	NO	G	PM	P	YES	YES	YES	YES	NO	YES	YES	YES	-	-	K;O	-	-
10	21-10	10:50-13:40	YES	I	PM	HI	YES	YES	YES	YES	NO	YES	NO	YES	3	-	K;KR	R	-
11	22-10	11:25-13:15	YES	I	O	P	YES	YES	YES	YES	NO	YES	NO	YES	-	-	-	-	-
12	25-10	10:30-11:55	NO	I	MP	HI	YES	YES	YES	No useful data: BC measurements on 1min frequency instead of 1second.									
13	26-10	12:00-16:40	NO	I	P	I	YES	YES	YES	YES	NO	NO	NO	YES	3	-	-	R;M	E;W
14	1-11	10:58-15:45	YES	I	P	P	YES	YES	YES	YES	NO	YES	YES	YES	1	-	U	R	-
15	3-11	15:50-18:50	YES	I	PM	I	YES	YES	NO	YES	NO	YES	YES	YES	3	-	U	-	-
16	4-11	10:45-12:30	YES	I	P	H	YES	YES	YES	YES	YES	YES	NO	YES	3	-	U	-	-
17	6-11	10:40-13:25	YES	I	PM	H	YES	YES	YES	YES	NO	YES	YES	YES	4	-	U	-	-
18	8-11	12:15-14:45	YES	I	PM	HI	YES	YES	NO	YES	NO	YES	YES	YES	-	-	U	-	-
19	9-11	10:50-12:20	YES	I	P	B	NO	YES	YES	YES	NO	YES	YES	YES	-	-	-	-	-
20	12-11	16:10-18:55	NO	I	PM	I	YES	YES	NO	YES	NO	YES	YES	YES	-	-	-	R;M	-
21	14-11	11:00-12:15	YES	I	PM	H	YES	YES	YES	YES	NO	NO	NO	YES	-	-	K	R	-
22	16-11	10:45-13:00	YES	I	PM	HI	YES	YES	YES	NO	YES	YES	YES	YES	3	-	K	R;M	-
23	16-11	19:55-22:20	NO	PB	PB	HI	YES	YES	NO	YES	NO	YES	YES	YES	3	-	U	-	LCH
24	19-11	11:00-13:40	YES	PB	PM	H	YES	YES	YES	YES	NO	YES	YES	YES	3	-	K;KR;KM	R	-
25	20-11	18:40-20:35	NO	B	O	H	YES	YES	NO	YES	NO	YES	YES	NO	-	D	K;KR	R	-
26	23-11	19:20-22:00	NO	I	WB	H	YES	YES	NO	YES	NO	NO	YES	YES	-	-	S;LD;KR	R	CH
27	26-11	10:30-12:20	YES	I	W	H	YES	YES	YES	YES	NO	NO	YES	YES	2	-	K;S	R	-
28	26-11	19:05-21:15	YES	I	P	H	YES	YES	NO	YES	YES	YES	YES	YES	3	-	K;S	R	-

29	28-11	10:40-12:25	YES	I	P	HI	YES	YES	YES	YES	NO	NO	YES	YES	2	-	S	R;M;S	-
30	28-11	18:40-20:25	YES	B	W	H	YES	YES	YES	YES	NO	YES	YES	YES	-	-	KM;KR	R	-
31	3-12	10:50-13:40	YES	B	P	HI	YES	YES	YES	YES	NO	YES	YES	YES	3	-	-	R;RO;M	-
32	3-12	19:45-22:15	NO	I	WP	H	YES	YES	NO	YES	NO	NO	YES	YES	2	-	S	R	-
33	5-12	12:25-14:20	YES	B	P	H	YES	YES	YES	YES	NO	YES	YES	YES	2	-	OR	R;S	-
34	5-12	18:55-20:55	YES	B	O	NA	YES	YES	NO	YES	NO	YES	YES	NO	-	D	-	R;M;S	CH;LCH
35	7-12	10:50-12:55	YES	PB	PB	HI	YES	YES	YES	YES	YES	YES	YES	YES	-	D;W	-	R;M;S	-
36	7-12	19:05-20:55	YES	I	P	HI	YES	YES	YES	YES	YES	YES	NO	YES	2	-	-	R;M;S	-
37	10-12	6:25-8:35	NO	I	B	I	NO	YES	YES	YES	NO	NO	NO	YES	**3**	-	-	R	-
38	11-12	17:40-21:00	NO	IB	B	H	YES	YES	NO	YES	NO	YES	YES	YES	-	D	-	R;M;S	-
39	14-12	11:55-13:15	YES	I	WP	H	YES	YES	YES	YES	NO	YES	YES	YES	-	D	-	R;S	-
40	14-12	19:40-21:25	YES	I	WP	H	YES	YES	YES	YES	YES	YES	YES	YES	-	W	-	R;S	-
41	18-12	20:00-22:10	YES	I	PM	H	YES	YES	NO	YES	NO	YES	YES	YES	-	D	-	R;M;S	-
42	19-12	19:40-22:00	YES	I	P	H	YES	YES	NO	YES	NO	YES	YES	YES	2	D	-	R;M;S	-

Explanation of columns:

1: *HH*: household number.

