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Household Air Pollution in a Changing Tibet:
A Mixed Methods Ethnography Amidst Particulate Matter and Black Carbon

By

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By

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2011

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2015

Abstract

Household Air Pollution in a Changing Tibet:
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By Steve Sclar

Background: Household air pollution (HAP) has recently been deemed the number one environmental health risk in the world, responsible each year for 4.3 million deaths globally and 420,000 in China. Tibetan regions of China are well known for pristine ambient air, but several recent studies have concluded that the indoor air quality in Tibetan homes is compromised. Yet these studies — like most HAP studies conducted globally — do not provide a clear picture of the complex socio-contextual ecosystem within which the indoor air becomes polluted. The sociology of Tibet is changing — some might say 'developing' — rapidly due to a variety of forces, and this study sought to holistically understand HAP in relation to these changes.
Methods: We took 28 measurements of fine particulate matter ($PM_{2.5}$) and black carbon (BC) in a variety of Tibetan dwellings in the Golog Tibetan Autonomous Prefecture. A semi-structured interview was also administered with residents to gain a sense of household behaviors and attitudes. Most importantly, ethnographic participant-observation was undertaken in order to gain 'thick' understandings of HAP in the Tibetan context.
Results: We measured very high concentrations of $PM_{2.5}$ across all residential sites. The highest concentrations were found in the traditional yak hair tent, but nomads living in plastic tarp tents with improved stoves and stovepipes also had very compromised indoor air quality. The air in sedentary homes with improved stoves and stovepipes was only marginally better than tarp tents. All of the nomads in this study said they would prefer to use a fuel other than yak dung. More nomads expressed concern about climate change than HAP, and indoor trash burning was seen at all sites.
Conclusions: HAP is certainly a cause for concern in Tibet, and several actors across various sectors are pursuing interventions. This study highlights the convoluted reality of HAP in Tibet and suggests that current 'development' trends are not adequately mitigating the issue. Lifestyles and attitudes in Tibet are in flux, and it will be crucial for HAP interventions to be community-based and community-driven in order to be successful.

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Chapter 1. Background

Household air pollution remains a significant public health concern. In 'underdeveloped' settings especially, the combustion of 'traditional' and transitional fuel sources for cooking and heating inside the home is viewed by international development agencies as a problem in need of a solution. A growing body of research from the Tibetan plateau has found that household air pollution (HAP) is commonly present at hazardous levels inside Tibetan homes. National and multinational stakeholders from various sectors are increasingly interested in solving the problem of Tibetan HAP. This thematic literature review will explore the multifaceted aspects of this topic.

Household air pollution

History

The World Health Organization (WHO) has deemed air pollution to be the gravest environmental health risk, and most of the attributable mortality is the result of indoor air pollution. In 2014, the WHO released the first guidelines on household air pollution, but this is not a new problem. According to the WHO, the response has been "historically slow, under-funded and marked by ineffective and/or unsustainable interventions...extending back for at least 30-40 years" (WHO, 2014). HAP emerged on the radar of major development agencies in the 1980s when there was concern that the world's poor were using biomass resources at unsustainable rates. Thus, resource conservation was the driving concern. In the 1990s, researchers began to measure the indoor pollution and ascertain its effects on inhabitants' health. Since then a plethora of studies has confirmed HAP to be a significant problem especially in rural and low-income settings. In the last 5-

10 years, climate change has sparked renewed interest from researchers seeking to understand greenhouse gas emission contributions from these households (Bank, 2011).

Health effects

Several disease burdens associated with HAP are well known by this point, even as more and more associations are still being studied. Po et al. (Po, FitzGerald, & Carlsten, 2011) conducted a systematic review and meta-analysis of 25 studies from 13 countries and found significant associations between domestic solid biomass fuel exposure and many disease outcomes: chronic bronchitis, asthma, acute respiratory infections, acute lower respiratory infections and chronic obstructive lung disease.

HAP is notable for its persistence near the top of the Global Burden of Disease (GBD) list. It's also notable for the sex disparity in its health effects. In 1990, HAP was the second most deleterious risk factor globally, but when disaggregated by sex HAP was number two for women and number three for men. By 2010, HAP fell to number four globally, but the burden-by-sex diverged further -- HAP remains the number two risk factor overall for women but fell to the fifth position for men (Lim, 2012). In a world characterized — on a coarse scale — by the transition from communicable to non-communicable disease burdens, HAP's role in this shift also indicates intricacies in its relation to a diversity of disease outcomes. While communicable diseases associated with HAP (i.e. lower respiratory infections) fell considerably in the two-decade interval, associated non-communicable diseases (i.e. cardiovascular diseases) grew in relative and absolute dimensions (Lim, 2012).

Despite the known associations between HAP and several disease outcomes, studies have yet to find conclusive health benefits derived from interventions (Rosenthal, 2015). The best regarded study — a randomized control trial (RCT) from Guatemala — showed a significant but relatively modest decrease in respiratory infections when improved vented stoves were used in the house. Yet RCTs are rare in this field, and results are mixed elsewhere (Kirk R Smith et al., 2006). This topic will be explored further at the end of this literature review.

$PM_{2.5}$

Many researchers and the WHO consider $PM_{2.5}$ (fine particulate matter with an aerodynamic diameter of 2.5 microns or less) to be the "key pollutant for which health risk is evaluated" (WHO, 2014). It has been linked to many disease outcomes (Lim, 2012; Pope et al., 2004). The Integrated Scientific Assessment for $PM_{2.5}$ published by the U.S. EPA in 2009 has deemed short-term exposure to be "causal" with regard to cardiovascular effects and mortality, and "likely to be causal" with regard to respiratory effects. Long-term exposure indicates the same, in addition to being "suggestive of a causal relationship" with regard to reproductive and developmental effects as well as cancer, mutagenicity and genotoxicity (EPA, 2009).

The concentration standards for $PM_{2.5}$ are not consistent around the world. The U.S. EPA lowered the 24-hour average standard from 65 $\mu g/m^3$ to 35 $\mu g/m^3$ in 2006. The WHO has set a 24-hour average standard at 25 $\mu g/m^3$ with interim targets set at 75, 50 and 37.5 $\mu g/m^3$ (WHO, 2005). The WHO's 2014 guidelines on HAP did not set a new concentration standard, but rather put forth a new emission rate standard of 0.23 mg/min for unvented combustion and 0.80 mg/min for vented combustion. These emission rates are intended to meet the WHO's interim target for average *annual* $PM_{2.5}$ exposure — 35 $\mu g/m^3$ (WHO, 2014).

The dose-response curve of $PM_{2.5}$ exposure has not been definitively established. Most studies that have looked at dose-response curves have examined only ambient exposures or firsthand tobacco smoking exposure. The ambient studies suggest linear dose-response curves, but maximum exposures never exceed a relatively modest 100 $\mu g/m^3$ (Dominici, Daniels, Zeger, & Samet, 2002;

Schwartz, Coull, Laden, & Ryan, 2008; Schwartz, Laden, & Zanobetti, 2002). The tobacco study suggests a dose-response curve that begins plateauing below 60,000 $\mu g/m^3$ (Pope et al., 2009). Burnett et al. (Burnett et al., 2014) combined data from ambient pollution, active smoking, secondhand smoke, and household pollution to fit an integrated exposure-response model. Their results varied depending on the disease outcome, with plateauing evident for ischemic heart disease and stroke, but a linear response evident for stroke and lung cancer even up to concentrations of 55,000 $\mu g/m^3$.

Black Carbon

Black carbon (BC) is a particular species of $PM_{2.5}$ that has attracted significant attention in recent years due to its climate forcing characteristics. It is most commonly the byproduct of incomplete combustion of carbon-based fuels (Andreae & Crutzen, 1997). One reason BC is considered hazardous to health is its tendency to absorb and transport toxic compounds such as polycyclic aromatic hydrocarbons (PAHs) (Ni et al., 2014). Most studies of BC emissions in relation to $PM_{2.5}$ emissions have occurred in the U.S. and Europe with variable results (Brown et al., 2008; Hoek et al., 2008; Jacquemin Leonard, 2007; Janssen et al., 2000; Sarnat, Coull, Ruiz, Koutrakis, & Suh, 2006). A meta-analysis has shown BC to be significantly associated with cardiovascular diseases, and cohort studies showed that BC was associated with all-cause mortality 5-14 times more strongly than $PM_{2.5}$ (WHO, 2012).

BC has been called the second-most important anthropogenic contributor to climate change after CO_2 due to its forcing abilities (Ramanathan & Carmichael, 2008; Shrestha, Traina, & Swanston, 2010). It is climate change that has put BC on the agenda such that the U.S. EPA submitted a 388-page report about the species to the U.S. Congress (EPA, 2012). BC has also been implicated in the melting of glaciers, including the Himalayas, through its deposition (Ramanathan & Carmichael, 2008; Xu et al., 2009). There is a concern that melting Himalayan glaciers (the third-largest snowpack in the world after Antarctica and the Arctic) could jeopardize the reliability of freshwater sources for billions of people downstream (Carmichael et al., 2009).

Increasingly, there is interest in the contribution of rural households to global BC emissions in order to build better climate models and predict future warming. It is estimated that 18% of BC emissions globally comes from residential biomass burning (Bond et al., 2004) and 40% of BC emissions in China comes from rural-residential biomass burning (Ni et al., 2014).

