ASAP
EAST AFRICA

Vulnerability Scoping Study: **Air Pollution Exposure and Public Transport in Addis Ababa**

EARF EAST AFRICA RESEARCH FUND

UKaid from the British people

Addis Ababa (Ethiopia)

About this report:

The ASAP-East Africa vulnerability scoping studies explore the experiences of those particularly vulnerable populations, occupations and locations in the East African cities of Addis Ababa, Kampala and Nairobi, exposed to high levels of both indoor and outdoor air pollutants. By undertaking vulnerability scoping studies, the research team seeks to generate a more textured understanding of specific characteristics and factors associated with vulnerability to air pollution. This will allow the exploration of these vulnerabilities across cities and facilitate the development of targeted recommendations that respond to the needs of specific populations, occupations or locations.

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About the A Systems Approach to Air Pollution – East Africa (ASAP-East Africa) project

ASAP-East Africa brings together leading UK and East African researchers in air pollution, urban planning, economic geography, public health, social sciences and development studies to provide a framework for improved air quality management in three East African cities: Addis Ababa (Ethiopia), Kampala (Uganda) and Nairobi (Kenya).

This timely and responsive programme of activity will enhance local decision-making abilities to improve urban air quality, reduce the effects of air pollution upon human health, and allow for sustainable development to proceed without further deterioration in air quality.

Central to the project's aims are strengthening research capabilities and technological expertise in East Africa, with local stakeholders and experts involved in the conception, implementation, and uptake of the programme and its outcomes.

Suggested citation:

Avis, W. Weldetinsae, A. Getaneh, Z. and Singh, A. (2018). *Air Pollution Exposure and Public Transport in Addis Ababa*. ASAP-East Africa Vulnerability Scoping Study no. 4. Birmingham, UK: University of Birmingham.

Title of Research Programme	**A Systems Approach to Air Pollution – East Africa**
Reference Number	17-0600
Name of Lead Organisation	University of Birmingham
Project Management Team	Dr Pope, Dr Andres, Dr Avis and Ms Blake
Key/Core Partners	Addis Ababa Institute of Technology/ Ethiopian Roads Authority African Centre for Technology Studies Cardiff University Ethiopian Public Health Institute Kampala Capital City Authority Ndejje University Strathmore University Uganda National Roads Authority University of Nairobi
Countries to be Covered by Research	Ethiopia (Addis Ababa), Kenya (Nairobi), Uganda (Kampala)
Project Start Date/End Date	01/09/17-30/06/2020

ASAP EAST AFRICA

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Acronyms

AAIT:	Addis Ababa Institute of Technology
AQ:	Air Quality
ARI:	Acute Respiratory Infection
ASAP-East Africa:	A Systems Approach to Air Pollution – East Africa
BRTS:	Bus Rapid Transit System
COPD:	Chronic Obstructive Pulmonary Disease
CSO:	Civil Society Organisations
DFID:	Department for International Development
EARH:	East African Research Hub
ICCT:	International Council for Clean Transportation
ICT:	Information and Communications Technology
IHME:	Institute for Health Metrics and Evaluation
IPCC:	Intergovernmental Panel on Climate Change
LAC:	Local Adaptive Capacity
LMIC:	Low and Middle-Income Countries
LRT:	Light Rail Transport
MRT:	Mass Rapid Transport
NCD:	Non-Communicable Disease
NGO:	Non-Governmental Organisation
OECD:	Organization for Economic Cooperation and Development
OPC:	Optical Particle Counter
PM:	Particulate Matter
SMR:	Standardised Mortality Ratio
US EPA:	United States Environmental Protection Agency
UoB:	University of Birmingham
WHO:	World Health Organisation
WP:	Work Package

Executive Summary

Air pollution is a global environmental health threat, contributing to an estimated 3-7 million deaths per year. Whilst various types of air pollution exist, particulate matter (PM) air pollution contributes the most to global burden of disease. The effects of air pollution on human health are well documented in a range of epidemiological studies; exposure increases the risk of lung cancer, heart disease, bronchitis and other cardiorespiratory conditions. Whilst air pollution is considered to impact on all groups, particularly when exposed over prolonged periods of time, some groups are considered to be more susceptible than others. Those that spend significant periods of time in microenvironments or hotspots where air quality is poor are particularly susceptible due to intensity and duration of exposure. The fourth of the ASAP-East Africa vulnerability scoping studies explores the vulnerability of commuters, bus drivers and street vendors who are exposed to poor air quality on buses or at bus stations. Vulnerability scoping studies provide readers with a synthesis of existing evidence and theoretical approaches to the study of air pollution exposure. This synthesis in turn contextualises the empirical data gathered during the study and allows the reader to relate findings to existing literature.

This study has explored the exposure to air pollution on buses and at bus stations in Addis Ababa via the deployment of low cost PM sensors in both indoor and outdoor settings. The study also probed perceptions of commuters, street vendors and bus drivers regarding air pollution. Findings underscore the vulnerability of these groups to air pollution and suggest that those from low socioeconomic backgrounds are likely to face a triple burden of exposure both at home, in work or during commutes. Data gathered during this study indicates that air pollution levels at both bus station (outdoor) and bus (indoor) settings regularly exceed World Health Organisation (WHO) guideline amounts. Bus station PM concentrations, in the $PM_{2.5}$ size range, were measured to be on average 113 ± 99 $\mu g/m^3$ and peaked at 323 ± 203 $\mu g/m^3$[1]. Further to this, air pollution levels tend to peak during early morning and late evening hours, consistently reaching unhealthy levels throughout the day. Measured levels of $PM_{2.5}$ on buses ranged between $PM_{2.5}$ 49 ± 19 $\mu g/m^3$ and 105 ± 45 $\mu g/m^3$ on journeys measured.

Survey findings suggest that survey respondents are relatively cognisant of their inherent vulnerability to air pollution, perceiving their vulnerability on a scale of 1-5 at an average of 3.87/5 (five indicating extreme levels of vulnerability). This may in part be explained by the prolonged periods of time spent in locations with poor air quality. Respondents demonstrated a mixed understanding of the potential sources of air pollution, though this is to be expected given the relative lack of knowledge regarding air pollution in many societies. This study underscores that good air quality is central to the provision of a safe, healthy, productive, and comfortable work and commute environment. Given the inherent vulnerability of certain groups to air pollution exposure, coupled with the significant proportion of time spent in the polluted environments, it is clear that there is a need to develop policies that protect certain groups from exposure to unhealthy levels of air pollution in such settings.

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[1] PM2.5 particles (sometimes termed fine particles) are those with a diameter less than 2.5 µm in diameter.

Introduction

Air pollution is a global environmental health threat contributing to an estimated three million deaths per year worldwide (Lelieveld et al., 2015). The Global Burden of Disease project (World Bank & IHME, 2016) estimates a figure for premature deaths closer to 5.5 million (one in every ten and the fourth highest factor for causing early death). The most extreme estimates are presented by the World Health Organisation (WHO, 2014), reporting that in 2012 over seven million people died (one in eight of total global deaths) as a result of air pollution exposure.

The effects of air pollution on human health are well documented in a range of epidemiological studies; exposure increases the risk of lung cancer, heart disease, bronchitis and other cardiorespiratory conditions (Kelly & Fussell, 2015). The economic cost of this health loss is also significant, the World Bank estimates that globally in 2013 air pollution led to $5.11 trillion in welfare losses, and $225 billion in lost labour income (World Bank & IHME, 2016). The World Bank concludes that air pollution "is not just a health risk but also a drag on development… causing illness and premature death, air pollution reduces the quality of life. By causing a loss of productive labour, it also reduces incomes" (ibid: 2).

Whilst these headline figures are alarming, they tend to gloss over the disproportionate impact of poor air quality on certain populations, locations and occupations. Common approaches to assessing the impact of air pollution have tended to assume an equal vulnerability, sensitivity or susceptibility to air pollution (Stilianakis, 2015). This assumption masks differences in exposure and risk across populations, locations and occupations with air quality in cities varying both spatially and temporally (Kathuria & Khan, 2007). Although average changes in risk associated with exposure to air pollution are considered small, some locations, individuals or groups can be considered more vulnerable or susceptible than others – Addis Ababa's public transport system represents an area where individual and locational susceptibility intersect but also an area where solutions to poor air quality can be developed and applied (Avis & Khaemba, 2018).