2: Date: date visited the household, year 2013.

3: Measurement period: the period between which the measurements are conducted.

4: Diary: weeksheet available. YES or NO.

5: Roof: material of the roof. I: Iron; IB: Iron and bamboo; PB: black plastic; B: bamboo; G: grass.

6: Wall: material of the walls. W: Wood; P: plaster; PM: muddy plaster; O: open; WB: Wood and bamboo; WP: Wood and plaster; PB: Plaster and bamboo.

7: FP: fire place type. H: Hole; HI: hole on increased height; P: pile of wood on the ground; B: biogas; I: injera stove

8: T_{Fire}: relative fire temperature measurements taken. YES or NO.

9: (CO_2) Kitchen: CO_2-measurements taken at a fixed place in the kitchen. YES or NO.

10: (CO_2) Outside: CO_2-measurements taken outside at the end of the measurement period. YES or NO.

11: (BC) People: Black carbon measurements taken close to the fire, where people are when they are cooking. YES or NO.

12: (BC) Prep: Black carbon measurements taken in the kitchen at the place where people are when they prepare food. YES or NO.

13: (BC) Fixed: Black carbon measurements taken in the kitchen at a fixed place above the fire (between 1.5-2 m high). YES or NO.

14: (BC) Main: Black carbon measurements taken in any of the rooms of the main building. YES or NO.

15: (BC) Outside: Black carbon measurements taken outside, during and/or after cooking. YES or NO.

16: (BC&Wind) Box model: Black carbon and wind measurements taken at different openings for box model calculations. #rounds.

17: (BC&Wind) Flux: Black carbon and wind measurements taken at an opening into the main building to calculate the flux. D: door; W: window.

18: (BC) Moving: Black carbon measurements taken while moving the sensor through a particular space. K: Kitchen round; KR: Kitchen round close to roof; KM: Kitchen round at middle level O: Outside round; OR: Outside close to roof round; S: Shifting measurement; U: Up-down measurement; LD: Round besides different living room doors.

19: (BC) Stationary: Black carbon measurements taken while holding the sensor(s) stationary for at least a minute. R: near roof; M: at middle height; S: simultaneous measurements; RO: near roof outside

20: (BC) 'One time': Some particular black carbon measurements taken when we encountered an interesting situation. CH: close to charcoal; E: close to electric; W: close to wetted fuel; LCH: in livingroom with charcoal.

Appendix B: Interview guide

Below the interview guide is shown as used within the households. During the research period, the interview changed. To show this, for each question is indicated at which households it is asked [between square brackets]. The colors of this indication gives further insight in the development of the interview.

Color legend: replaced/replacement||often skipped||evolved from new insights/better way of asking||~~deleted – apparently not relevant~~||simply always asked

Household number:___ **Family name:___**
Interview with:

FIRE

➔ Is the fire always in the same place? Why is the fire place in this place?
[HH01-HH27]

➔ At what times, and how long, is the fire on, approximately?

	Breakfast	*Lunch*	*Dinner*	*Other moment*
Monday				
Tuesday				
Wednesday				
Thursday				
Friday				
Saturday				
Sunday				

[HH01-HH02] --> Diary

➔ At which places is cooking conducted?
[HH28-HH42]

➔ Where are dishes like injerra or bread prepared?
[HH28-HH42]

➔ Is the fire used for other activities besides cooking?
[HH01-HH42]

➔ Which other sources with burning are used in this household, and how often approximately?
[HH03-HH42]

➔ Are there temporal differences (seasonal, or maybe something else)?
[HH01-HH42]

➔ Why is the kitchen constructed as it is? What do you like and dislike about it?
[HH09-HH42]

➔ Why this kind of fire place?
[HH25-HH42]

FUEL

➔ Which type of fuel are you using today?
[HH01-HH02]-->Diary

➔ Do you use other types of fuel at other times? If so, which and why?
[HH01-HH02]

➔ Which different types of fuel are used in this household?

[HH03-HH42]

➔ Where do you store your fuel? Do you have a dry place to store it?
[HH28-HH42][...]

➔ Why do you use this type of fuel?
[HH01-HH02]

➔ Why are these types of fuel used? (Answer per fuel type)
[HH03-HH42] [...]

➔ Where do you buy / collect your fuel? (answer per fuel type)
[HH01-HH42]

➔ How much do you spent (weekly/monthly/?) on fuel?
[HH14-HH42]

➔ If you had the means, would you like to use another fuel type? If so, which and why?
[HH01-HH42]

➔ Why have you not yet shifted to that fuel?
[HH21-HH42]

COOKING

➔ How are the cooking activities divided over the household members? (times cooking)
[HH01-HH02]-->Diary

➔ Who does the cooking in this household?
[HH03-HH42]

➔ Do men ever cook? Why (not)?
[HH05-HH42]

➔ Are you during cooking often near the fire? (Also observe, and ask whether it differs for other times)
[HH01-HH02]

➔ When does someone has to be close to the fire?
[HH03-HH42]

SMOKE

➔ Is there (often) smoke from the fire?
[HH01-HH42]

➔ When is smoke more intense? And when less? (eg during a certain dish, time, weather, circumstances, etcetera)
[HH01-HH42]

➔ Which things influence the amount of smoke, according to you?
[HH01-HH42]

➔ On scale 1 to 5, with 1 almost no influence and 5 very much influence, how intense to you think the following factors contribute to smoke production?