The Tibetan context

HAP studies in Tibet

To date there have been six studies that have measured HAP in Tibet. All of these studies were conducted in the Tibetan Autonomous Region (TAR), a province level division of China. Five of these studies were conducted in a population of nomads around Namtso Lake north of Lhasa, the capital of Tibet (Chen et al., 2011; Kang, Li, Wang, Zhang, & Cong, 2009; Li, Kang, Chen, Zhang, & Fang, 2012; Chaoliu Li et al., 2012; Xiao et al., 2015), and the other study was conducted in agricultural populations south of Lhasa (Gao et al., 2009). Kang et al. (Kang et al., 2009) measured total suspended particulate matter (TSP) in a pilot study of 13 samples from two tents. They recorded daily TSP averages of 3,160 $\mu g/m^3$ and also found presence of toxic elements cadmium, arsenic and lead. Li et al. (Chaoliu Li et al., 2012) conducted personal $PM_{2.5}$ monitoring and carbon monoxide (CO) measurements in 9 tents. They found a daily average $PM_{2.5}$ concentration across all study sites to be 1,420 $\mu g/m^3$. Li et al. (C. Li et al., 2012) measured trace metals and PAHs within four tents and found them to be "seriously polluted." Chen et al. (Chen et al., 2011) measured $PM_{2.5}$ and CO in Tibetan tents. They recorded daily average $PM_{2.5}$ concentrations of 1,272 $\mu g/m^3$ in homes without stovepipes and 97 $\mu g/m^3$ in homes with stovepipes. This study concluded, "although the outdoor air in the Tibetan Plateau is very clean, the air of the Tibetan tents are seriously polluted and mainly caused by yak dung combustion." Xiao et al. (Xiao et al., 2015) conducted a survey and measured $PM_{2.5}$ and BC in six households, finding 6-hour average concentrations ranging from 42.95—1530 μg/m^3 and 0.52—24.28 μg/m^3, respectively. Gao et al (Gao et al., 2009) conducted a questionnaire and measured $PM_{2.5}$ daily averaged at several points around the home. They found the highest concentrations in the kitchen (134.91 μg/m^3) and the lowest in the bedroom (76.13 μg/m^3).

Tibetan geography and sociology

Tibetans have historically occupied a large region 2.27 million km^2 in size, making up roughly 25% of the current Chinese mainland by landmass. Geologists usually refer to this region as the Qinghai-Tibetan Plateau. Within modern-day China, Tibet usually refers to the Tibetan Autonomous Region. Yet substantial Tibetan populations live outside of the TAR in 10 Tibetan Autonomous Prefectures within neighboring provinces. The Haixi, Haibei, Huangnan, Hainan, Golog and Yushu TAPs are within Qinghai Province. The Garze and Ngaba TAPs are within Sichuan Province. The Dechen TAP is in Yunnan Province and the Gannan TAP is in Gansu Province. Yushu has the highest proportion of ethnic Tibetans of any TAP, and Golog has the second-highest proportion with 91% (Government, 2010).

Tibetan sociology has shifted rapidly in the past several decades due to globalization and Chinese national policies. These policies include the "Restore Grassland Policy" (*tuimu huancao*) which assumed that nomadic grazing patterns were degrading the soils and sought to limit their pasturelands; the "Comfortable Housing Project" (*anju gongcheng*) which aimed to use subsidies and short-term loans to build concrete homes for rural Tibetans; and the "Building a New Socialist Countryside" (*shehuizhuyi xinnongcun jianshe*) which intended to provide greater resources for rural

Tibetans (Yeh, 2003). Such policies have led to a trend towards semi- or non-nomadic lifestyles among Tibetans.

Health in Golog

A disease survey carried out in 2005 in Golog found the greatest burdens of disease to be (from most prevalent to least): digestive issues, respiratory diseases, rheumatoid arthritis, cardiovascular and neurovascular diseases, and infectious diseases. It also found that the prevalence of respiratory diseases is disproportionately high in women and children, and that herders have the highest prevalence of disease by occupation (Zhou, Yue, & Xu, 2005). Yet, the latest local government statistics show that the 2009 mortality rate in Golog was 6.0 (Government, 2010), which compared favorably to the Chinese national rate of 7.0 (Bank).

Yak dung

Yak dung has historically been essential to the survival of the Tibetan people on the Qinghai-Tibetan Plateau. The importance of yak dung — though being slowly diminished by sociological trends and modernization — still persists today throughout Tibet, especially as a fuel source for cooking and heating. An ethnographic film made in Golog shows clearly how important yak dung is for Tibetan nomads, providing fuel, building material, toys and medicine (Lanzhe, 2013). Annual consumption of dung has been estimated to be 14.3 million tons in Qinghai Province and 24.26 million tons in the TAR (Ping, Jiang, & Li, 2011).

Climate Change in Tibet

Research on climate change in Tibet has unequivocally confirmed that the region is warming. Wei and Fang (Wei & Fang, 2013) suggest that a 1.6°C warming has already occurred since 1961 and it has been accelerating in the last 20 years. Further research has concluded that warming is decreasing the quality of the Tibetan grasslands (Klein, Harte, & Zhao, 2007; Yu, Xu, Okuto, & Luedeling, 2012) and that the summer growing season is being shortened (Yu, Luedeling, & Xu, 2010). Qualitative research has found that Tibetan nomads are noticing the changes in their microclimates and are concerned about the health effects and the snowmelt from sacred mountains (Byg & Salick, 2009). One study has already documented adaptive strategies to climate change in a Tibetan community (Li, Tang, Luo, Di, & Zhang, 2013).

Air quality and 'development'

In China

The World Bank and others consider China's National Improved Stove Program (NISP) — begun in the 1980s — to be the biggest success story of all HAP interventions. It was intended to improve fuel efficiency in rural homes and introduce stovepipes to vent smoke. The program is said to have distributed 180 million stoves throughout China by the mid-1990s (Bank, 2011, 2013). However, studies have found that these improved stoves do not lower the household air pollution to adequate levels (Edwards et al., 2007; Sinton et al., 2004). It is estimated that HAP from solid fuel combustion is to blame for 420,000 premature deaths in China annually (Zhang & Smith, 2007). This represents 120,000 more premature deaths than can be attributed to urban air pollution in China (Cohen et al., 2004). Use of coal as a fuel in rural homes is increasing in China even while its use has been declining in many cities (Zhang & Smith, 2007). Although there have been small-scale attempts at HAP interventions throughout China, the problem is only getting worse. It has been suggested that a massive coordinated effort between the Chinese government and private enterprise is the only way to address the issue (Zhang & Smith, 2007).

In 2007 the Chinese government launched the One Solar Cooker and One Biomass Stove Program specifically in Tibetan regions (the TAR and TAPs) and distributed 79,833 biomass stoves and 244,474 solar cookers over four years. In 2012 the "China Clean Stove Initiative" launched as a collaboration between the Chinese government and the World Bank, aiming to "scale up access to clean cooking and heating solutions for poorer, primarily rural households who are likely to continue relying on solid fuels beyond 2030" (Bank, 2013).

Interventions globally

As has been previously written, attempts to solve the HAP problem have largely failed throughout the last 30-40 years. HAP is today considered the number one environmental health risk, responsible for 4.3 million deaths annually. To this day, 3 billion people are still reliant on dung, wood, charcoal, coal and crop biomass for cooking and heating in the home (WHO, 2014). Many stakeholders and sectors are increasingly focusing on this issue but it remains unclear if enough attention and funding is being channeled to make a dent. The World Bank and the Global Alliance for Clean Cookstoves (a public-private partnership hosted by the UN) are major multinational and multi-sectoral players. Other major funders include the U.S. EPA, USAID, and the UK's DfID (Rosenthal, 2015).

In the case of HAP, the challenges are broad and varied. It has been suggested that the biggest challenge is the lack of sufficient evidence to inform large-scale programming and interventions. Rosenthal (Rosenthal, 2015) suggests that more exposure assessments and biomarker studies are necessary to gain a clearer sense of the relationship between household smoke and inhabitants' bodies. He also suggests more evidence is needed regarding which technologies mitigate HAP to adequate levels and which technologies will be adopted and implemented sustainably and exclusively.

The reality is that HAP studies are difficult to conduct and analyze because of the complex mixture of shifting factors. The nature of household fuel combustion is volatile by nature. Families may keep two or more different stoves in the house — “stove-stacking” — and they may use different fuels from season to season, or even day to day, depending on fuel costs, fuel availability or personal preference (Rosenthal, 2015). It is also difficult to engineer improved stoves (Still, Bentson, & Li, 2014), as well as to translate laboratory results into real world settings (Sambandam et al., 2014). Crucially, there is also no consensus as to whether the priority should be the distribution of advanced stoves or investment in infrastructure so that low-income settings can have access to the same standards of living realized in the ‘developed’ world (K. R. Smith, 2014a, 2014b).

Given that the UN has declared 2014-2024 to be the “Decade of Sustainable Energy for All,” there is reason to believe that global agendas and funding mechanisms may finally catch up with the severity of the issue. However, there is reason to be concerned that a clear path forward has not been agreed upon in the scientific community or the development community.