Vulnerability scoping studies

The ASAP-East Africa vulnerability scoping studies explore the experiences of particularly vulnerable populations, occupations and locations in the East African cities of Addis Ababa (Ethiopia), Kampala (Uganda) and Nairobi (Kenya), exposed to high levels of indoor or outdoor air pollutants. By undertaking vulnerability scoping studies, the research team seeks to generate a more textured understanding of specific characteristics and factors associated with vulnerability to air pollution. This will allow the exploration of these vulnerabilities across cities and facilitate the development of targeted recommendations that respond to the needs of specific populations, occupations or locations.

Whilst air pollution is considered to impact on all groups, particularly when exposed over prolonged periods of time, some groups are considered more susceptible than others. The WHO considers as vulnerable groups; young children, the elderly, persons with certain underlying diseases, foetuses, groups exposed to other toxicants that interact with air pollutants and those with low socioeconomic status (WHO, 2004). The fourth of the ASAP-

East Africa vulnerability scoping studies explores levels of air pollution on Addis Ababa's public transport (bus) system. This will involve an exploration of how exposure to air pollution may impact on bus drivers, commuters and street vendors.

Vulnerability scoping studies provide readers with a synthesis of existing evidence and theoretical approaches to the study of air pollution exposure. This synthesis in turn contextualises the empirical data gathered during the study and allows the reader to relate findings to existing literature.

Urbanisation, mobility and air pollution

Rapid urbanisation is a global trend exerting an increasing impact on society. It is broadly accepted that for the first time, the majority of the world's population lives in what can loosely be classified as 'urban areas'[2]. In 2014, an estimated 54% (around 3.8 billion people) lived in towns or cities (UNDESA, 2014: 1). By 2050, 66% of people are projected to be living in urban areas, with the highest rates of urban growth expected in low- and middle-income countries (LICs and MICs) (ibid.).

With increasing numbers living in towns and cities, existing urban infrastructure is struggling to cope with the increased demands of urban residents. Rapid expansion and growth has led to urban and suburban sprawl i.e. the unrestricted growth of housing, commercial development, and roads. Urban sprawl is a term that also relates to the social and environmental consequences associated with this form of development. Urban sprawl is often associated with longer commutes and contributes to traffic congestion and air pollution.

Access to people, goods, services and information is considered the foundation of economic development in cities with transport an indispensable component, playing a major role in spatial relations between locations (Venables et al., 2014). The better and more efficient access, the greater the economic benefits through economies of scale, agglomeration effects and networking advantages. Cities with higher levels of agglomeration tend to have higher GDP per capita and higher levels of productivity. The way in which cities facilitate accessibility through their transport systems is also considered to impact on human development, well-being and the environment.

According to the Rode & Floater (2014), rapid urbanisation in sub-Saharan Africa has led to intense traffic congestion, as demand for transport has increased faster than cities can provide. In turn, mounting dependency on motorised transport is creating health and safety risks, impeding economic development, and producing more emissions. A report by UN-Habitat (2013) has commented that those countries that fail to ensure mobility within towns and cities face a risk of weakening economic advantage. They continue, the agglomeration economies are diminished by the lack of connectivity, urban mobility and infrastructure, stressing the need to strengthen urban

[2] National differences mean the distinction between urban and rural populations is not amenable to a single definition for all countries or even to the countries within a particular region: 6% of countries have no official urban definition and 11% report that their population is either entirely urban or entirely rural (Buettner, 2014).

Table 1: ***Traffic congestion and hours lost by drivers per year***

The INRIX 2018 Global Traffic Scorecard is an analysis of congestion and mobility trends in more than 200 cities across 38 countries.

City	Hours Lost in Congestion
Moscow	210
Istanbul	157
Bogota	272
Mexico City	218
Sao Paulo	154

efficiency through a network of well-connected transport links and of promoting public and non-motorised modes of transport.

Despite the importance of efficient and effective urban mobility, national and city governments often provide disproportionate levels of investment and institutional support for private vehicle use relative to public and non-motorised transport (Rode & Floater, 2014). A by-product of this focus is traffic congestion which is considered a growing problem in many cities resulting from rapidly growing populations, increased motorisation rates and the crowding of motorised traffic onto often limited and poorly functioning road networks (see table 1).

Congestion has been estimated to cost as much as 2-4% of national GDPs according to measures such as lost time, wasted fuel, and increased cost to business. In the U.S. alone, congestion cost $305 billion in 2017, an increase of $10 billion from 2016 (INRIX Website[3]). In East Africa, Nairobi (Kenya) is reported to have one of the longest average journey-to-work times in Africa, "heavy congestion, high rates of walking, informal collective transportation, and the spatial distribution of jobs and residents lead to low employment accessibility in Nairobi and the misallocation of labour" (Lall, et al, 2017). The value of time lost to travel in Nairobi is substantial, estimated at US$0.8 to 4 million per workday (World Bank, 2014; JICA, 2014). This is based on the 47 minute average travel time of a journey in Nairobi, daily time costs per capita, valued as a percentage of household income. In a similar vein, research undertaken by Andarjie (2017) in Addis Ababa estimates congestion costs including delay, wasted fuel and operating cost of vehicles at road segments on average at circa Birr 53.2 million (US$1.7 million) per year.

Transport also has a significant impact on urban air quality. Road transport is estimated to be responsible for up to 30% of particulate emissions (PM) in European cities and up to 50% of PM emissions in OECD countries (mostly due to diesel traffic). Although transport emissions per capita in the global south are relatively low compared to OECD countries, around 90% of the increase in global transport-related CO2 emissions is expected to occur in such setting resulting from private vehicles and freight (UNCSD, 2012). LIC and MIC countries suffer disproportionately from transport-generated pollution, particularly in Asia, Africa and the Middle East. In part, this is due to the use of old and inefficient diesel vehicles and a lack of public and active transport networks. Safe, affordable and reliable public transport is considered to be a vital component of successful urban areas, enabling people to reach jobs and services, employers to access labour markets and businesses to serve customers. PWC

[3] http://inrix.com/scorecard/

(2014) notes that on average, cities that are better connected by public transport not only achieve higher economic productivity, greater purchasing power and better quality of life, but also attract more direct investment.

Box 1: ***Major pollutants from motor vehicles (Union of Concerned Scientists - https://www.ucsusa.org/clean-vehicles/vehicles-air-pollution-and-human-health/cars-trucks-air-pollution)***

Air pollution from cars, trucks and buses is split into primary and secondary pollution. Primary pollution is emitted directly into the atmosphere; secondary pollution results from chemical reactions between pollutants in the atmosphere. Heavy-duty vehicles comprise only about 5% of all vehicles on the road, yet they generate more than 25% of global warming emissions and significant amounts of pollution.

Particulate matter (PM). Fine particles pose a serious threat to health. PM can be a primary pollutant *or* a secondary pollutant from hydrocarbons, nitrogen oxides, and sulphur dioxides. Diesel exhaust is a major contributor to PM pollution.

Volatile Organic Compounds (VOCs). These pollutants react with nitrogen oxides in the presence of sunlight to form ground level ozone, a main component of smog. VOCs irritate respiratory systems, causing coughing, choking, and reduced lung capacity. VOCs (including the toxic air pollutants benzene, acetaldehyde, and 1,3-butadiene) have been linked to different types of cancer.

Nitrogen oxides (NO_x). These pollutants form ground level ozone and PM (secondary). Also harmful as a primary pollutant, NO_x can cause lung irritation and weaken the body's defences against respiratory infections such as pneumonia and influenza.

Carbon monoxide (CO). This odourless, colourless, and poisonous gas is formed by the combustion of fossil fuels. When inhaled, CO restricts oxygen to the brain, heart, and other vital organs.

Sulphur dioxide (SO_2). Motor vehicles emit this pollutant by burning sulphur-containing fuels. SO_2 can react in the atmosphere to form fine particles and poses a health risk to young children and asthmatics.