Explaining sentence: [HH27-HH42]

Fuel type:	1	2	3	4	5	[HH03-HH42]
Size of kitchen:	1	2	3	4	5	[HH03-HH42]

Doors and windows open:	1	2	3	4	5	[HH03-HH42]
Weather circumstances:	1	2	3	4	5	[HH03-HH13]
Rain:	1	2	3	4	5	[HH14-HH42]
Wind:	1	2	3	4	5	[HH14-HH42]
Place of opening:	1	2	3	4	5	[HH28-HH42]
Newness of fire place:	1	2	3	4	5	[HH09-HH42]
Depth of fire place:	1	2	3	4	5	[HH08-HH42]
Placing of fuel:	1	2	3	4	5	[HH18-HH42]

CONFOUNDERS

➔ Are there other sources of smoke at certain places where you come? (eg industry, cultural events, etcetera)
[HH01-HH42]

AWARENESS AND CHANGES

➔ Can you mention some positive and negative effects of smoke?
[HH01-HH42]

➔ Do you ever take measures to increase the smoke? Which measures? When and why?
~~[HH01-HH27]~~

➔ Do you ever take measures to reduce the smoke? Which measures? When and why?
[HH01-HH42]

➔ Do you know others that take measures to increase or decrease the smoke? Which measures? Why?
[HH01-HH42]

➔ Does the smoke bother you? If yes, in what way? Is it something you would want to reduce?
[HH01-HH42]

➔ What would be ways to reduce the smoke?
[HH01-HH42]
If the government organization would fund ideas for reduction, what would you do with that money?
[HH27-HH42]

➔ Have you heard of a catalyst to reduce cooking time? Do you use it? Why (not)?
[HH05-HH42]

➔ If you had the means, would you be willing to change …, if this would reduce exposure?
Cooking time: ~~[HH03-HH18]~~
Fuel type: ~~[HH03-HH18]~~
Cooking place: ~~[HH03-HH18]~~
Cooking device: ~~[HH03-HH18]~~
Taking often a new fire place: ~~[HH09-HH18]~~
Depth of fire place: ~~[HH09-HH18]~~

Appendix C: Diary

An Amharic translation of the below sheet was handed to the households and collected one week later by Tekalign. Tekalign showed the household how to fill out the sheet by filling out one day with them.

Family name: **Date:**

Please write on every day of the coming week the cooking activities of this household.
'other moment': you can indicate the moments of coffee making, or other fire activities.
Amount of fuel: for example the amount of sticks, or use words like 'few', 'normal', 'many'.
Thank you very much!

	Moment	Start Time	End time	Who is cooking, including % of time near fire	Fuel	Amount of fuel
Monday	Breakfast					
	Lunch					
	Dinner					
	Other moment					
Tuesday	Breakfast					
	Lunch					
	Dinner					
	Other moment					
Wednesday	Breakfast					
	Lunch					
	Dinner					
	Other moment					
Thursday	Breakfast					
	Lunch					
	Dinner					
	Other moment					
Friday	Breakfast					
	Lunch					
	Dinner					
	Other moment					
Saturday	Breakfast					
	Lunch					
	Dinner					
	Other moment					
Sunday	Breakfast					
	Lunch					
	Dinner					
	Other moment					

Appendix D: Observation sheet

Household number:___

People present during my stay:

Dish prepared:

Living room: mention anything of relevance

Kitchen: describe type and other things

Describe the fire place:

Further remarks (such as materials, and possible other relevant things):

Place of temperature plate:

Frequent observations:

Time	Fire state	Fire temp.	Participant	Remarks, activities

Appendix E: transcript of the Group Discussion

General information

Participants	*Normal fuel use*	*Remark*
Fanti Torora	Wood & Charcoal	HH1
Aster Ajeba	Wood & Charcoal	
Dodei Domba	Wood & Charcoal	gone earlier
Astatik Butoro	Wood & Charcoal	
Ynadam Amuna	Wood & Charcoal	
Meskalesha Debo	Wood & Charcoal	HH6
Sister Baturo	Wood & Charcoal	arrives later

Also: mother of Tekalign, father of Tekalign and friend of Tekalign.

Topic: cooking time and common dishes

Dishes with a short cooking time:

Posose with moringa; Kurkufa with moringa; Kita [thin bread]; Genfo [between solid and liquid – eaten with spoon; mostly with milk, and adding then flower, and a lot of butter]; Macaroni pasta; Firfer [prepared from injera, small pieces – only thing: preparing sauce]; Enkulale Tifse [egg dish – may be combined with injera or bread; eaten at Milkias]; Gomen with kita; Potato; Maize (not roasted); Aif (some product of milk) [milk is boiled; divided in liquid and solid; aif is the solid end product]

Dishes with a long cooking time

Chicken meat; Beef meat; Msrwat [sauce for injera; mrsw is the main ingredient]; Kinje (something rice like) – [gerst]; Posose with aringuade – [an ingredient; first boil the aringuade for a long time, then do the rest]; Nufru [aringuade with maize]; The total process of injera.