Chapter 2. Manuscript

Household Air Pollution in a Changing Tibet:
A Mixed Methods Ethnography Amidst Particulate Matter and Black Carbon

Steve Sclar and Eri Saikawa

Background: Household air pollution (HAP) has recently been deemed the number one environmental health risk in the world, responsible each year for 4.3 million deaths globally and 420,000 in China. Tibetan regions of China are well known for pristine ambient air, but several recent studies have concluded that the indoor air quality in Tibetan homes is compromised. Yet these studies — like most HAP studies conducted globally — do not provide a clear picture of the complex socio-contextual ecosystem within which the indoor air becomes polluted. The sociology of Tibet is changing — some might say 'developing' — rapidly due to a variety of forces, and this study sought to holistically understand HAP in relation to these changes.

Methods: We took 28 measurements of fine particulate matter ($PM_{2.5}$) and black carbon (BC) in a variety of Tibetan dwellings in the Golog Tibetan Autonomous Prefecture. A semi-structured interview was also administered with residents to gain a sense of household behaviors and attitudes. Most importantly, ethnographic participant-observation was undertaken in order to gain 'thick' understandings of HAP in the Tibetan context.

Results: We measured very high concentrations of $PM_{2.5}$ across all residential sites. The highest concentrations were found in the traditional yak hair tent, but nomads living in plastic tarp tents with improved stoves and stovepipes also had very compromised indoor air quality. The air in sedentary homes with improved stoves and stovepipes was only marginally better than tarp tents. All of the nomads in this study said they would prefer to use a fuel other than yak dung. More nomads expressed concern about climate change than HAP, and indoor trash burning was seen at all sites.

Conclusions: HAP is certainly a cause for concern in Tibet, and several actors across various sectors are pursuing interventions. This study highlights the convoluted reality of HAP in Tibet and suggests that current 'development' trends are not adequately mitigating the issue. Lifestyles and attitudes in Tibet are in flux, and it will be crucial for HAP interventions to be community-based and community-driven in order to be successful.

Introduction

In late 2014, the World Health Organization (WHO) released the first guidelines for household air pollution (HAP). The executive summary declares that "air pollution from household fuel combustion is the most important global environmental health risk today" (WHO, 2014). According to WHO, HAP prematurely kills 4.3 million people globally per year. This epidemiological statistic coupled with a newfound interest in the contribution of HAP to climate change has recharged the issue's notoriety (Rosenthal, 2015). Observational studies continue to emerge about HAP exposure among the 3 billion people reliant on dung, wood, charcoal, coal and crop biomass for cooking and heating (K. R. Smith et al., 2014; WHO, 2014).

Air pollution is a particularly burdensome issue throughout Asia. The region is increasingly notorious for dense ambient particulate matter pollution in cities such as Beijing and New Delhi. In East Asia, this ambient pollution constitutes the fourth-greatest risk factor for disease, while HAP is close behind in the fifth spot. In South Asia, HAP is the number one risk factor for disease. In fact, of the top 43 risk factors ranked in the 2010 Global Burden of Disease analysis, HAP showed the most extreme disparity in risk distribution globally: it is the number one risk factor in South Asia, yet the penultimate risk factor in High-Income Asia Pacific. In comparison, ambient particulate matter pollution is more balanced, ranking number six in South Asia and number nine in High-Income Asia Pacific (Lim, 2012). This comparison is indicative of broader urbanization, globalization and market reform trends, which have exacerbated inequality within and between Asian countries (Kanbur, Rhee, & Zhuang, 2014). 'Developing' regions tend to exchange dispersed risks such as HAP for concentrated metropolitan risks. Yet little research has been done to study HAP within the same population at residences in various stages of 'development.'

This study was designed to measure HAP in the Tibetan context, which is technically part of East Asia but shares a great deal in common with South Asian countries such as Nepal, Bhutan and India.

Specifically, this study sought to understand HAP in various indoor settings in order to characterize and compare exposure among various Tibetan lifestyles, and it was designed to holistically understand the socio-contextual ecosystem within which the indoor air becomes polluted. It was carried out in the summer of 2014 in the Golog Tibetan Autonomous Prefecture (TAP) within the Qinghai Province, a high-altitude region with pristine ambient air (Han, Zhou, Li, & Li, 2014) where yak dung remains the primary fuel source even while sociological conditions are shifting rapidly (Figure 1). This study builds on the growing HAP literature that has emerged from Tibetan homes in the last six years, which unequivocally reported concerning pollution levels. These six HAP studies were all carried out in the Tibetan Autonomous Region (TAR) — five of the six were conducted within nomadic populations around Namtso Lake (Chen et al., 2011; Kang et al., 2009; C. Li et al., 2012; Chaoliu Li et al., 2012; Xiao et al., 2015) and the final study was conducted in agricultural populations south of Lhasa (Gao et al., 2009) (Figure 1).[1] Four of these studies measured $PM_{2.5}$ (fine particulate matter with an aerodynamic diameter of 2.5 microns or smaller), two measured carbon monoxide, two measured trace elements, one measured total suspended particles, and one measured black carbon (BC). This study measured $PM_{2.5}$ and BC, and employed a semi-structured interview and ethnographic participant-observation.

There are several broad societal trends that are worth noting for the ways in which they shaped the study design. First, it is well known that due to globalizing lifestyle choices and overt Chinese policies — such as the "Restore Grassland Policy" (*tuimu huancao*), "Comfortable Housing Project" (*anju gongcheng*), and "Building a New Socialist Countryside" (*shehuizhuyi xinnongcun jianshe*) — Tibetans have been and continue to be sedentarized into semi- or non-nomadic lifestyles (Yeh, 2003). This 'progression' — as defined by the government — has had broad ripple effects, which will be explored later in this paper.

[1] These studies use the spelling "Nam Co"

Second, China has pursued improved cookstove programs in the past and recently launched a new endeavor. The National Improved Stove Program (NISP) of the 1980s and 1990s is still hailed by the World Bank as "an enormous success by any standard" (Bank, 2013). However, research has indicated that NISP was successful by the standard of distributing 180 million stoves across China, but not by the standard of adequately mitigating HAP (Edwards et al., 2007). In 2007, the Chinese government launched the One Solar Cooker and One Biomass Stove Program specifically in Tibetan regions (the TAR and TAPs) and distributed 79,833 biomass stoves and 244,474 solar cookers over four years. In 2012 the China Clean Stove Initiative was launched as a collaboration between the Chinese government and the World Bank, aiming to "scale up access to clean cooking and heating solutions for poorer, primarily rural households who are likely to continue relying on solid fuels beyond 2030" (Bank, 2013).

Third, fuel habits in Tibet are changing with the sociological landscape. Tibetans have been historically dependent upon dried yak dung as the primary fuel source for heating and cooking, and this is still the case throughout Tibetan regions. Annual consumption of dung has been estimated to be 14.3 million tons in Qinghai Province and 24.26 million tons in the TAR (Ping et al., 2011). Yet coal has become an increasingly prevalent fuel source as it has been commercialized along with improved stoves (Bank, 2013). Similarly, natural gas is becoming a more prevalent household fuel source in Qinghai Province (Ping et al., 2011).

Finally, it is known that fires for cooking and heating are not the only potential source of HAP in Tibet. It is common for incense sticks and yak butter lamps to be burned on a daily basis. These sources may add marginal pollutants into the indoor air, but no attempt has been made to determine their contributions.

Because modern science has been and continues to be predominantly executed within the zeitgeist of 'Western' culture and lexicography, it is worth noting that Tibet has occupied a uniquely misunderstood place in the Western psyche for centuries up until present-day (Lopez, 1999). Tibetans are the ninth-most populous ethnic minority in China, but none of the top eight are nearly as well-known globally (Hathaway, 2013). The various reasons for this should remind readers that the complex context of Tibet has often complicated the process and representation of scientific research in the region. This study does not avoid the context, but does avoid the reification of preconceived notions about Tibet.

Methods

Study Site And Participants

The Tibetan people of modern-day China have historically occupied a vast area (2.27 million km^2) that in relative terms is slightly larger than Greenland and makes up 25% of the Chinese mainland by landmass. Today this region is politically demarcated into the TAR, a province-level division of China and ten TAPs that are located in four provinces (Qinghai, Gansu, Sichuan, and Yunnan) north and east of the TAR (Figure 1). Six of the TAPs are located in Qinghai, two in Sichuan, and one each in Yunnan and Gansu. The entire area is unofficially divided into three Tibetan regions: U-Tsang in the west, Kham in the southeast and Amdo in the northeast. Each of these regions has unique histories, cultural traits and mutually unintelligible dialects based on the same literary language.

This study was carried out between June-August 2014 in the Golog TAP of the Qinghai Province, a strongly Amdo region.[2] Golog Tibetans are themselves categorized as a unique subgroup with a distinctive subdialect, historically documented as a fierce and rebellious nomadic tribe (Gelek, 2002). Today, 91% of Golog's 160,000 residents are Tibetan, the second-highest proportion of all TAPs (Government, 2010). It is presently considered an important region where 'traditional' Tibetan

[2] Sometimes spelled Golok or Guoluo

culture and lifestyle persists (Gelek, 2002). This region was chosen for study mainly because it showcases the way in which the traditional Tibetan lifeworld is incorporating into the modern Chinese society and economy. The field researcher spent three months in Golog in 2009 and therefore had baseline knowledge of the region.