Greenhouse gases. Motor vehicles also emit pollutants, predominantly carbon dioxide, that contribute to global climate change with emissions from cars, trucks and buses account for over one-fifth of US total global warming pollution.

Investigating exposure at air pollution hotspots and the susceptibility of groups that are found in these areas is important as it provides a better understanding of the risk of exposure and serves as an important input into air quality standards. Available studies, drawn from a range of geographic settings, suggest that those who work on or regularly use public transport are often exposed to poor air quality. In such environments a number of factors affect air quality; including emissions from transport, resuspension of dust and air pollutants from surrounding areas. Studies exploring this issue in East Africa are, however, limited. The present study seeks to address this paucity of evidence and was initiated to fulfil four objectives:

1) to measure the levels of $PM_{2.5}$ at bus stations and on buses in Addis Ababa to assess exposure to air pollution;
2) to study the relationship between $PM_{2.5}$ concentrations at bus stations and on buses;
3) to investigate perceptions of air pollution amongst those who work on or use Addis Ababa's bus system (i.e. bus drivers, commuters and street vendors);
4) to develop recommendations to improve air quality or reduce exposure to air pollution amongst the above groups.

Methodology

Based on initial findings from urban profiling and stakeholder mapping alongside data collected in Work Packages 1-5 (WP), six case studies (two per city) are being undertaken that explore the spatial and demographic impact of air pollution, focusing on areas exposed to high levels of air pollution, or particularly vulnerable populations. Case studies focus on the following subset of vulnerability issues: vulnerable locations (e.g. informal settlements or areas close to sources of pollution such as roads or factories); vulnerable populations (e.g. the urban poor, women, children or the elderly who may be more susceptible to air pollution) and vulnerable occupations (e.g. street vendors, motorcycle taxi drivers that may be exposed to higher levels of PM over sustained periods of time). A mixed methods approach is used, combining quantitative and qualitative data collection and drawing on other WPs. This approach includes:

A desk review to identify and incorporate existing and available information, including previously conducted research, surveys and assessments. Our desk review was undertaken using a Boolean methodology searching a range of databases and including both academic and grey literature.

Standardised surveys are conducted in vulnerable areas and amongst vulnerable groups. Surveys are co-designed with research partners and tailored in relation to findings from WP1-5, urban profiles and stakeholder mapping. A total of 20-30 surveys are conducted per case study Survey modules are tailored for specific occupations, locations and populations[4].

Semi-structured key informant interviews are undertaken with a minimum of 5 stakeholders including relevant representatives of; Local Government, Private Sector, Civil Society Organisations and Informal Community based organisations.

Synthesis of data collection and analysis (WP1-5), information gathered from other WPs also informs the development of vulnerability scoping studies.

Study site

The ASAP-East Africa research team partnered with Anbessa City Bus Service Enterprise (a state-owned public transport operator based in Addis Ababa see box 2) to undertake this study exploring air pollution exposure amongst workers and users of Addis Ababa's bus system. Addis Ababa is the capital and largest city of Ethiopia, first settled in the mid-15th century, although the current city was not founded until 1886. According to the 2007 census Addis Ababa has an estimated population of 3,384,569. This figure has been contested by some who believe it to be an underestimate. The city's annual population growth rate has been estimated at 3.8%, with the number of residents expected to grow to 6.2 million by 2025 and 13.2 million by 2050 (Hoornweg & Pope, 2014: 9-10). Addis Ababa is currently home to 25% of the country's urban population and considered Ethiopia's growth

[4] This scoping study includes 30 completed surveys. Respondents included 10 bus drivers, 10 commuters and 10 street vendors.

engine and central to the country's vision of becoming a middle-income, carbon-neutral and resilient economy by 2025. The city alone currently contributes approximately 50% of national GDP, highlighting its strategic role within the overall economic development of the country (World Bank, 2015: 25).

Box 2: ***Anbessa City Bus Service – a history***

Anbessa City Bus Service was the first public transport service to be established in Addis Ababa in 1943 under the auspices of the Ministry of Work and Communication using vehicles and garage materials, which were formally the property of the Italian colonial government. Anbessa was established as a commercial enterprise in 1952. In 1959, the company expanded its coverage from four to fourteen routes and increased the number of vehicles per route from two to three. In 1974 Anbessa became part of the Public Transport Corporation (PTC). It was re-established as a separate entity when the PTC was disbanded up in 1994. Responsibility for Anbessa currently sits with the city administration. Anbessa states as is its vision to 'give modern and fast service which satisfies the need of the public'. It is mandated to provide public transport services to the city and the surrounding areas. The enterprise currently operates over 100 routes, with a fleet size in excess of 800 buses. The enterprise dispatches buses from Legahar, Merkato, Piazza and Megenagna stations. There are over 1,700 check points, where passengers can hail services. It also has four service centres (Yeka, Shegole, Makanisa and Akaki) where there are workshops, gas stations, stores and offices. The enterprise employs over 7,500 staff. Fares on Anbessa buses are set according to distance travelled: trips between 6-12.4 km cost 0.50 Birr. Long distance trips ranging between 9-13km cost 0.75 Birr and trips of 13-15km distance are 1 Birr.

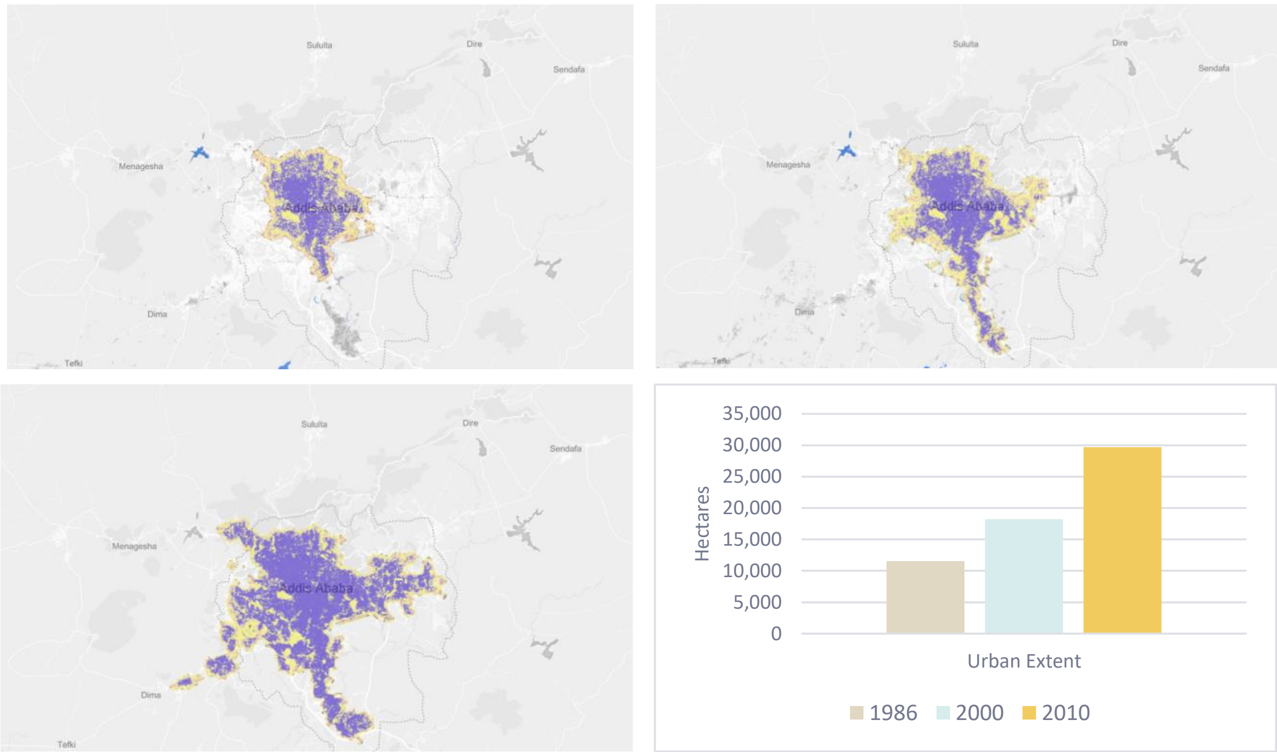
The Addis Ababa and Oromia Special Zone Integrated Development Master Plan (Girma et al., 2019) articulates a vision for Addis that includes three core elements: to be a safe and liveable city; to ensure the national goal of becoming a middle-income country and to become Africa's diplomatic capital and a world class city. To deliver on this vision Addis Ababa must address a number of significant development challenges (World Bank, 2015: 17):

- **Unemployment and poverty levels remain high**, estimated at 23.5% and 22% respectively. More than one in four households include an unemployed adult and the informal sector employs about 30% of the economically active labour force.
- **Local government struggles to deliver basic services to residents**, providing clean water to only 44% of the population and sewerage services to less than 30%. Transport infrastructure is also overburdened.
- **Urban development is driving up the cost of infrastructure delivery**. Growth in urban extent is outpacing population growth.