Topic: attention time and dishes

Not much attention needed

Potato (doesn't need any attention at all); Nufru; Maize (not roasted); Any food kinds that are already the end product, but only need some fire time.

Much attention needed

Coffee; Roasting maize; Enkulale Tifse; Genfo.

Topic: wood types

There is generally a distinction between wood from two places: highland and lowland. Wood from highland does not give much smoke, and wood from lowland gives a lot of smoke. [Tekalign adds information: if it is dense and white: it does not give much smoke. If there are holes or knots, it gives more smoke]

Even though the wood from the highland is not long enough seasoned, they prefer it; its density makes sure that it burns long. It is more costly than the lowland wood.

Topic: dry wood during rainy season

Mostly they try to store the wood. If that is not the case, and they get wet wood, they dry it on daytime. And if that is not possible, then they use it anyway, and add some flammable material.

Topic: kitchen preferences

Height: three meters and higher (the lowest point of the inclination 3 meters);

Area: four by four meters;

Without animals. They want a separate kitchen. It depends on the number of animals.

Openings: a window of one by two meters, and a door of 90 by 210 centimeters.

Roof material: iron roofing is preferred. One girl gives a reason for black plastic: she would prefer that as roof material, as its color is not influenced by the smoke.
Wall material: preferably plaster with animal waste. This is not so dense, so it leaves more openings. Also, it can be recycled.
Place on the compound: they want it detached from the main building; otherwise it might change the color etcetera of the living room.

Topic: outside cooking
Only bread is outside prepared; that is not a problem because the preparation method encloses the dish. For other dishes, especially related to oil and butter [and telba – also fat, mostly used for production of oil. When preparing telfa, and putted on the fire, it will be dispersed immediately], there is the phenomenon 'mitch'. All of them have experienced it.
Other reasons not to cook outside: things can enter the food, there is wind from all directions and the smell of the outcome is not always good.

Topic: possibilities to change the kitchen
[It seems Tekalign explains the chimney we observed as an example]
A major issue in Limat: low income. Some for example even have to cook outside; they would like a proper kitchen place, but it is not possible. For some, but not much, it might also be a case of knowledge – unawareness.

Topic: positive and negative sides of different fuel materials

Fuel	Positive	Negative
Wood	- Speed - Food cooked on wood is prepared well - Price and availability	- Smoke - The start-up is hard
Charcoal	- When started, it stays on - You can leave it. You can even put a dish on it through the night and in the morning it is still warm. - Food on charcoal is prepared slowly; this gives a good outcome	- It is hard to start [*starting it with wood*] - You need expertise to know about good charcoal
Electricity	- Speed - Less smoke - It does not change the color of the cooking instrument	- It may need high safety
Biogas	*They do not know enough about it*	*They do not know enough about it*
Butagas	- Especially suitable for single persons, eg students. It is moveable to any place you want, and the start up is easy	- You totally depend on the distributor; when it is not available, you cannot get it
Animal Waste	- It stays warm for long	- It gives a huge amount of ash, which is useless
Grass	- It is good material, highly inflammable	- It gives a lot of smoke

Topic: is money needed for solutions?
One of them tells: there are people living closer to the university campus, some staff residents; among their houses there clearly is less smoke. It is a business matter: they do not release smoke, because of investments made.

In some cases, it might be related to unawareness. For example, people just burning with rubber or plastic. However, mostly it is directly related to a lack of resources.

Appendix F: Measurement set-up of NO_2-measurements.

The below tables gives an overview of the different research goals and the related set-ups used for NO_2-measurements.

Date ('13)	HHN	Goal	Set-up
14-11	**18**	-Difference amongst individual badges -Difference within a kitchen	Three badges left and three badges right of the fire place; the three badges with same sampling time and same place
14-11	**21**		
19-11	**24**	Difference between fire and no-fire concentration	Three badges at the same place, one exposed during cooking time, one exposed before and during cooking time and one exposed during and after cooking time
21&22-11	**3**	-Difference across the roof -Difference between roof and normal level	Three badges at the roof level: in the back, middle and front of the kitchen. And two badges at normal level, left and right of the fire place.
21-11	**22**		
21-11	**8**		
21-11	**27**		
21-11	**4**	Difference across the kitchen at normal level	Four badges divided over the kitchen at normal level.
21-11	**6**		
23-11	**9**		
23-11	**29**		
21-11	**1**	NO2 in a livingroom	One badge at the roof level in the livingroom, two badges at normal level in the kitchen.
21-11	**5**		
21-11	**20**	NO2 during injera preparation	Three badges at normal level divided a kitchen in which injerra is prepared.
23-11	**2**	Horizontal and spatial variability; the direction of a 'plume'	A 'layer' of three badges (about 40 centimeters height in between the badges) above the fire place, and a layer close to an opening in the kitchen
23-11	**18**		
23-11	**NV1**	NO2 during cooking with canned gas	Three badges divided over a kitchen in which a canned gas stove is used
23-11	**5**	NO2 during cooking with biogas	Two badges divided over a kitchen in which a biogas stove is used, as well as one outside to control for other sources
23-11	**NV2**	NO2 during cooking with electricity	Two badges divided over a kitchen in which an electric stove is used
23-11	**16**	NO2 with only an outside source (charcoal pot)	Two badges at normal and one at roof level in a kitchen in which no cooking is conducted, but in front of it a charcoal pot is used