In order to be eligible for the study, participants needed to be Tibetans who used yak dung as a primary or secondary fuel source in the home. We aimed to measure an equal number of tents and sedentary homes, as well as a few miscellaneous sources and ambient readings. In the end, we took measurements within 11 tents, nine sedentary homes, six miscellaneous sources, and two ambient. Four measurements occurred in a yak hair tent, seven in tarp tents, and all of the sedentary homes were concrete structures. Figure 2 provides representative photos of the different structures. In addition to various structures, different combustion sources were also measured, as shown in Figure 3. All of the residences used improved stoves, but the yak hair tent used a traditional adobe stove in addition to an improved stove.[3]

The field researcher was heavily reliant on local assistants to locate study participants, obtain consent (forms were written in the local Amdo dialect), and translate during interview administration. Study participants were chosen using a combination of convenience and snowball sampling. Every attempt was made to take measurements at each study site on at least two different days, but this was not possible in every instance due to time limitations and transportation issues.

Quantitative Measurement of $PM_{2.5}$ and BC Concentrations

Three distinct devices were used to measure real-time levels of $PM_{2.5}$ and BC. $PM_{2.5}$ concentrations were measured using the DustTrak II Aerosol Monitor 8530 (TSI Inc., range: 0.001 -

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[3] This paper follows the useful convention put forth by the World Bank: "*Traditional stove* refers to either open fires or stoves constructed by artisans or household members that are not energy efficient and have poor combustion features. *Improved cookstove* is used in the historical sense for stoves installed in "legacy" programs, usually with a firebox and chimney, but without standards and with poor quality control."

400 mg/m^3, resolution: ±0.1% of reading or 0.001 mg/m^3) at a 3.0 L/min flow rate. The DustTrak recorded a measurement every minute. Additionally, the $PM_{2.5}$ particle count was measured using a DC1700 AQM (Dylos Corp.), a laser light-scattering counter that records the number of particles between 0.5-2.5 μm in the sampled air as a concentration per 0.01 ft^3. The DC1700 also recorded a measurement every minute. Although the DC1700 is a lower-budget instrument marketed towards health-conscious consumers, previous research has corroborated its validity against a comparable high-end scientific instrument (Semple, Ibrahim, Apsley, Steiner, & Turner, 2015; Semple & Latif, 2014). The DC1700 was used as a backup in case the DustTrak stopped working, and ultimately this paper will only explore the DustTrak's measurement of $PM_{2.5}$ concentrations.

$PM_{2.5}$ was chosen for measurement for a variety of reasons. Most notably, many studies have linked $PM_{2.5}$ to various disease outcomes (Farmer, Nelin, Falvo, & Wold, 2014; Lim, 2012; Pope et al., 2004), and the WHO has deemed $PM_{2.5}$ to be "the key pollutant for which health risk is best evaluated" (WHO, 2014). The latest Integrated Scientific Assessment of $PM_{2.5}$ has deemed short-term exposure to be "causal" with regard to cardiovascular effects and mortality, and "likely to be causal" with regard to respiratory effects. Long-term exposure indicates the same, in addition to being "suggestive of a causal relationship" with regard to reproductive and developmental effects as well as cancer, mutagenicity and genotoxicity (EPA, 2009).

The majority of HAP (and ambient) research in China and elsewhere has measured PM_{10} and $PM_{2.5}$. For $PM_{2.5}$, the U.S. EPA has set a 24-hour average daily ambient standard at 35 μg/m^3, and the WHO has set a 24-hour average daily ambient standard at 25 μg/m^3 with interim targets set at 75, 50 and 37.5 μg/m^3 (WHO, 2005).[4] China has actually set a national 24-hour average indoor air quality standard for PM_{10} of 150 μg/m^3 but has not set an indoor standard for $PM_{2.5}$ (Zhang & Smith, 2007). A handful of studies have quantified indoor $PM_{2.5}$ concentrations in other parts of

[4] WHO also has set annual average standards for $PM_{2.5}$ and PM_{10} and they are significantly lower than the daily-average guidelines. See WHO 2005 for those standards.

Tibet and recorded average concentrations between 97 - 1670 μg/m^3 (Chen et al., 2011; Gao et al., 2009; Kang et al., 2009; C. Li et al., 2012; Chaoliu Li et al., 2012; Xiao et al., 2015).

We measured the concentration of BC using the microAeth AE51 (AethLabs Inc., range: 0-1 mg/m^3, resolution 0.001 ug/m^3) at 50 mL/min flow rate with a $PM_{2.5}$ size-selective inlet. Measurements were recorded every 5 minutes. BC is important not only because of adverse health effects (EPA, 2012; Grahame, Klemm, & Schlesinger, 2014; WHO, 2012), but also because it has emerged as an important player in global climate change — it has been suggested that BC is the second-most important anthropogenic contributor to climate change after CO_2 (Ramanathan & Carmichael, 2008). It is estimated that 18% of BC emissions globally comes from residential biomass burning (Bond et al., 2004) and 40% of BC emissions in China comes from rural-residential biomass burning (Ni et al., 2014). Previous studies have also posited that BC soot particles settling on glaciers may be partially responsible for their rapid melting on the Tibetan plateau (Ramanathan & Carmichael, 2008; Xu et al., 2009).

The three measurement devices were always positioned in a similar fashion in a location that closely approximated residents' sitting and breathing location. The intake tubes of the DustTrak and microAeth were always propped on top of the DC1700 (which pulled in air from the back of the unit) so that all three units were sampling air parcels within a 1-2 inch radius. The battery life of the DustTrak and logistical constraints of recharging limited measurement periods. Twenty-six out of the 28 measurement periods were between 3 - 4.5 hours. The two shorter measurement periods were 2.25 hours and 1 hour.

Semi-Structured Interview

A semi-structured interview was carried out once in each residential site where air quality was measured with consenting adults. The interview guide can be found in the appendix. The questions were adapted from Xiao et al. (Xiao et al., 2015) and designed to gain a sense of household demographics, stove use patterns, fuel use habits, and health concerns in the home. This was a semi-structured interview because some questions were open-ended and the interviewee was allowed to carry questions in unplanned directions. If the interviewee began to talk about a relevant topic of interest, the interviewer was free to ask follow-up questions before returning to the interview guide. It was administered in the Amdo Tibetan dialect with a translator, transcribed in English and later analyzed.

Ethnographic Observation

The field researcher — having worked previously in Golog, having studied the language as well as Tibetan culture and history, and having studied and practiced ethnographic techniques — was well-positioned for "deep hanging-out," as anthropologists often characterize ethnography (Clifford, 1996). Given the privilege to eat and sleep alongside study participants, the researcher was able to gain a more holistic understanding of household air pollution in Tibet. This is not a methodology often employed for HAP studies. We believe it is a useful methodology because household air pollution is much more than a number on a scale from 'good' to 'hazardous.' It is an emergent property of socio-contextual ontologies, behaviors, and economies operating at the household level. Ethnography provides the tool and lens that allowed us to access this context.

Throughout the quantitative data collection periods, the field researcher kept detailed observational fieldnotes relevant to air quality, such as when fuel was added to the stove, what kind of fuel was added, when a cigarette was lit inside, and how the smoke looked/smelled at notable times. In most instances, the field researcher was asked to visit or live with study participants beyond the daily battery capacity of the measurement devices. The researcher was also invited to take part in household practices — such as collecting and spreading fresh yak dung or fetching dry yak dung from outside caches. Such participant-observation allowed the researcher to write extensive ethnographic fieldnotes and gain relevant knowledge that positivist methodologies would miss.

Results

By the end of data collection, 28 measurements had been taken in a variety of settings and nine semi-structured interviews were conducted. Meteorological conditions varied widely across the study period. At elevations over 4,000 m, temperatures still dipped below freezing and snow fell up until mid-June. By late July, temperatures on a cloudless day could soar between 20-26 °C.

$PM_{2.5}$ and BC Measurement Findings

Concentrations of $PM_{2.5}$ and BC measured across all study sites are shown in Table 1. The sample size (N) does not represent the unique number of sites because most (but not all) sites were measured multiple times. Six different tents were studied, providing 11 distinct measurements. Only one yak hair tent was studied, but its air quality was measured on four different days. Four sedentary homes were studied, providing nine total measurements. One prayer room provided two distinct measurements. One teacher's kitchen provided three distinct measurements. Finally, the roof of a three-story building in a large town provided two ambient measurements. Due to logistical challenges, measurements were not always taken during the same exact period of the day, but they were either taken during a period around lunchtime or dinnertime.

Table 1 shows that average $PM_{2.5}$ pollution levels in Golog are orders of magnitude higher than the WHO guideline. Only the ambient measurement fell below the standard. The average $PM_{2.5}$ concentration inside tents and sedentary homes during sampling periods was 2,286 $\mu g/m^3$ and 509 $\mu g/m^3$, respectively. Stratifying by tent type, tarp tents showed an average concentration of 755 $\mu g/m^3$, and the yak hair tent showed 4,964 $\mu g/m^3$. The teachers' kitchen was set up in a very similar manner to a sedentary home — and in fact the cook lived and slept in the kitchen — but it was categorized separately because it represents a 'workplace' exposure for the teachers who spend time in there during breakfast, lunch and dinner. This kitchen was measured on three occasions and had an average $PM_{2.5}$ concentration of 880 μg/m^3. The single school cafeteria measurement was taken in the cafeteria-style kitchen, which was connected to the eating-space by a door and pass-through window, and it had an average $PM_{2.5}$ concentration of 55 μg/m^3. The prayer room in which yak butter lamps and incense were burned had an average $PM_{2.5}$ concentration of 76 μg/m^3 across two measurement periods.