Urban expansion along the city's five radial roads has led to increased transportation costs, congestion, and posed challenges for the delivery of public infrastructure services. Historically there has been a lack of coordination between transport investment and urban development. According to the World Bank (2014) housing and land-use decisions have typically been based on the availability of land, with limited assessment of transport impacts, minimising opportunities to integrate public transport in terms of coverage, routes, fares, schedules and facilities. Low coverage of streets and a lack of a street grid network and associated infrastructure has resulted in mobility challenges and impacted on productivity, quality of life and social inclusion. Walking and public transport are the main modes of transport in the city, with an estimated 2.2 million people using public transport and circa 3.6 million trips occurring on a daily basis (Fenta, 2014: 122).

Box 3: ***Addis Ababa Urban Extent 1986 (top left), 2000 (top right), 2010 (bottom left) Purple = Urban Built Up Yellow = Urbanized Open Space (Atlas of Urban Expansion -*** *http://www.atlasofurbanexpansion.org/cities/view/Addis_Ababa* ***)***

The urban extent in 2000 was 18,245 hectares, increasing at an average annual rate of 3.1% since 1986, when its urban extent was 11,550 hectares. In 2010 this had increased to 29,628 hectares, an average annual rate of growth of 4.8% since 2000.



Whilst congestion is increasing, one mitigating factor has been the city's low motorisation rate. In 2016, the total vehicle fleet in Addis Ababa was estimated at 447,669. Experience worldwide suggests that vehicle ownership increases with per capita income levels, implying that growth in vehicle ownership is likely to increase rapidly in the foreseeable future.

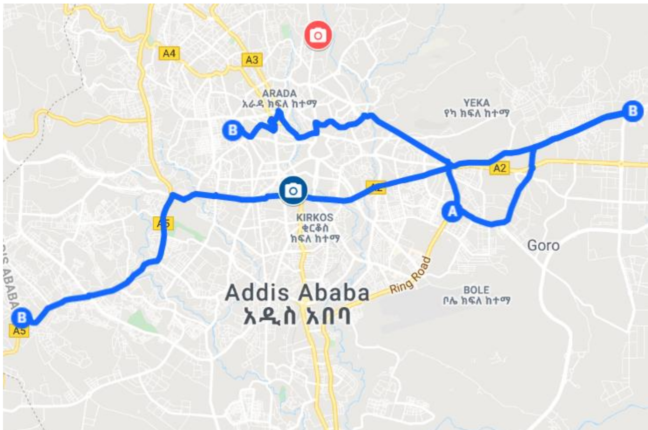
Given low rates of motorisation, congestion in the city suggests shortcomings in traffic management, rather than a fundamental mismatch between transport supply and demand (World Bank, 2014: 3). Poor traffic management makes travel times by public transport longer and more expensive, driving up the cost of public transport provision for the operators. Traffic management issues are related to: (i) limited institutional capacity and ineffective traffic management; (ii) pedestrian safety concerns and high accident rates; (iii) lack of traffic control at major intersections and few signalised junctions; (iv) lack of a central control system (World Bank, 2014).

Table 2: ***Total number of vehicles Addis Ababa: Road networks and Vehicle to Road length ratio (Tarekegn and Gulilat, 2018: 8)***

Year	Total Road Network (km)	Total Vehicles	Vehicles/km
2012	1807	310,180	172
2013	2002	326,994	163
2014	2165	360,869	167
2015	2443	410,101	168
2016	2616	447,669	171

Improvements to urban mobility and the provision of public transport, have the potential to significantly contribute to the city's plans for improving air quality, as well as providing socio-economic, environmental and sustainability co-benefits (C40)[5]. In recent years, Addis Ababa has been making a concerted effort to improve the urban transport situation, investing in new infrastructure, including roads, a Light Rail Transit system (LRT) and plans for a Bus Rapid Transit system (BRT), as well as improved standards and practices for integrating pedestrian facilities in major transport projects.

Image 1: ***Location of Addis Ababa Stadium bus Station (Blue Circle), US Embassy (Red Circle) and the bus routes on which air pollution was monitored (Blue Lines)***



To gather data on exposure to air pollution, the ASAP-East Africa research team monitored outdoor air pollution at Addis Ababa Stadium bus station. Measurements at the bus station were collected between the 4th and 12th of September 2019 and bus measurements were conducted on 15th and 16th of August 2019. Measurements were collected using calibrated Alphasense optical particle counters (OPC-N2) which recorded $PM_{2.5}$ and PM_{10} at ten-second intervals, aggregated to one-hour time steps. The calibration approach and the use of the OPC-N2 are discussed in Crilley et al. (2017) and Pope et al. (2018). Bus station sensors were located 1.5 meters above the ground at a point where passengers

[5] https://www.c40.org/awards/2016-awards/profiles/107

assembled or que for buses. Sensors deployed on buses were mounted on the passenger seat near the central entrance door. To contextualise these measurements, data was also gleaned from the air pollution monitor located at the United States Embassy operated by US EPA.

Thirty volunteers including bus drivers (10), street vendors (10) and commuters (10) were recruited and surveyed by ASAP-East Africa researchers to explore perceptions of air pollution. Exploring these perceptions provides an opportunity to investigate societal attitudes towards air pollution and to draw associations between perceived and actual exposure. A number of studies have identified correlations between perceptions of air quality and monitoring data (Hunter et al., 2004) whilst other studies challenge this association (Semenza et al., 2008). Given the small number of participants involved, the survey is primarily used for illumination purposes to identify areas of future research and to highlight broad trends and differences across participant responses. Surveys were conducted in English and Amharic.

Vulnerability and air pollution

Understanding vulnerability to air pollution presents a unique challenge for researchers. Authors commonly refer to vulnerability as the level of exposure of human life, property and resources to the impact from hazards (in this case air pollution) (Fussell, 2007; O'Brien et al., 2009). Factors, such as sex, age, education, and occupational exposure can modify the relationship between hazards and mortality (Kan et al., 2008). Further to this, the effects of air pollution exposure on health are considered greater in people from lower socioeconomic backgrounds (O'Neil, 2003). According to Stilianakis (2015: 10-11) exposure to air pollution may have different effects on individuals and population groups due to differences in innate and acquired characteristics. Innate characteristics are mainly biological and physiological and reflect the capacity of the human body to respond to exposure. Acquired factors, such as socioeconomic status, are those that affect social coping or adaptive capacity and do not allow the individual or the population group to minimise exposure. Vulnerability is thus considered to involve two components:

- External risks, shocks and stresses to which an individual or household is subject.
- Internal abilities which offer a means for coping without causing damage or loss.

The ASAP-East Africa programme adopts the WHO's (2004) definition of vulnerability i.e. "the likelihood of being unusually severely affected by air pollutants either as a result of susceptibility to the effects of these substances or as a result of a greater than average exposure". Three dimensions of vulnerability are commonly identified in the literature and are explored in the ASAP-East Africa Vulnerability Scoping Studies (Howe et al., 2013):

- **Exposure** i.e. the degree to which the subjects or areas could be effected by air pollution.
- **Susceptibility** i.e. the likelihood of being harmed by air pollution.
- **Adaptive capacity** i.e. the ability to take actions to either reduce or avoid risk.