NB: the household number (HHN) refers to the numbers given to households when I have visited them for black carbon measurements. NV1 and NV2 are two kitchens that are not visited with these measurements.
NB2: 'normal level' is at a height between 1,5 and 2 meters.

Appendix G: Emission and Ventilation rates. The following three tables show (1) Emission values, (2) Ventilation values based on wind measurements and (3) Ventilation values based on calculations from either CO_2 or BC data.

HHN	E [µg/s]	E [µg/s]	E [µg/s]	E [µg/s]	Remarks	V1†: f_W internal	V2†: f_W vs f_{CO2}/f_{BC}	V3†: f_{in} vs f_{out}	V4‡: phys
***E**nr* -->	1	2	3	4					
HH02	407					-	1**	1*	*
HH03	22	40	81			-	3*	-	*
HH04	186[1,2]	428[1,3]	65[1,4]		1: Ignoring (high) F_{in}-concentrations; 2: F_{in}=12µg/s; 3: F_{in}= 199 µg/s; 4: F_{in}=40 µg/s	1,2*	NA	3*	-
HH06	2133[1]	93			1: Ignoring the concentration at the door - the fire place was practically in the door opening.	-	-	1**,2*	*
HH07	31[1]	16[1]	21[1]		1: f_{in} not known	2*,3*	2*,3**	-	-
HH08	265	270	61			-	NA	-	*
HH10	56[1]	56	13[2]		1:Assuming f_{Roof} equals f_{Door} and f_{Window}, and ignoring concentration at the door 2: f_{Roof} based on additional wind measurements. f_{Door} and f_{Window} for this case much smaller. This time f_{in} not zero (but 5 µg/s)	2*,3*	2,3*	-	*
HH13	788[1]	508[1]	107[1,2]		1: Simply taken W1:W3 as F_{in} and Door+Rooftop as F_{out} - though at all places there are high concentrations... 2: This lower concentration might be due to a wrong f_{out} - which is much lower than the measured fin. On the other hand does that f_{out} agree with f_{CO2}.	1,2*	3*	1**,2*	*
HH14	188					-	NA	1*	*
HH15	528	119	79			1,2,3**	1,2,3**	1,2*,3**	*
HH16	82[1]	37[2]	56[1]	68[1]	1: Assuming f_{door} as the correct f; 2: Assuming $f_{W1:W3}$ as correct	2,3,4*	2,3,4*	2*	*
HH17	32	85	5	142		2,4**	4*	4**	-
HH22	209	72	72			2,3*	1,2*,3**	1**	*
HH23	213[1]	94[1]	20[1]		1: Difficult to distinguish f_{in}/f_{out}	1,2**	NA	1*,3**	-
HH24	23	47	9			-	2,3*	1,2*,3**	-
HH27	1	3				1,2*	NA	1,2*	-
HH28	12[1]	5[2]	9[1]		1: Possibly underestimation due to vertical air movement. However, f_{in} unknown 2: Possible underestimation due to vertical air movement; however, f_{in} already too low	1,2,3*	-	2*	*
HH29	68[1]	14			1 Concentration at door ignored	-	-	-	-
HH31	201	411	9			1*,2*	1*	-	-
HH32	51	81				-	NA	1,2*	*
HH33	33	26				-	1,2*	-	-
HH36	93[1,2]	136[2]			1 High concentration at door ignored; 2: $f_{Chimney}$ calculated (assumed to fill gap) rather than measured	-	NA	-	-
HH42	21	16				1,2*	1,2**	-	*

†: Validation: within range of 50% (*) or 10% (**) of the minimum value with the value(s). V1: f_w vs other f_w; V2: f_w vs f_{CO2} or f_{BC}; V3: f_{in} vs f_{out}.

‡: Validation V4: no hidden or unmeasured openings (*); see section **Error! Reference source not found.**.