Extreme acute measurements were recorded across all sites, which are also shown in Table 1. The maximum instantaneous $PM_{2.5}$ concentration in the yak hair tent reached 157,000 μg/m^3, at which time the visibility in the tent was reduced to ~3 meters — one could not see from one side of the tent to the other. Table 2 provides observational context for each of the maximum instantaneous concentrations. Most of the maximum values correspond with a time when the fire is being built-up and stoked in preparation for making a meal and/or tea.

BC concentration levels represented between 0.32-4.74% of total $PM_{2.5}$ concentrations. In general, as $PM_{2.5}$ concentrations decreased, BC accounted for a higher proportion of the total particulate matter content, as shown in Table 1.

Semi-Structured Interview Results

Findings from the nine semi-structured interviews are presented in Table 3. Interviews were conducted with residents in four tents (three tarp and one yak hair) and five sedentary homes. All of the homes and tents used an improved stove, including the yak hair tent, which used both an improved and a traditional adobe stove. Tent dwellers seemed more likely to indicate that they use the stove all day unconditionally, while all sedentary home residents said that the stove is only used during certain meal times (usually breakfast and dinner), or it's used less frequently in the summer. On average, the sedentary homes had older improved stoves, and they have been using a stovepipe for one year longer than the tents.

All of the tents used yak dung as the primary fuel source year-round, and only one used coal as secondary fuel source. Four of the five sedentary homes use yak dung as the primary fuel source in the summer, but one of those four switches to coal primarily in the winter. Three of the five sedentary homes use a gas burner for cooking, compared to just one of the tents. Residents in all four of the tents said that they would prefer to use another fuel source, and none of the residents in sedentary homes said the same. Of those four tents, residents in three said they would prefer to use coal, and residents in the fourth tent said they didn't know which alternative source they would prefer to use. In one instance, residents said that coal would be preferred if it could be provided for free. At the same time, yak dung was often extolled as a good primary fuel source because it was free and easy to use. Some even stated that they wouldn't know how to start a fire with coal. One respondent said that yak dung was natural so it was better for cooking. Additionally, residents in two of the three sedentary homes with natural gas burners said that gas was used only to make lunch because it was fast.

Two residents of tents and two residents of the sedentary homes indicated that they notice smoke in the home at certain points in time. Of the sedentary homes, one said that the stovepipe sometimes clogged and the room would get smoky, while the other said they sometimes noticed smoke in the mornings. Residents of one tent indicated that they have health concerns related to the stove use. These were the residents in a yak hair tent, which used both an improved stove and an adobe stove. The respondent said that smoke from the improved stove is harmful to the eyes and other parts of the body, yet smoke from the adobe stove is beneficial because the yak eat herbal grasses. This was an interesting response because yak dung was burned in both stoves. Residents in a second tent indicated being uncertain about health concerns related to stove use. None of the residents in sedentary homes reported health concerns. Two of the residents in tents and four of the residents in sedentary homes reported chronic health problems in the home, with hypertension, backaches and stomach issues being the most common.

Ethnographic Participant-Observation

The sense of home

Although the study was initially designed to dichotomize nomadic and sedentary lifestyles, it became clear that this is hardly a simple dichotomy. Sedentarization and modernization are trends that have changed aspects of the 'traditional' nomadic lifestyle relevant to HAP, but these trends emerge along a complex spectrum. Up until the late 1990s, most nomads lived in black woven yak hair tents. Today, these yak hair tents are few and far between in Golog as most nomads have transitioned to store-bought white plastic tarp tents, which are largely preferred because they are lighter, more waterproof and easier to setup. This transition is important due to the type of stove used in each tent. In yak hair tents, residents will have an open fire using an iron ring or a homemade adobe mud stove. Therefore, yak hair tents have an opening in the ceiling of the tent for ventilation. Tarp tents, on the other hand, utilize cast iron improved stoves with stovepipes that vent the smoke through the ceiling of the tents. The yak hair tents are not seen by Tibetans as a mark of poverty or 'backwardness' but rather are viewed with a deferential respect as a symbol of the commitment to a 'traditional' Tibetan lifestyle. The yak hair tent in this study was 30 years old, took 3-4 years to make and revealed the complex spectrum of sedentarization and nomadism. While the residents expressed a great deal of pride in their home, they persist in using it because religious leaders say it is the right way to live and the 'traditional' ways must be maintained. The matriarch said that "development" is good, but not when it causes nomads to give up their livestock and tents.

However, on a separate occasion the patriarch expressed his desire to give up the yak herd and move into town.

Given the context, it is interesting that this particular yak hair tent utilized both an adobe and an improved stove. This is a global phenomenon known as "stove stacking" (Rosenthal, 2015). The improved stove had a stovepipe, yet the stovepipe terminus was kept within the tent. If the stovepipe was sent through the ventilation gap (which ran across the length of the tent's ceiling), it would prevent the residents from sliding a piece of canvas over the ventilation gap when it rains. Incidentally, this is exactly what caused the extreme instantaneous maximum $PM_{2.5}$ concentration of the whole study: 157,000 $\mu g/m^3$. A rainy day, the residents of the yak hair tent covered the ventilation gap with canvas and covered the adobe stove with plastic to protect it from leaks. The improved stove was used but had no direct ventilation except small gaps between the canvas and the tent, as well as the tent flap door when open (though the open tent flap sometimes caused the smoke to swirl without escaping).

Yak dung is usually added to stoves using a scooper. When added, the researcher would note the time and 1, 2 or 3 "SYDA" (scoop(s) yak dung added). In the yak hair tent, the cycles of smokiness correspond very tightly with noted "SYDA," except one spike, which corresponds with two people smoking cigarettes. The periods of smokiness were not treated with any noticeable sense of alarm or dis-ease. During the period when the maximum instantaneous $PM_{2.5}$ concentration was recorded, the matriarch remained seated next to the stove thumbing her prayer beads. She had already said that smoke in the yak hair tent is auspicious; if there is no smoke in the yak hair tent, "it's not good." However, her positive association between smokiness and auspiciousness does have a limit; she also said that excess smoke from the improved stove harms the eyes and other parts of the body. The following day was overcast and the adobe stove was back in use, but the canvas was left half-covering the ventilation gap, as if in preparation for anticipated rain.

The complex mixture of sedentary and nomadic lifestyles was found in other ways. Four out of the five sedentary home interviews occurred with townspeople, but one occurred with nomads who have a 'sedentary' home on their pasture. It is increasingly common for a) individual nomad families to have a non-tent home built on their winter pasturelands or b) for the leader of a nomadic clan to have a non-tent home built on each of the seasonal pasturelands. The field researcher encountered both cases. The yak hair tent was pitched on the family's summer pastureland, but their concrete winter home was nearby (due to the micro-climate, this family only needed a summer and winter pasture and did not need to travel far between the two). In the latter case, at the summer pasture of a nomadic clan, the leader lived in a small concrete home while the other families and hired herders lived in surrounding tarp tents. Though nomadic by profession, the leader's concrete home was categorized as a sedentary residence due to its structural likeness to sedentary homes in town.

The term 'profession' is used deliberately. The village leader said that increasing economic development in Golog has led more young nomads to attend urban schools and ultimately give up the nomadic lifestyle in favor of living in a town or city. Tibetans old and young from other TAPs will then move to Golog seasonally or permanently to fill the vacuum and seek employment as hired herders. Hired herders sleep in small satellite tents without stoves, but take meals and tea in the main tent of their nomadic sponsors.

The fuels at play

The study was also designed to attempt to understand how different fuels may cause different pollution levels, but this also proved complicated. Yak dung was by far the dominant fuel measured in this study. For nomads, yak dung is a free and constantly available resource.[5] There are several ways in which the dung is dried. Clumps of fresh dung may be piled on the grass and then spread in

[5] In one tarp tent, sheep dung was once mixed with yak dung in the stove. This is an uncommon practice.

a thin layer. Without precipitation for a few days, the layer will dry and can then be picked up in brittle pieces and added to a pile beside the home. Alternatively, fresh dung may be formed into corral-type wall around the home. Fresh dung can be slapped onto the outer walls of the home in order to dry beneath the eaves. Dry dung chips from the pastures may also be collected and piled up. Large plastic tarps are used to cover the dry dung pile to keep it out of the rain. If dung is being harvested from a corral wall, the plastic sheet will be kept over the section that's being harvested and then gradually moved along the wall. Often a large bin is kept inside the home to store a few hours worth of dung brought in from outside. Townspeople could find plenty of yak dung in the surrounding fields, but they are more likely to buy sacks of dried yak dung. Occasionally, but not often, yak dung could be heard loudly popping during combustion, indicating that the dung chips had retained moisture. Smokier conditions tended to correspond with the popping. Previous studies (Xiao et al., 2015) have suggested that higher dung moisture inhibits complete combustion and leads to higher emissions.