Vulnerability may thus be compounded by factors including location; adaptive capacity (i.e. the ability to protect oneself from harm including access to materials, technology, knowledge, information and social protection), the extent of assistance and support, including services, resources and technical expertise, that society can provide. For an overview of relationships between population, location and occupation characteristics and associated factors that contribute to vulnerability see Avis and Khaemba (2018: 20).

An individual's vulnerability to air pollution is thus complex, the product of interactions between environmental stressors, innate and acquired susceptibility, differential exposure and adaptation mechanisms (US EPA, 2003). Further to this, vulnerability to air pollution consists of a number compounding factors inherent in the individual and influenced by broader social or environmental contexts e.g. smoking and co-exposures. It is also important to note that concerns regarding air pollution compete for space alongside a number of other issues (see table 3).

Table 3: ***Survey respondents ranking of issues of concern (1 = most pressing concern, 10 = least pressing concern)***

Concerns	
1. Food shortages	6. Energy shortages
2. Lack of clean drinking water	7. Energy shortages
3. Lack of employment opportunities	8. Government corruption
4. Poor healthcare	9. Lack of access to clean toilets
5. Air pollution	10. Crime

Vulnerability Dimensions

In the context of ASAP-East Africa research, exposure to high levels of particulate matter (PM) is a focus. PM or atmospheric aerosols is the term used to indicate any solid or liquid particles suspended in the atmosphere. Atmospheric particles vary widely in their physical parameters such as size and chemical composition. PM is generated from a variety of natural and anthropogenic processes. Natural sources of PM include dust storms, ocean/sea spray (sea salt), dust erosion due to wind, forest fires, volcanic eruptions, and the release of biogenic PM (e.g. pollen and spores). Man-made sources include traffic, non-combustion and combustion industrial processes, power plants, construction activities, agricultural activities (including agricultural waste burning) (Haq & Schwela, 2008: 6). A key contributor to heightened levels of PM in urban settings is the combustion of solid and liquid fuels for power generation, domestic heating, cooking or lighting and in vehicle engines. PM of small size fractions are considered to be particularly detrimental to public health as they can enter the respiratory system and lead to respiratory disease, asthma, strokes, cancer and heart disease (Thurston et al., 2016). Other health-effects of exposure to air pollution include dermal absorption and ocular exposure which may result in eye or skin irritation. The smaller the size of PM particle, the more impact they are considered to have on health. $PM_{2.5}$ and PM_{10} are particulate matter with aerodynamic diameters less than 2.5 and 10 µm, respectively (Seinfeld & Pandis, 2016). The $PM_{2.5}$ size fraction is the focus of this study since it has greater association with determinental health outcomes.

To guide discussions of vulnerability to air pollution, the ASAP-East Africa research team have adapted the US Environmental Protection Agencies (US EPA) Air Quality Index Scale to illustrate how different levels of air pollution contribute to different health impacts amongst different groups. An air quality index identifies limits on the amount of a given pollutant in the air. The standards are designed to protect people's health and have been calculated to allow a margin for people most at risk e.g. the young and old and people with pre-existing health conditions. The ambient air quality standards most often utilised include those developed by the European Union, the United States and the WHO. The WHO air quality standards (25 μg/m^3 24 hour mean) are not legally binding, rather they represent a guideline for countries and are significantly tougher than those suggested by others. Table 4 provides a guide to different levels of exposure to $PM_{2.5}$ over a 24 hour period, health implications associated with that level of exposure and provides a cautionary statement identifying those groups likely to be affected.

Table 4: ***Air Quality Index scale as defined by the US EPA (2016)***

$PM_{2.5}$ μg/m^3 (24 hour average)	***Air Pollution Level***	***Health Implications***	***Cautionary Statement for $PM_{2.5}$***
0.0-12.0	Good	Air quality is considered satisfactory, and air pollution poses little or no risk.	None
12.1-35.4	Moderate	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.	Active children and adults, and people with respiratory disease such as asthma should limit prolonged outdoor exertion
35.5-55.4	Unhealthy for Sensitive Groups	Members of sensitive groups may experience health effects. The general public is not likely to be affected.	Active children and adults, and people with respiratory disease such as asthma should limit prolonged outdoor exertion
55.5-150.4	Unhealthy	Everyone may begin to experience health effects; members of sensitive groups may begin to feel more serious health effects.	Active children and adults, and people with respiratory disease such as asthma should limit prolonged outdoor exertion; everyone else, especially children, should limit prolonged outdoor exertion.
150.5-250.4	Very Unhealthy	Health warnings of emergency conditions. The entire population is more likely to be affected.	Active children and adults, and people with respiratory disease such as asthma should limit prolonged outdoor exertion; everyone else, especially children, should limit prolonged outdoor exertion.
250.4-500.4	Hazardous	Health alert; everyone may experience more serious health issues.	Everyone should limit outdoor exertion.

Exposure

Exposure denotes the degree to which subjects or areas could be affected by air pollution. The level of exposure is generally defined by several components and measures including: the frequency and intensity of exposure and the location relative to sources of air pollution. Exposure to air pollution is thus largely determined by the concentration of air pollutants in the environments where people spend time and the duration spent within them.

To understand exposure of vulnerable populations to air pollution it is therefore important to identify the micro-environments in which they spend significant amounts of time.

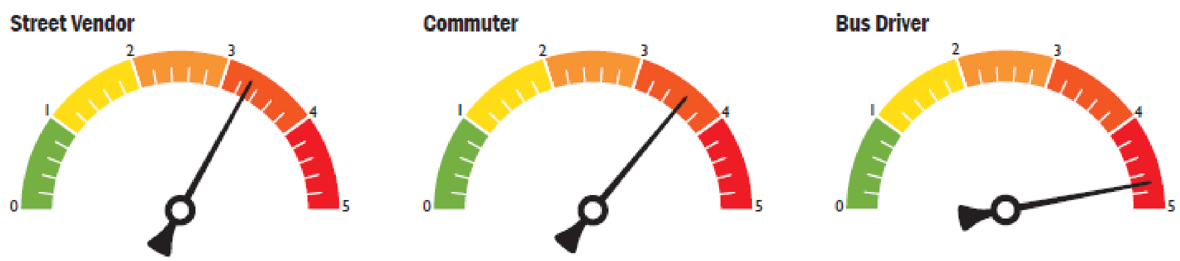
Locations with locally increased air pollution are often referred to as hotspots. The elevated pollution levels in such locations may be the product of limited dispersion of pollutants (e.g. a street canyon) or high local emissions (e.g. near a highway, railway station, airport, harbour, or in the case of this report, a bus station or bus). Air pollution levels in such hotspots warrants further exploration, however, few studies have examined exposure in such locations (WHO, 2005: 68).

Alongside hotspots, some groups may be exposed to higher levels of pollution e.g. people who live and work near busy roads and those who travel or commute in heavy traffic. The intake of pollutants is itself influenced by choice of transport e.g. drivers, cyclists, and pedestrians as well as the routes used. Exposure to transport-related air pollution is thus difficult to separate from exposure to total air pollution.

To gauge perceptions of air pollution, bus drivers (10), street vendors (10) and commuters (10) were asked the following questions, “do you consider the air at the bus station to be polluted?” Of the sample 90% (27 of 30) indicated that they felt they were exposed to air pollution at Addis Ababa Stadium bus station (all respondents bar three street vendors). Commuters and bus drivers were also asked “do you consider air on the bus to be polluted?” 100% (20 of 20) responded yes.

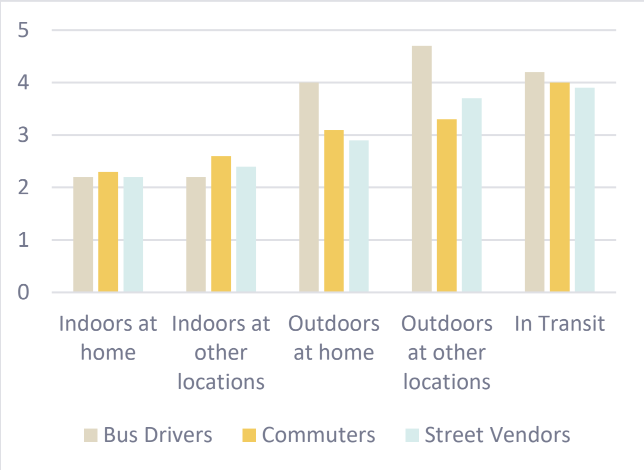
Survey respondents were also asked “how would you rate your vulnerability to air pollution on a scale of 1-5 (one being not vulnerable at all, five being extremely vulnerable)?” Survey responses were grouped according to occupation and commuter status. The average score of those surveyed was 3.87/5, suggesting a relatively high perception of vulnerability. There was, however, variance across the different groups surveyed – bus drivers considered themselves most vulnerable (4.7/5), commuters reported an average vulnerability score of (3.6/5) finally street vendors considered themselves least vulnerable (3.3/5).