HHN	**f_W [m3/s]**	**f_W [m3/s]**	**f_W [m3/s]**	**f_W [m3/s]**	**Remarks**	**V1†: f_W internal**	**V2†: f_W vs f_{CO2}/f_{BC}**	**V3†: f_{in} vs f_{out}**	**V4‡: phys**
f_{NO} -->	**1**	**2**	**3**	**4**					
HH02	0.12[1]	0.21			1: If we combine window and roof, and take door as unknown	-	1,*2**	2*	*
HH03	0.15	0.27	0.47			-	3*	-	*
HH04	0.66[1]	0.99[2]	0.58[3]		1: fin is 1.31; 2: fin is 2.03; 3: fin is 0.74;	1,2*	NA	3*	-
HH06	1.01	1.63[1]			1: A*u of door (Fin) reduced to close the gap	-	-	1**,2*	*
HH07	0.08	0.32	0.27			2,3*	2*,3**	-	-
HH08	0.24[1]	0.52[1]	0.1[1]		1: Weighing of fW3 and fW4 by 50%: we might have measured the same wind there;	-	NA	-	*
HH10	0.12[1]	0.253[1]	0.214[2]		1: Assuming fRoof equals fDoor+fWindow; 2: Based on additional wind measurements; the average of three rounds, σ=0.12	2,3*	2,3*	-	*
HH12	0.91[1]	0.8[1]			1: Simply half the sum;	1,2*	-	-	*
HH13	1.96	1.44	0.36[1]		1: f_{in} is 1.4 m3/s;	1,2*	3*	1**,2*	*
HH14	0.22[1]	0.378	0.67[1]		1: No Rooftop measurements;	-	NA	2*	*
HH15	0.29	0.32	0.3			1,2,3**	1,2,3**	1,2*,3**	*
HH16	0.46[1]	0.21[2]	0.15[3]	0.18[1]	1: Very low W1 through W3 wind measurements; taken f_door here; 2: f_{out}: 16_3=f_{in}; 3: f_{in}: 16_2=f_{out}	2,3,4*	2,3,4*	2*	*
HH17	0.8	0.17	0.41	0.154		2,4**	4*	4**	-
HH22	0.16	0.27[1]	0.24[2]		1: f_{in}=0 m3/s; 2: f_{in}=0.11 m3/s;	2,3*	1,2*,3**	1**	*
HH24	0.45	0.23	0.12			-	2,3*	1,2*,3**	-
HH27	0.22	0.27				1,2*	NA	1,2*	-
HH28	0.07[1]	0.05	0.09[1]		1: f_{in} unknown	1,2,3*	-	2*	*
HH29	0.52	0.15				-	-	-	-
HH31	0.46[1]	0.47[1]	0.38[1]		1: Wind through roof opening not measured – assumed it equal to f_{in} of door and window combined	1,2**,3*	1*	-	-
HH32	0.27	0.52			1: f_{in} = 0.37 m3/s;	-	NA	1,2*	*
HH33	0.27[1]	0.17[1]			1: All measurements assumed f_{out}: f_{in} unknown;	1,2*	1,2*	-	-
HH36	0.26[1]	0.62[1]			1: Not measured $f_{chimney}$: assumed that one to fill the gap;	-	NA	-	-
HH42	0.1[1]	0.13[1]			1: f_{in} unknown;	1,2*	1,2**	-	*

†: Validation: within range of 50% (*) or 10% (**) of the minimum value with the value(s). V1: f_w vs other f_w; V2: f_w vs f_{CO2} or f_{BC}; V3: f_{in} vs f_{out}.

‡: Validation V4: no hidden or unmeasured openings (*); see section **Error! Reference source not found.**.

HHN	f_{CO2} [m3/s]	f_{CO2} [m3/s]	f_{CO2} [m3/s]	f_{BC} [m3/s]	f_{BC} [m3/s]	f_{BC} [m3/s]	f_{BC} [m3/s]	Remarks	V1†: f_{BC}/ f_{CO2} vs f_W	V2†: internal	V3†: f_{BC} vs f_{CO2}
f_{No} -->	1	2	3	4	5	6	7		VALIDATION	VALIDATION	VALIDATION
HH02	0.17			0.22					1*,4**	NA	1,4*
HH03	0.1			0.38[1]				1: Had to add the negative values to make it all positive	1,4*	NA	-
HH05	0.08								NA	NA	NA
HH06	0.08[1]	0.23						1: Much lower than the wind measurements: variability in ventilation	-	-	NA
HH07	0.25	0.094		0.38	0.684				1**;2,4*	-	-
HH09	0.06	0.052							NA	1,2*	NA
HH10	0.49			0.166	0.619	0.252[1]	0.305	1: Filter change in between	4,7*;6**	6,7*	1,5*
HH12				0.055	0.26				-	-	NA
HH13	0.3[1]							1: Not used in analyses, as it is within 50% range of f_{max} (see section 2.3.4)	1*	NA	NA
HH15	0.05	0.293							2**	-	NA
HH16	0.16	0.384		0.114	0.098				1**;2,4*	4,5*	1,4*
HH17	0.12								1*	NA	NA
HH19	0.10[1]							1: Much higher than the measured wind speeds. Possibly not well-mixed conditions. We measured only f_{window}=0.012 m3/s;	NA	NA	NA
HH20				0.865[1]	0.746[1]			1: Based on non-averaged values; probably not ventilation, but offset...;	NA	4,5*	NA
HH21	0.15	0.227							NA	1,2*	NA
HH22	0.21			0.226					1*;4**	NA	1,4**
HH24				0.165					4*	NA	NA
HH28				0.126[1,2]	0.169[1,3]			1: based on shifting measurements during an event of high smoke. No background correction; 2: At K_Roof; 3: At K_People;	-	4,5*	NA
HH29				1.096[1]	0.295[2]	0.437[2]		1: At K_People; 2: At K_Roof;	6*	5,6*	NA
HH31				0.128					-	NA	NA
HH33	0.91			0.224[1]	0.28[2]			1: At K_People; 2: At K_Fixed;	4*;5**	4,5*	-
HH35	0.40			0.717[1]				1: At K_People;	NA	NA	-
HH38	0.23[1]	0.055	0.148					1: Linked to the moment that the fire goes out due to water boiling over. Probably best representative of 'no source';	NA	-	NA
HH39	0.20			0.321[1]				1: The measurement period has been chosen very arbitrarily. Also: not well-mixed because of only a short peak.	NA	NA	-
HH40	0.27			1.545[1]	0.672[1]	0.55[2]		1: Based on a peak, rather than a steady decline; 2: Based on a peak, but in the graph the decline at least seems somewhat more steady;	NA	5,6*	-
HH41				1.277[1]	0.379[2]	3.115[3]		1: At K_Beam; 2: At K_People, over a longer period than 41_6; 3: At K_People, over a shorter period than 41_5	NA	-	NA
HH42	0.08			0.172[1]	0.101[1]	0.134[2]	0.106[2]	1: At K_People; 2: At K_Fixed;	1,4*;5,6,7**	5,7**; 5,6,7*; 4,6*	1,5,7*