If the fire is dead, the initial lighting of the stove often creates some of the smokiest conditions in the home. Yak dung is the preferred fuel for starting fires. Some homes use a store-bought sleeve of wax to assist with fire starting. Others use wads of paper. If coal is used as a supplemental fuel source, it will be added after the dung fire is lit. Coal is considered difficult to light from scratch but when added to an existing fire it is said to burn hotter and longer than yak dung. All of the coal seen in this study was a dull and soft variety, indicative of bituminous nature. Coal is considered a higher-end fuel source for those with greater financial means. None of the tent-dwellers in this study used it. Natural gas burners are another increasingly common higher-end fuel source, and it was seen in several sedentary homes and one nomadic tent. While stoves are used for heating and cooking, the gas burners are only used for cooking — usually quick cooking tasks like reheating food or boiling water. Although natural gas would normally be considered a mark of 'development,' the use of the gas burner to fry bread contributed to one of the highest $PM_{2.5}$ concentrations recorded in a tarp tent.

An unexpected 'fuel' burned at every study site was trash. Plastic drink bottles, plastic food wrappers, aluminum cans and other miscellaneous rubbish were all seen being put into the stoves. In fact, the bins or buckets that store the yak dung or coal inside the home often doubled as trashcans — everything inside had the same destination. When asked, residents did not seem concerned about trash burning. However, on one occasion a young woman preparing to light the stove at a sedentary home was observed first removing several pieces of trash that her father had earlier put into the combustion chamber. She took the trash to an overflowing dumpster in the street and then proceeded to build the fire with yak dung.

Lastly, it is worth noting that all residences had electricity in the home. The townspeople were connected to an electrical grid, and the nomads had solar panels connected to charging stations. The Chinese government has subsidized these photovoltaic systems. Nomads use the electricity mostly to keep their smart phones charged and power a single light bulb at night. One tent even had a satellite television set.

Problems in perspective

At several instances when talking about HAP, climate change came up in conversation with nomads in the foothills of Amnye Machin, a 6,282-meter snowcapped mountain revered by Amdo Tibetans. Some of these nomads, but not all, knew about 'climate change' as a global phenomenon. Yet whether or not it was known in a global context, all described local climatic changes. The consensus is that winters are getting longer and summers are getting wetter with poorer grass. Amnye Machin's year-round snowpack is also seen to be getting smaller and more brittle year after year. Two nomads claimed to have seen large calvings recently. One said the snowpack began dwindling ever since the road construction began in recent years. The pavement factory — which sits 100 meters from his tent — is a sign of "development" which is "good," but he also said it creates problems for animals and people and reduces the quality of the grassland. When asked what would happen if Amnye Machin were to completely lose his snowpack, another nomad said it would mark the end of the world.

In addition to climate change, ambient air pollution in Chinese cities was also a well-known reference point for all study participants in multiple conversations about HAP. Many were surprised to learn that the air quality in their home could be worse than the notorious air quality of Beijing. In a fascinating turn of events, the facemasks that are worn by almost all pedestrians in Chinese cities on smoggy days are also becoming ubiquitous in Golog, but not for the expected reasons. Tibetan townspeople and nomads, especially women, are wearing these masks outside to protect their nose and cheeks from the high-altitude sun and wind. The multicolored masks with printed designs or messages (in English or Tibetan script) are also treated like a fashion accessory.

Discussion

Building on the emerging Tibetan indoor air quality literature, our study is notable, first of all, because it is the first to work with Tibetan populations outside of the TAR. Because reference to "Tibet" within China most often refers strictly to the provincial TAR, many who are not familiar with the complex political demarcations of China may be unaware that significant Tibetan populations live outside of "Tibet." These populations in the Qinghai, Sichuan, Yunnan and Gansu provinces are more varied due to their locations in central China, but they are no less Tibetan.

All of the previous studies concluded that Tibetans are being exposed to very hazardous levels of particulate matter, carbon monoxide and trace elements. Our findings affirm and 'double down' — to say the least — on their conclusions. We found the air quality in sedentary homes to have roughly

75% less $PM_{2.5}$ and 50% less BC compared to tents. However, both sedentary homes and tents have average $PM_{2.5}$ concentrations that exceed WHO's daily average $PM_{2.5}$ air quality guideline by 20 times and 90 times, respectively. These are big numbers in absolute terms, but there is also a big relative difference. Previous studies are mixed with regard to the $PM_{2.5}$ dose-response curve. Some suggest a somewhat linear dose-response curve with regard to health effects, but the curves in those studies maxed out well below the levels measured in ours (Dominici et al., 2002; Schwartz et al., 2008; Schwartz et al., 2002). Other studies suggest plateauing curves for certain diseases (Burnett et al., 2014; Pope et al., 2009). It is therefore unclear whether a $PM_{2.5}$ threshold exists at which point health effects are imminent whether exposure exceeds the guideline by 20 times or 90 times.

There are of course a few shortcomings of our study. This study was carried out in the summer months when the weather was most favorable. It is expected that our results do not portray the winter reality when Golog is perennially snowed-in and difficult to reach. Also, due to logistical and instrumentation constraints, we were unable to record measurements for longer than 4-5 hours at a time. Therefore we were unable to convey 24-hour average $PM_{2.5}$ concentrations. Finally, the extreme smokiness measured in the yak hair tent on one of the final measurement days caused the DustTrak and microAeth to malfunction. After the event, the DustTrak failed to fully zero-calibrate for the final three measurements and the microAeth reported a filter error in the middle of the final measurement day. Despite these errors, the data do not appear abnormal and were retained.

Nevertheless, the findings in this — and previous — studies first and foremost raise concerns about the health and welfare of the chronically exposed. Women and children are said to be especially burdened by household air pollution globally (Lim, 2012) and within Tibetan homes (Gao et al., 2009; Kang et al., 2009; C. Li et al., 2012; Chaoliu Li et al., 2012). A disease survey carried out in 2005 in Golog found the greatest burdens of disease to be (from most prevalent to least): digestive issues, respiratory diseases, rheumatoid arthritis, cardiovascular and neurovascular diseases, and infectious diseases. It also found that the prevalence of respiratory diseases is disproportionately high in women and children, and that herders have the highest prevalence of disease by occupation (Zhou et al., 2005). Yet, according to the latest local government statistics the 2009 mortality rate in Golog was 6.0 (Government, 2010), which compared favorably to the Chinese national rate of 7.0 (Bank).

Rather than simply restate what is obvious at this point — the air quality inside Tibetan homes is extremely polluted and hazardous to health — we would like to discuss the ways in which this study could be used to inform current and future 'interventions' planned for the region. The WHO has characterized HAP as the world's top environmental health risk and 2014-2024 has been declared the UN's Decade of Sustainable Energy for All. This has attracted attention and grant funding, but context-specific knowledge is critical to building successful interventions 'in the field.' The context of Tibetan HAP is no exception. Previous Tibetan HAP studies have offered advice such as replacing yak dung, changing people's lifestyles, and introducing improved stoves, but such advice belies the complexity.

The voices of Tibetan people themselves seem conspicuously absent in the discourse about the air in their households. This is not abnormal in a global health and development sector which tends to esteem donors' concerns above beneficiaries' (Biehl & Petryna, 2013). It is clear that there are many entities interested in solving the problem of HAP in Tibet. The Chinese government, the World Bank, and the Global Alliance for Clean Cookstoves (a public-private partnership hosted by the UN) are involved. Small non-profits such as One Earth Designs (www.oneearthdesigns.com) are working on small-scale interventions. The U.S. EPA recently awarded a $1.5 million grant to an American-Chinese academic collaboration for a project called "Improving Air Quality, Health and the Environment Through Household Energy Interventions in the Tibetan Plateau" (Baumgartner et al., 2013). Plus, researchers in China have released studies describing the current energy-use landscape across Tibet and future directions that could be taken towards the sustainable development of wind and solar power (Ping et al., 2011; Wang & Qiu, 2009).

There is much that these actors can take away from this study. First, we note that the vast majority of study participants were not concerned about their indoor air quality. Other research in the TAR (Xiao et al., 2015) has suggested that Tibetan nomads are more concerned about health impacts related to stove use than our study. It's possible those results were influenced by a social desirability bias, which our study worked to mitigate using interviewers and questions characterized by greater neutrality. On the other hand, it's very possible that distinct Tibetan populations perceive HAP-related risks differently. Still, in the face of such uncertainty about the biological gradient and exposure-disease causality, we must acknowledge that HAP more often than not is an insidious risk. Accretional in nature and attritional in effect, household air pollution can be normalized for the chronically exposed and therefore not perceived to be problematic (Mobarak, Dwivedi, Bailis, Hildemann, & Miller, 2012). Rob Nixon has usefully termed such environmental risks to be examples of "slow violence," which may be the best explanation as to why the majority of participants in this study fail to perceive any health problems associated with their combustion practices. Nixon describes "a violence that occurs gradually and out of sight...dispersed across time and space" (Nixon, 2011). If this is the case, development actors should be wary about using improved health outcomes as the primary motivator for behavior change.