Figure 1: ***Survey respondent’s perceptions of vulnerability by occupation and commuter status***



To explore perceptions of air pollution exposure further, survey respondents were asked to provide an assessment of air pollution levels at different locations (indoors at home, indoors at other locations, outdoors at

Figure 2: ***Survey respondents perceptions of air pollution levels (1 being not polluted at all, 5 being extremely polluted)***



home, outdoors at other locations, and in transit). Bus drivers identified higher levels of air pollution in the majority of settings, with street dwellers recording broadly similar perceptions of air pollution exposure in all locations.

Air pollution exposure in Addis Ababa

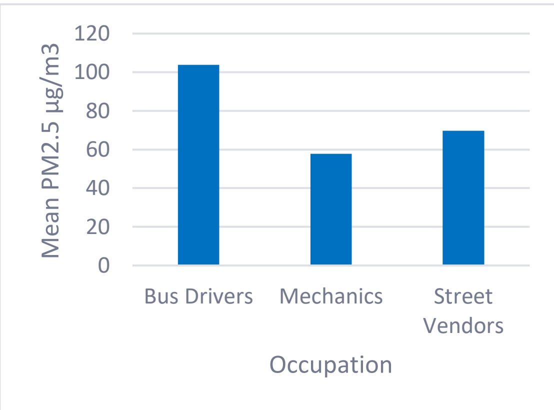
Air quality is considered to be declining and an issue of increasing concern. This decline is thought to be exacerbated by population growth, increasing numbers of vehicles, construction and the continued widespread use of biomass as a source of fuel for cooking and heating. The Addis Ababa 2002 - 2010 master plan acknowledged the role public transport plays in the city and the increasing pressure on transport services due to factors including an insufficient number of buses, passenger security at transport and freight terminals and a sub-standard traffic management system. Subsequently, the Transport Policy adopted in 2011 promoted the expansion of mass transport systems along with non-motorised mobility to achieve a more socially inclusive, economically affordable, environmentally friendly and technologically advanced transport system.

Despite this commitment, population growth and increasing numbers of vehicles within the city has exacerbated congestion and concomitantly led to worsening air quality. Vehicle registration has grown from circa 310,180 in 2012 to circa 447,669 in 2016 (Tarekegn & Gulilat, 2018: 8). Congestion has emerged as an issue of particular concern. Commuters surveyed for this report indicated a range of average daily commute times with the majority indicating daily commutes of over an hour - 0-20 minutes (1 respondent), 21-40 minutes (1), 81-100 minutes (2), 100-120 minutes (3) and over 121 minutes (2).

Air pollution exposure at bus stations and on buses

Bus drivers, commuters and street vendors may be exposed to higher levels of vehicle-based pollution, including PM, while waiting or working at bus stations, because of their proximity to the roadway and the types of vehicles operated in these areas. Although the study of exposure to air pollutants at bus stations and on buses is not a new field of research, there has been limited focus on this issue in East Africa. Several studies, predominately drawn from Europe, the US and South Asia, have assessed levels of pollution at bus stations using a variety methods, and found that the $PM_{2.5}$ and PM_{10} levels are often high compared with standard air quality guidelines (Dales et al., 2007; Velasco & Tan, 2016). Air quality monitoring studies conducted by the Centre for Science and Environment (India) have also shown that the particulate levels that people are exposed to while travelling can be 2-4 times higher than ambient concentrations.

*Figure 3: **Summary statistics of 8-hr average $PM_{2.5}$ concentrations (µg/m3) (Ngo et al., 2015)***



Studies have also explored the issue of occupational exposure, with a limited number of these exploring this issue in African cities. The work of Ngo et al. (2015) explored average exposure to $PM_{2.5}$ µg/m^3 amongst bus drivers, mechanics and street vendors in Nairobi during an eight hour period. Findings suggested that bus drivers and street vendors may be particularly vulnerable to air pollution due to prolonged exposure in highly polluted areas.

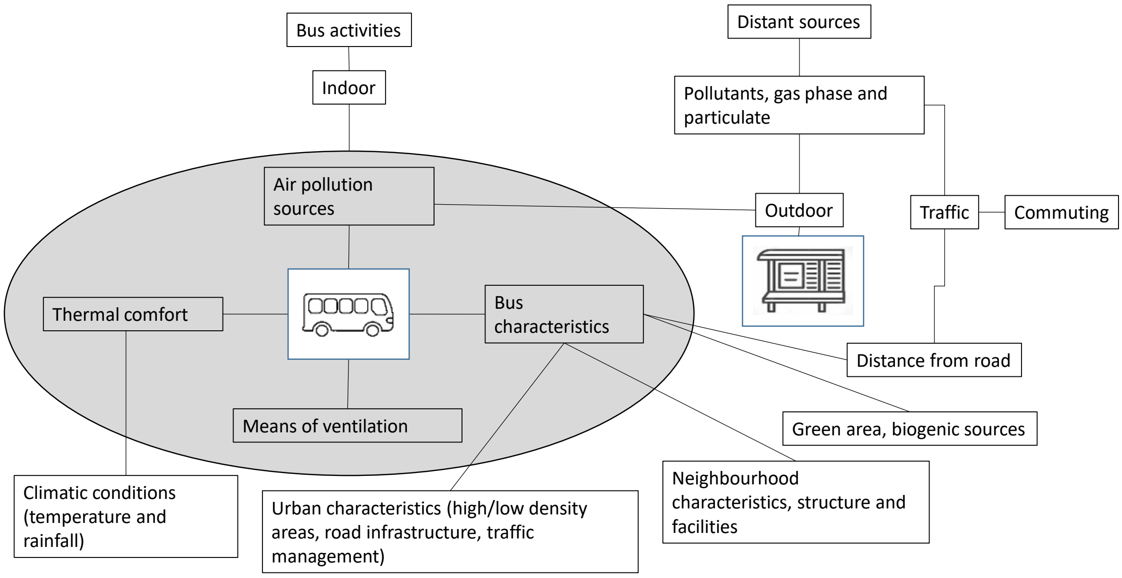
These studies acknowledge that bus stations and buses represent complex settings in which to undertake air quality assessments with a number of factors influencing exposure. Factors affecting the characteristics and composition of PM include industrial emissions and meteorological factors (temperature, humidity, wind speed, rain fall) as well as bus station related factors such as fuel combustion, vehicle maintenance and age, smoking and vehicle flow (Ngoc et al., 2018 and see image 2). These factors are in turn affected by other aspects inside and outside bus station and bus environments.

On-bus air quality represents an even more complicated picture. Buses that operate close to industrial areas, busy roads or sources of dust are likely to experience higher levels of air pollution. Quantifying the contribution of on-bus exposure with observed health symptoms, poses further challenges. In addition to ascertaining the impact of ambient exposure, daily patterns of physical and traffic activity make it difficult to compare exposures in different environments (WHO, 2000).

Assessing air pollution in such settings requires outdoor assessment techniques, including efforts to estimate personal exposure and quantification of contribution from a variety of sources. Improving understanding of activity patterns and practices is also an essential input into the development of effective interventions, such as clean air zones, improved traffic management and educational programmes.

Understanding the relative contribution of exposure in such locations to population disease burden will also enable investigation of what intervention measures are most suitable to the local context and meet the needs of end users. Identifying feasibility and acceptability of such measures requires mixed-methods research to identify barriers and facilitators for intervention uptake.