†: Validation: within range of 50% (*) or 10% (**) of the minimum value with the value(s). V1: f_{CO2} or f_{BC} vs f_W; V2: different f_{CO2} or f_{BC} comparable to each other; V3: f_{CO2} and f_{BC} comparable to.

Appendix H: Calculation of accumulated exposure

In order to calculate accumulated exposure, I have used the following two formulas.

Cooker:

$C_{kitchen,cooking}*T_{Attention}+C_{Kitchen,start-up}*T_{Start-up}+(C_{outside,cooking}+C_{Main,cooking})*0.5*T_{NoAttention}+C_{coffee}*T_{coffee}+C_{Background-cooking}*(T_{Background-cooking}-T_{HH-cooking})+C_{Background}*T_{Background}$

Non-cooker:

$(C_{Outside,cooking}+C_{Living,cooking})*0,5*T_{HH-cooking}+C_{coffee}*T_{coffee}+C_{Background-cooking}*(T_{Background-cooking}-T_{HH-cooking})+C_{Background}*T_{Background}$

The tables below H1 through H3 explain the different parts of the formula, and show the values used and the calculations conducted for each of the concentration and exposure variables. Only the variables for which there was a change, are shown (e.g. wall material is left out). The values and calculations are based on the relations found in this study. The gaps of knowledge have been filled with the following assumptions:

- The ratio between the measured black carbon and NO2 concentrations in the kitchen is equal to the ratio between BC and NO2 in other areas of the main building during cooking.
- The living room concentration during cooking equals the background concentration during cooking. Changes in the variables can never bring concentrations below the background cooking concentrations.
- A change of kitchen concentrations due to a change in an emission variable results in the same ratio of change for concentrations in other areas of the household.
- A change of kitchen concentrations due to a change in a transportation variable does not change the concentrations in other areas of the household.

Table H.1: The different parts of the accumulated exposure formulas, and the values used in the reference case.

Part of formula	**Explanation**	**Reference value**	
		BC	NO_2
$C_{kitchen,cooking}$	Concentration exposed to (CET) in the kitchen during cooking	156 μg/m^3	680 μg/m^3
$C_{Kitchen,start-up}$	CET in the kitchen during start-up	156 μg/m^3	680 μg/m^3
$C_{outside,cooking}$	CET outside during cooking	60 μg/m^3	262 μg/m^3
$C_{Main,cooking}$	CET in main building during cooking	24 μg/m^3	105 μg/m^3
$C_{Living,cooking}$	CET in the living room during cooking	12 μg/m^3	52 μg/m^3
C_{coffee}	CET during coffee making	20 μg/m^3	n.a.
$C_{Background-cooking}$	CET during the time cooking is conducted by other households	12 μg/m^3	52 μg/m^3
$C_{Background}$	CET during all other moments of the day	3 μg/m^3	11 μg/m^3
$T_{Attention}$	Time close to the fire during cooking	2.5 hr	
$T_{Start-up}$	Time taken by start-up of the fire	0.25 hr (5 minutes * 3 cooking moments)	
$T_{NoAttention}$	Time spent at another place than close to the fire during cooking	0.92 hr	
$T_{HH-cooking}$	Time spent in total on cooking in the household (equals $T_{Attention}+T_{Start-up}+T_{NoAttention}$)	3.67 hr	
T_{coffee}	Time spent on coffee preparation	0.5 hr	
$T_{Background-cooking}$	Time that cooking by other households resulting in $C_{Background-cooking}$ is conducted	4 hr	
$T_{Background}$	All remaining time	19.5 hr	