Second, the concern among Tibetans about local climate change deserves greater attention. Nomads in this study were drawing conclusions that are corroborated by recent studies — climate change in Tibet is causing a shorter summer growing season and poorer grassland quality (Klein et al., 2007; Yu et al., 2010; Yu et al., 2012). Further corroborating our ethnographic findings, a 2009 survey performed in a different TAP revealed "health problems" to be the most commonly cited consequence of climate change for "people and quality of life," while "less snow" was the most commonly cited consequence for "sacred mountains" (Byg & Salick, 2009). If Tibetans see climate change — not HAP — as a major cause for concern, that warrants the attention of scientists and development practitioners. As their perception of climate change shifts from a local to global phenomenon, Tibetans may become less motivated to work with external actors pushing for HAP mitigation. After all, external actors are largely coming from climate change-exacerbating populations. On the other hand, it's possible that climate change could become an effective motivator for HAP mitigation when local concern about indoor smoke is absent or secondary. Whatever the context, it could be problematic to exaggerate the contribution of small and disparate Tibetan populations to such a massive environmental trend for programmatic leverage and care should be taken to characterize the issues accurately.

Third, this study has revealed two novel realities about Tibetan HAP — the first rooted in tradition; the other an unfortunate mark of modernity. The measurements from the prayer room suggest that even if air quality is mitigated from heating/cooking sources, there is yet another potential and non-negligible source of air pollution. Because yak butter lamps are burned frequently and for long durations, this source cannot be ignored. Tibetans can now buy plastic battery-powered flickering 'butter lamps' — this may or may not be a solution to the HAP issue, but it does relate to the second novel reality uncovered by this study. Indoor trash burning is a prevalent practice across all household types now that packaged consumer goods are accessible. A study on solid waste management in urban areas of the TAR concluded that lack of infrastructure and regulation was a major cause for concern, but made no mention of indoor trash combustion (Jiang, Lou, Ng, Luobu, & Ji, 2009). Little research has been done on household trash burning, but a study from Ghana linked the practice with low birthweight (Amegah, Jaakkola, Quansah, Norgbe, & Dzodzomenyo, 2012). A global assessment of *open* burning of domestic waste found that China burns more residential waste than any other country (Wiedinmyer, Yokelson, & Gullett, 2014). Any HAP intervention should understand that Tibetans are consuming/creating more trash, but they do not have access to adequate waste management infrastructure. If it doesn't get burned, trash often ends up littering the grasslands and streams.

Fourth, a more nuanced characterization of exposures is useful to gain greater discernment about the extent of exposures. Previous studies have identified women and children as the most exposed members of the Tibetan home, but the family unit is not the only denominator for indoor air pollution. For example, the social dynamic of hired herders who live in stove-less satellite tents is a notable detail that changes the characterization and nature of the HAP exposure. From a distance, hired herders look like part of the family, but they spend less time in the cooking tents and technically the 'household' air pollution is a 'workplace' exposure for them, in certain respects. In addition, the measurements from the cafeteria kitchen and the teachers' kitchen also provide a limited glimpse into different types of exposures. Absent more rigorous exposure science testing, this nuanced breakdown helps to avoid exposure misclassification when extrapolating average measurements to the potentially exposed.

Finally, it is tempting for external agents to perceive 'culture' as a major impediment to 'development' in the case of Tibetan HAP, but we challenge that notion. The combustion of yak dung for heating and cooking is certainly an interesting aspect of Tibetan culture, especially from an outsider's perspective. However, no study participants claimed to use yak dung for cultural reasons or out of respect to ancestral traditions. Rather, participants prized it for being free, easy to burn, or natural. Additionally, all of the nomadic tents said they would prefer to use an alternative fuel source other than yak dung. Even the matriarch of the yak hair tent — who spoke of the importance of preserving the old tent and nomadic way of life — said she would prefer to use coal if it could be provided for free. Such evidence leads us to believe that economics and convenience/comfort are first and foremost preserving yak dung as the primary household fuel. Furthermore, the notion of 'development' is also problematic in light of our study. Obviously this is a value-laden term that could — and most assuredly does — mean different things to different stakeholders, from the Chinese government to the Tibetan people, from the World Bank to the EPA (Portes, 1973). 'Development' is a term that Tibetans use with favorable connotations (Ljunggren, Zuli, Fang, & Johansson, 2010), but our findings suggest it's often used with conditions. We commonly heard the phrase that "development is good, but…" All stakeholders need to engage in a deeper dialogue to understand each other's definition of 'development.' If Tibetans are talking primarily about *economic* development such that everyone can afford to build sedentary homes on their pastures and buy coal from the market, the HAP problem would not be solved. The trends of sedentarization and modernization — which may or may not represent 'development' depending on who's judging — are also not lowering HAP remotely close to acceptable levels. Future research and interventions should be careful not to inflate the import of 'culture' and 'development' above the stubborn constraints of economics and simple convenience.

Surely the diverse actors trying to understand and solve the issue of household air pollution in Tibet are working with good intentions. It is our hope that these actors will not only maintain open dialogue with each other, but also leave ample room for Tibetan voices in the conversation at all stages of research and implementation. Their voices are glaringly omitted from the international development rhetoric. We believe it is unlikely household air pollution will be mitigated in Tibet without the active participation of the Tibetan people.

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Figures and Tables

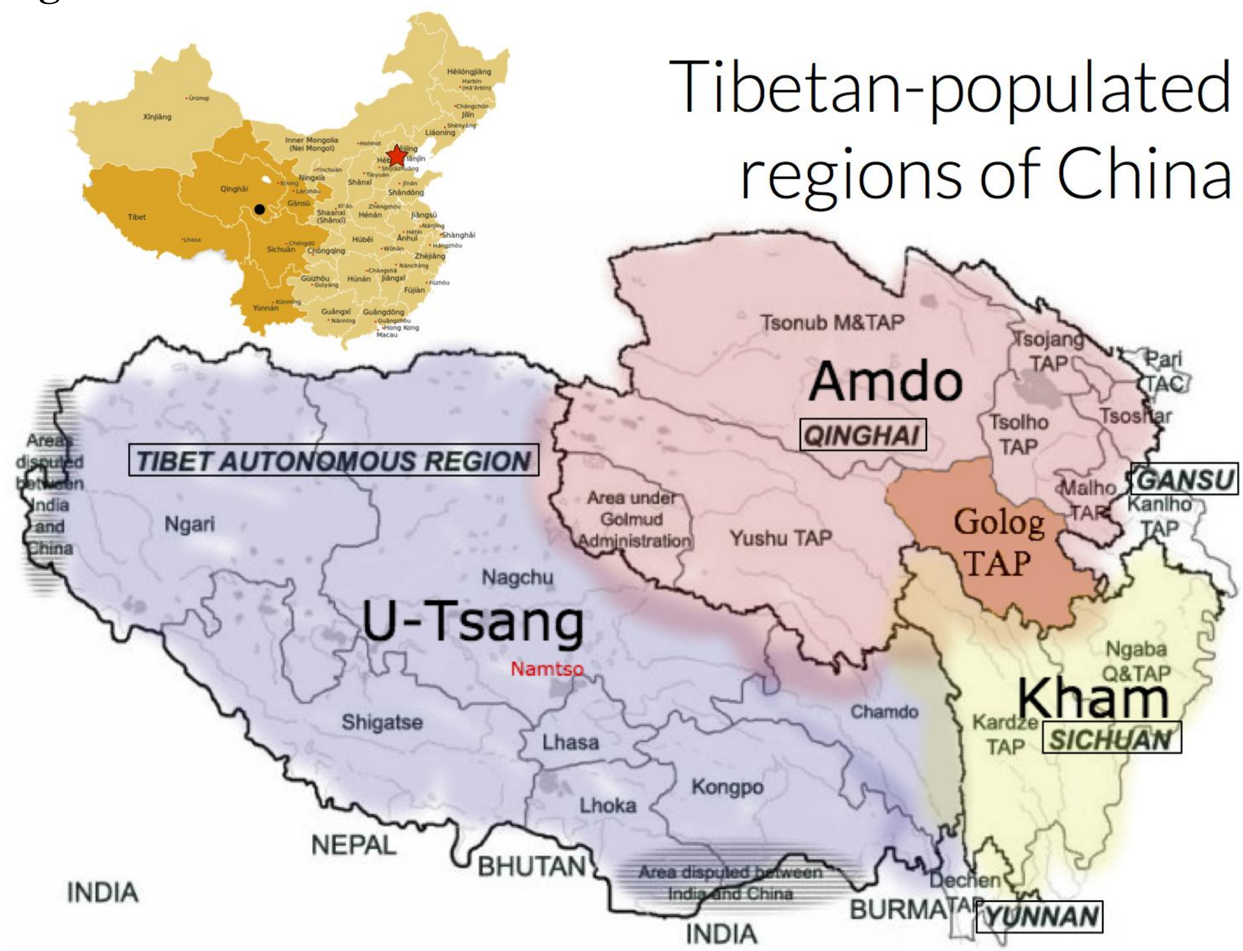

Figure 1. *Top-left map*: China mainland with Tibetan-populated provinces in a darker shade, Beijing marked by a red star and Golog TAP marked by a black dot. *Zoomed-in map*: Tibetan regions (TAR and TAPs with Golog in a darker shade), including a rough breakdown of the three historical/cultural regions of Tibet: U-Tsang, Kham and Amdo.