*Image 2****: Representation of factors and linkages with possible impact on the indoor air quality at bus stations and on buses (adapted from Salthammer et al., 2016: 197)***



Although reliable data on commuter habits are sparse, statistics collected by the WHO (2005) present a consistent global picture. In general, people seem to spend 1–1.5 hours a day travelling, though this varies with occupation, age, gender and socioeconomic status. High levels of exposure may be determined by the means of transport and the places where people spend the majority of their time – that is, where they work or live.

Bus station exposure

Table 5: ***Average and peak bus station $PM_{2.5}$ ($\mu g/m^3$) daily concentrations***

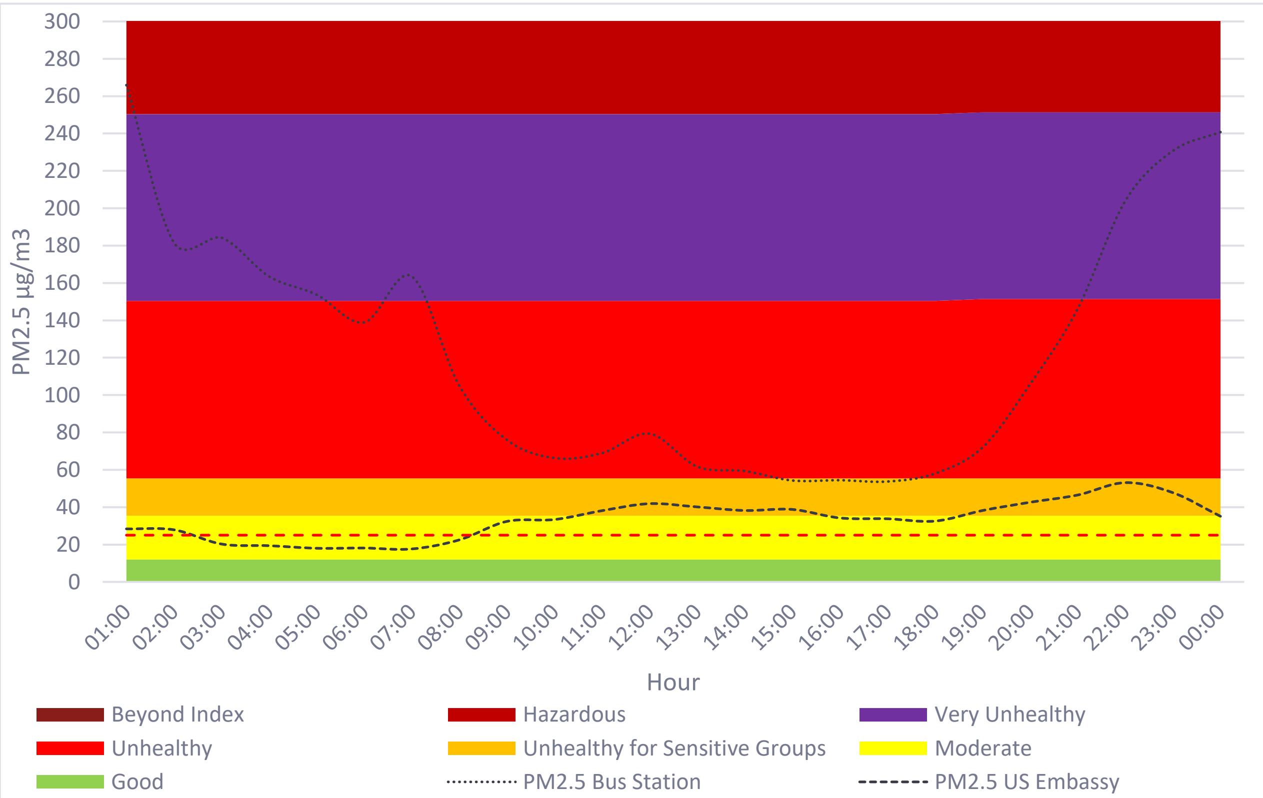
Average $PM_{2.5}$ ($\mu g/m^3$) daily concentration (week day)	Average $PM_{2.5}$ ($\mu g/m^3$) daily concentration (weekend)	Average $PM_{2.5}$ ($\mu g/m^3$) daily concentration (Combined)	Peak concentration $PM_{2.5}$ ($\mu g/m^3$)
117 ± 110	101 ± 58	113 ± 99	323 ± 203

Whilst the majority of studies exploring air pollution monitor background ambient air pollution levels, air quality at particular hotspots is also a concern, particularly in locations where large numbers of people spend significant amounts of time e.g. bus stations. Studies of air quality that focus on background readings or fixed location monitoring alone may fail to provide an accurate estimation of variance in exposure between different locations. This is particularly important given that time activity patterns vary significantly between groups. When compared with the general population, people with outdoor occupations in urban areas are typically exposed to higher concentrations of transport-related air pollution and may be in contact with it for longer periods. Such occupations include police officers, taxi and bus drivers and street vendors. The extent of exposure to transport-related air pollution for many of these occupations is, however, poorly understood (WHO, 2005).

Indeed in this study, whilst commuters will only spend a limited period of time at bus stations, the duration of exposure for bus drivers and street vendors will be significantly higher. Bus drivers reported spending significant periods collecting passengers from a number of bus stations and stops across the city working. In turn, street vendors reported spending between six and fifteen hours per day working in close vicinity to the bus station (working on average 10.5 hours daily with 6/10 respondents indicating they worked seven days a week). These figures suggest that some street vendors may spend an estimated 44% of their time in the vicinity of bus stations.

For our study, bus station sensors were located 1.5 meters above the ground at a point where passengers assembled or queue for buses. At the bus station monitoring site, the average $PM_{2.5}$ daily concentration was 113 ± 99 µg/m³ and peak concentration was 323 ± 203 µg/m³ (see figure 4). Over the eight days air quality was monitored, pollution levels exceeded WHO guidelines for $PM_{2.5}$ at all times and on all days monitored. Outdoor air quality at bus stations is thus considered to be at persistently unhealthy levels. To contextualise these readings, figure 4 maps both outdoor air pollution data collected at the bus station and data collected from the US Embassy onto the US EPA air quality index during an average day. At the US Embassy monitoring site, the average $PM_{2.5}$ daily concentration was 33 ± 22 µg/m³ and peak concentration was 81 ± 10 µg/m³ (see figure 3).

Figure 4: ***Average bus station concentration of $PM_{2.5}$ (outdoor)***



Bus exposure

In-vehicle concentrations are highly variable and depend upon many factors including travel mode, meteorology, fleet mix, traffic parameters, fuel type, cabin ventilation, exhaust treatment, filtration, deposition etc. (Ham et al., 2017). Although people spend comparatively relatively little time travelling, they may be exposed to high levels of air pollution during these periods which can be attributed to two main factors; many transport environments are often more heavily polluted than other areas and, most journeys are made during rush hours, when the increased volume of traffic results in high ambient pollution levels.

Studies in China have shown that background fixed site monitoring data did not capture disparities in personal commuting exposure, especially during rush hour periods (Huang et al. 2012). Analysing exposure on different modes of transport (taxi, bus and cycling) the authors found that the mean concentrations of $PM_{2.5}$ (µg/m^3) during commutes were as follows; taxi 31.64, bus 42.4 and bicycle 49.10 (Huang et al. 2012). Similar findings have been reported in India with Pant et al. (2017: 170) estimating average $PM_{2.5}$ concentrations (1 min average) for auto rickshaw and buses as 59.4 (2.37) and 53.9 (1.98) µg/m^3.

Whilst the ASAP study focuses on $PM_{2.5}$, it is important to note that other pollutants are often found to be at elevated levels. Comparisons between in-vehicle exposures and concentrations at background measurement sites have demonstrated increased exposures to a number of pollutants. A summary of 16 studies conducted in the US between 1966 and 1994, found that the carbon monoxide concentration in vehicles was generally about 3.5 times higher than ambient levels. A number of European studies provide a similar picture (van Wijnen & van der Zee, 1998). In-car exposure to benzene has been shown to be 5–8 times higher than city background concentrations (van Wijnen et al., 1995). Studies carried out in Amsterdam and Delft (Holland), Frankfurt-am-Main (Germany) and elsewhere reported in-car exposure to nitrogen dioxide to be 1.5 times city background concentrations (van Bruggen et al., 1991).