Additional values, used in the calculations of the influence of the variable changes (Tables H.2 and H.3): E_{Wood}=127 μg/s; $E_{Kerosene}$=103 μg/s; E_{Dung}=28 μg/s; E_{Rubber}=2133 μg/s; E_{Injera}=362 μg/s; u_{low}=0.19 m/s; $u_{high/low}$=0.23 m/s
f_{ref}=0.35 m^3/s; $f_{opening}=f_{ref}+0.12*(9.6-6.8)$ m^3/s; $f_{chimney}=f_{ref}+0.55$ m^3/s

Table H.2: The changes conducted for each of the variables in relation to Black Carbon.	
Wood vs. biogas	$C_{kitchen,cooking}$ & $C_{outside,cooking}$ &$C_{Main,cooking}$ = $C_{Background-cooking}$. $T_{HH-cooking}$ = 2.2 hr, $T_{Attention}$ =100%*$T_{HH-cooking}$. $T_{Start-up}$=0 hr.
Wood vs. electricity	$C_{kitchen,cooking}$ & $C_{outside,cooking}$ &$C_{Main,cooking}$ = $C_{Background-cooking}$. $T_{Start-up}$=0 hr.
Wood vs. kerosene	$C_{kitchen,cooking}$ & $C_{outside,cooking}$ &$C_{Main,cooking}$ = $C_{Background-cooking}$. $C_{Start-up}$ multiplied with ($E_{Kerosene}$/E_{Wood})
Wood vs. charcoal	$C_{kitchen,cooking}$ & $C_{outside,cooking}$ &$C_{Main,cooking}$ = $C_{Background-cooking}$. $C_{Start-up}$=60 µg/m^3. $T_{Start-up}$=10 min * 3 moments.
Wood vs. wood&dung	$C_{kitchen,cooking}$& $C_{Kitchen,start-up}$& $C_{outside,cooking}$ &$C_{Main,cooking}$ &$C_{Living,cooking}$ multiplied with ((0.5*E_{Wood}+E_{Dung})/E_{Wood})
Rubber as start-up vs. other start-up materials	$C_{Start-up}$ multiplied with (E_{Rubber}/E_{Wood})
Wet wood vs. dry wood	$C_{kitchen,cooking}$& $C_{Kitchen,start-up}$& $C_{outside,cooking}$ &$C_{Main,cooking}$ &$C_{Living,cooking}$ multiplied with (1368/208)
Much wood vs. little wood	$C_{kitchen,cooking}$& $C_{Kitchen,start-up}$& $C_{outside,cooking}$ &$C_{Main,cooking}$ &$C_{Living,cooking}$ multiplied with (E_{Injera}/E_{Wood})
Low vs. (1/2)high& (1/2)low openings	$C_{kitchen,cooking}$& $C_{Kitchen,start-up}$ multiplied with ($u_{high/low}$/u_{low})
Mean opening (6.8m^2) vs. 3rd quintile opening (9.6m^2)	$C_{kitchen,cooking}$& $C_{Kitchen,start-up}$ multiplied with ($f_{opening}$/f_{ref})
Chimney structure vs. no chimney structure	$C_{kitchen,cooking}$& $C_{Kitchen,start-up}$ multiplied with (f_{ref}/ $f_{chimney}$)
Chimney on injera stove vs. no chimney on injera stove	$C_{kitchen,cooking}$& $C_{Kitchen,start-up}$=36 µg/m^3
Kitchen de-attached vs. attached from main building	C_{Main}=49 µg/m^3; C_{Living}=24 µg/m^3
Distinct kitchen vs. no distinct kitchen	C_{Main}&C_{Living}=$C_{Kitchen,cooking}$
2 vs. 1 persons are active in cooking	$T_{attention}$ and $T_{NoAttention}$ reduced by half.
Mean area (9.9m^2) vs. 3rd quintile area (12.8 m^2)	Subtracted ((12.8-9.9)*13) from $C_{kitchen,cooking}$& $C_{Kitchen,start-up}$
Mean height (2.8m) vs. 3rd quintile height (3.2m)	Subtracted ((3.2-2.8)*300) from $C_{kitchen,cooking}$& $C_{Kitchen,start-up}$
Yes vs. no coffee ceremony	T_{Coffee}=0, $T_{Background}$=20

Table H.3: The changes conducted for the variables that are different for NO_2.	
Wood vs. biogas	$C_{kitchen,cooking}$& $C_{Kitchen,start-up}$& $C_{outside,cooking}$ &$C_{Main,cooking}$ &$C_{Living,cooking}$ multiplied with (1683/1008). $T_{HH-cooking}$ = 2.2 hr, $T_{Attention}$ =100%*$T_{HH-cooking}$. $T_{Start-up}$=0 hr.
Wood vs. electricity	$C_{kitchen,cooking}$ & $C_{outside,cooking}$ &$C_{Main,cooking}$ = $C_{Background-cooking}$. $T_{Start-up}$=0 hr.
Wood vs biogas kitchen with chimney	$C_{kitchen,cooking}$& $C_{Kitchen,start-up}$ from biogas situation multiplied with (0.1/(0.1+0.55)). Rest same as biogas situation.