Figure 2. Types of residences where HAP was measured: *top left*, yak hair tent; *top right*, tarp tent; *bottom left*, concrete sedentary home

Figure 3. Various combustion sources where HAP was measured: *top left*, improved stove in a tarp tent; *top right*, traditional adobe stove beside an improved stove in yak hair tent (note how stovepipe terminates inside tent); *middle left*, teachers' kitchen; *middle right*, different type of improved stove in cafeteria kitchen; *bottom*, yak butter candles in a prayer room

Measurement Site (N)		Avg [BC][a] (μg/m³)	Avg [$PM_{2.5}$][a] (μg/m³)	[BC]:[$PM_{2.5}$] (%)	Max [$PM_{2.5}$] (μg/m³)
Tents (11)		13.0	2,286	0.6%	157,000
Tarp tent (7)		11.5	755	1.5%	11,700
	only yak dung (5)	11.2	637	1.8%	11,700
	yak dung + gas (2)	12.0	1,052	1.1%	10,500
Yak-hair tent (4)	*only yak dung*	15.8	4,964	0.3%	157,000
Sedentary Homes (9)		6.9	509	1.4%	11,300
	only yak dung (5)	8.4	482	1.7%	11,300
	yak dung + coal and/or gas (4)	5.1	543	0.9%	6,850
Other (6)					
Prayer Room (2)	*butter lamps + incense*	3.6	76	4.7%	617
School Cafeteria (1)	*yak dung + coal*	1.8	55	3.3%	502
Teacher's Kitchen (3)	*yak dung + coal*	15.6	880	1.8%	12,400
Ambient (2)		1.1	25	4.4%	400

[a] Based on entire measurement period

Table 1. $PM_{2.5}$ and BC measurements across all sites

Measurement Site		Max [$PM_{2.5}$] (μg/m³)	Time and context of max measurements
Tents			
Tarp tent			
	only yak dung	11,700	20:00; fire is being stoked in preparation of heating tea; plastic iced tea bottle and yak dung are added to stove
	yak dung + gas	10,500	18:33; deep-frying bread in oil using a skillet on a one-burner natural gas stove; stove is also burning very hot with yak dung
Yak-hair tent	*only yak dung*	157,000	14:49; rainy day, piece of canvas is covering the ceiling vent hole; adobe stove is covered with plastic to protect from rain, not being used; yak dung added to improved stove and tent fills with white smoke
Sedentary Homes			
	only yak dung	11,300	16:40; fire is being made using yak dung and newspaper; stoked and extreme amount of smoke seeps out of the stove; door is open but smoke hangs in the air
	yak dung + coal and/or gas	6,850	17:18; yak dung is added to stove to heat tea; dinner ingredients are being prepped; a yak butter lamp is also burning
Other			
Prayer Room	*butter lamps + incense*	617	19:28; no observations within temporal proximity of max reading, but 43 yak butter lamps and incense were burning
School Cafeteria	*yak dung + coal*	502	18:28; dinner is being cooked
Teacher's Kitchen	*yak dung + coal*	12,400	17:26; dinner is starting to get cooked; only yak dung in use at the moment; very smoky; door is open; at 17:28 the cook opens the window
Ambient		400	18:37; many homes are preparing dinner

Table 2. Maximum $PM_{2.5}$ concentrations and corresponding context

	Tents (4)	Sedentary (5)
Demographics		
Avg # of residents	5 people	5 people
Children under 5 present	25%	40%
Resident(s) smoke cigarettes	25%	20%
Stoves		
Use improved stove	100%	100%
Use traditional stove	25%	0
Stove used all day unconditionally	75%	0
Avg age of improved stove	4.8 years	7.6 years
Avg time stovepipe has been used with improved stove	3.6 years	4.6 years
Fuels		
Yak dung is primary fuel in summer	100%	80%
Yak dung is primary fuel in winter	100%	60%
Coal is primary fuel in summer	0	20%
Coal is primary fuel in winter	0	40%
Coal is secondary fuel anytime	25%	60%
Natural gas burner used for cooking	25%	60%
Would prefer to use another fuel source	100%	0
Said yak dung is good because…		
it's free	50%	40%
it's easy to burn	50%	60%
it's natural	25%	0
Said coal is good because…		
it burns hotter	0	60%
it burns longer	50%	40%
Said gas burner is good because it's fast	0	40%
Smoke and Health		
Notice the smoke anytime	50%	40%
Has health concerns related to stove use	25%	0
One or more resident(s) has chronic health problem(s)	50%	80%

Table 3. Semi-Structured Interview Results

Chapter 3. Summary and Public Health Implications

This research found HAP to be present at alarming levels in a variety of different Tibetan dwellings — yak hair tents, canvas tents, sedentary homes and prayer rooms. It builds upon a growing body of literature that confirms the air quality in Tibetan homes is compromised by current combustion practices. However, it goes well beyond a conventional observational indoor air quality study. This research relied heavily on the participant-observation methodology of ethnography to uncover the complexities and challenges surrounding HAP in Tibet. Ethnography is not a methodology that is widely embraced — let alone utilized — in the field of environmental health (EH). In 2003, Phil Brown hoped that research "will evolve to a point where there is no distinction between health effects research and community ethnography, where any project seeking to examine environmental health would combine epidemiologic approaches with sociologic/anthropologic analysis rooted in community collaboration."[6] Over ten years later, it is evident that his hope has not come to pass.

In the few cases when it has been done, EH ethnography has mostly been conducted in a community only after epidemiologic studies suggest significant p-values. This research is conducted by ethnographers who do not collaborate with the positivist scientists who came before them. A good example is Javier Auyero's work in South American slums. Alternatively, EH ethnography may be superseded altogether by classic journalism, perhaps because a great deal of time has passed since the exposure(s). A good example of this is Dan Fagin's Toms River.

It is my hope that this study provides some inspiration for the ways in which quantitative and qualitative methodologies can be incorporated in EH research as Phil Brown wished for back in

[6] Brown, P., *Qualitative Methods in Environmental Health Research.* Environmental Health Perspectives, 2003. **111**(14): p. 1789-1798.

2003. Part of the challenge is convincing EH schools that qualitative methodologies such as ethnography should be incorporated into curricula. Without such a step, these schools will continue to churn out positivist EH professionals who lack the confidence or desire to incorporate qualitative research methodologies into research and programming.

This mixed-method study should also be valuable to the work of the development sector, especially since we've just begun the UN's "Decade of Sustainable Energy for All." Three billion people still burn solid fuels inside their homes, and this statistic goes far beyond the scope of epidemiology. It represents a confluence of anthropology, economics, sociology and history. The challenges posed by HAP are numerous and convoluted. It is likely that more resources will be devoted toward the issue of HAP in low-income settings, but it remains unclear how the problem should be addressed. This research does not provide answers, but it does make the argument that solutions should be context-specific and community-based.

At this point, the science seems clear that the air inside Tibetan homes is hazardous. The next step should be to communicate these findings to Tibetan communities. This work has already been begun, but there is more to be done. In March 2015, this research was showcased on the campus of Emory University in a collaborative event between the Atlanta Science Festival and Emory-Tibet Week. A nomadic style tent was set up in the middle of campus and real yak dung was burned in a cast iron stove. The Emory community was welcomed inside the tent and invited to make tsampa — the staple Tibetan food — outside the tent. In the evening, a panel discussion was held with the field researcher and two Tibetan students. The discussion was heavily attended by members of the Emory and Greater Atlanta Tibetan community. These audience members expressed much appreciation of the event. Although it seems quite natural and unextraordinary, it is actually quite rare for scientists to communicate their work and findings directly to lay audiences. If anything, the media will serve as a filter for the scientists' message, which often results in a misrepresentation in some shape or form.

More work can and will be done to communicate the scientific findings directly to Golog Tibetans. In the meantime, this study has shown how people being studied can 'come first' in scientific research, rather than be viewed as incidental anecdotes or 'barriers' to global 'development.' First, in its utilization of ethnography, this study has demonstrated the importance of talking, working and living closely with people. Second, in its focus on translating these findings to the development sector, this study has prioritized the connection of powerful stakeholders — scientific researchers and programmatic practitioners — in order to remind them that Tibetans are too often left out of the conversation. Finally, the findings of this study have begun to be translated to the Tibetan people and other members of the lay public so that all can acknowledge and appreciate the complexity of HAP, not only in Tibet, but globally.

Appendix

Semi-structured Interview Guide

1) How many people reside in this home?
2) What are the ages and genders of the residents?
3) What is the annual income for this household?
4) Do any residents smoke cigarettes? [If yes] where do they smoke?
5) How old is the stove?
6) Does the stove require maintenance? [If yes] please describe.
7) Please rank the stove on a scale of poor, OK, good or not applicable with regard to the following uses: cooking? heating the air? heating the bed? cooking for people? cooking for animals? lighting?
8) How many times per day is the stove used?
9) [If stovepipe is present] How long have you used a stovepipe? [If not present] would you like to use a stovepipe? [If yes] what prevents you from doing so?
10) What is the primary fuel source?
11) What is the secondary fuel source?
12) Does the primary/secondary fuel source change at any time of year?
13) Why do you use [X] as your primary fuel source?
14) Would you prefer to use an alternative fuel source?
15) Do you ever notice smoke inside the home? [If yes] please describe.
16) Do you have any health concerns related to your stove use? [If yes] please describe.
17) Do any residents have chronic health problems? [If yes] please describe.