Exposures to primary exhaust gases and PM are especially high as these penetrate the vehicle either directly from the exhaust system or by recirculation from outside. Exposures to $PM_{2.5}$ were up to 11 times higher in London than urban background concentrations reported in other studies, while the mass of $PM_{2.5}$ was only some 2.3 times higher (Adams et al., 2002).

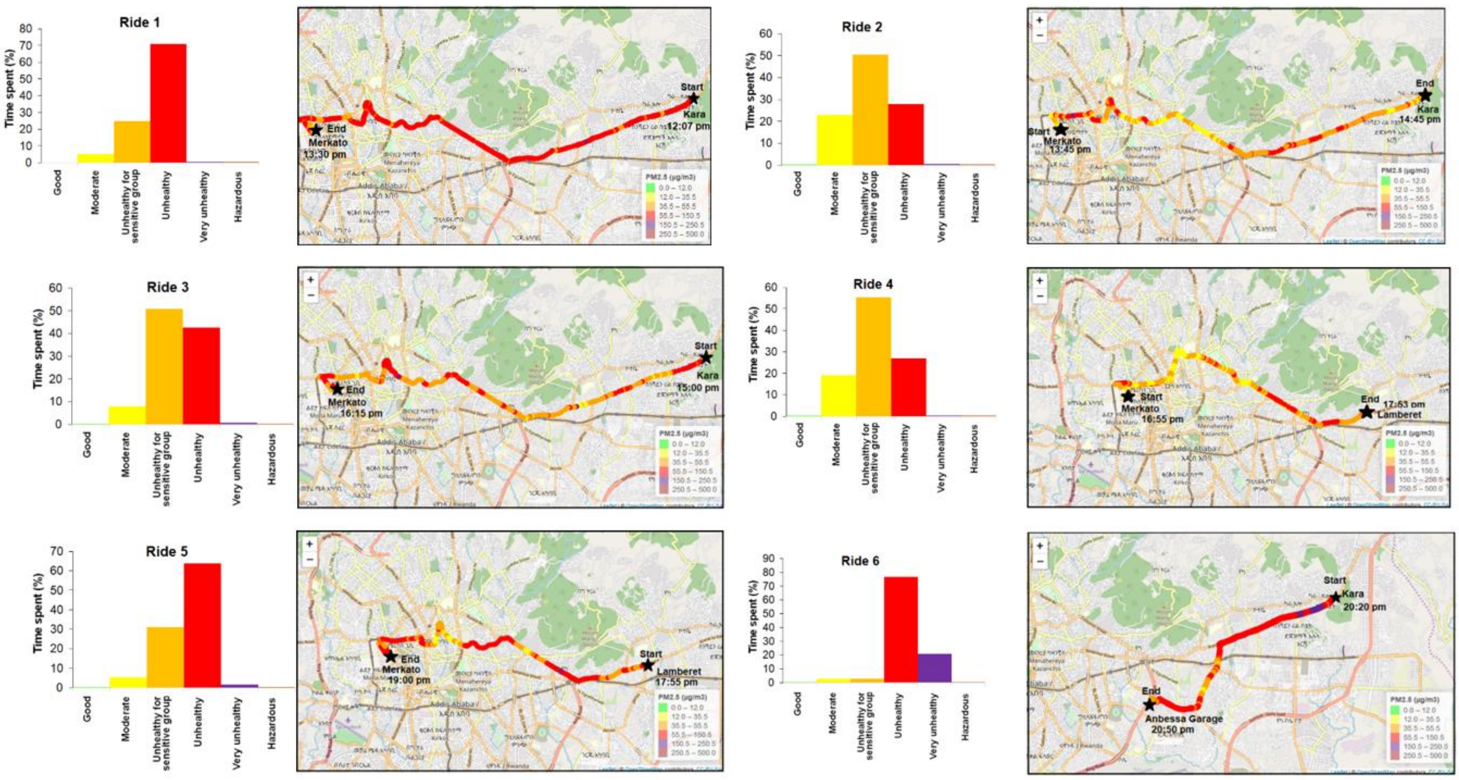
For our monitoring study, sensors deployed on buses were mounted on the passenger seat near the central entrance door. To contextualise these measurements, data was also gleaned from the air pollution monitor located at the United States Embassy operated by US EPA.

Findings from this study illustrate that bus drivers and commuters who spend extended periods of time on Addis Ababa's roads are exposed to consistently poor air quality. Across the journey's studied air quality levels ranged between $PM_{2.5}$ 49 ± 19 µg/m^3 and 105 ± 45 µg/m^3. According to the US EPA air quality index, this range entails air quality that is consistently unhealthy for sensitive groups or unhealthy. Histograms illustrate the percentage of each journey spent in different levels of air quality and highlight the consistently poor air quality that bus driver's and commuters are exposed to during the study period.

*Table 6: **Mean journey $PM_{2.5}$ µg/m^3 concentration (colour coded according to the US EPA AQI)***

Journey	Ride 1 (a)		Ride 2 (b)		Ride 3 (c)		Ride 4 (d)		Ride 5 (e)		Ride 6 (f)	
	Start Kara (12:07)	End Merkato (13:30)	Start Merkato (13:45)	End Kara (14:45)	Start Kara (15:00)	End Merkato (16:15)	Start Merkato (16:55)	End Lamberet (17:53)	Start Lamberet (17:55)	End Merkato (19:00)	Start Kara (20:20)	End Anbessa Garage (20:50)
Mean journey $PM_{2.5}$ concentration	70 ± 24 µg/m^3		50 ± 19 µg/m^3		59 ± 23 µg/m^3		49 ± 19 µg/m^3		70 ± 28 µg/m^3		105 ± 45 µg/m^3	

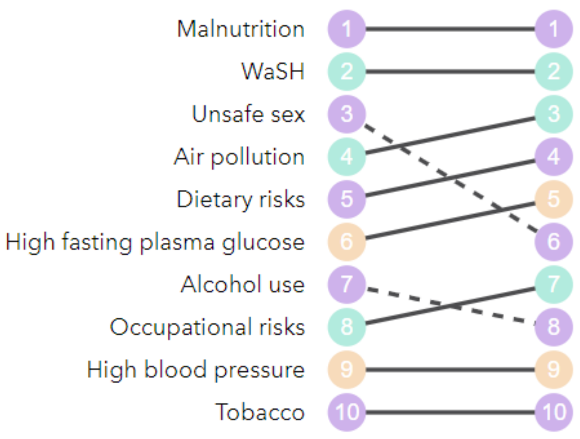
*Figure 5: **Bus journey monitoring combining air quality and global positioning (GPS) data to estimate exposure to air pollution on buses. Histograms illustrate proportion of journey spent in different levels of air quality***



Susceptibility

Susceptibility to air pollution is more difficult to assess than exposure and one needs to consider both its components and measures. Demographic factors such as age, gender, and socioeconomic status play an important role in assessing susceptibility to air pollution. However, these factors are highly context-specific, and can also interact with one another. Whilst it is difficult to quantify premature mortality related to air pollution, notably in regions where air quality monitoring is absent or limited, and because of the toxicity of particles may vary**,** various authors conclude that model projections based on a business-as-usual emission scenario indicate that the contribution of outdoor air pollution to global premature mortality could double by 2050 **(**Lelieveld et al., 2015).

Figure 6: ***Risk factors drive the most death and disability combined in Ethiopia 2007 and 2017 (IHME Website)***



In 2007 air pollution was estimated by IHME to be the fourth leading cause of death and disability in Ethiopia (2017 saw air pollution move to third on the list). Evidence gleaned from epidemiological studies has highlighted links between air pollution and premature mortality particularly from cancer, cardio-respiratory diseases and stroke (Shah et al., 2015). The number of studies that explore the effects of transport-related air pollution on health have increased substantially, although it is only a fraction of the total evidence on the effects of urban air pollution on health. A review of this evidence indicates that transport-related air pollution affects a number of health outcomes, including mortality, non-allergic respiratory morbidity, allergic illness and symptoms (such as asthma), cardiovascular morbidity, cancer, pregnancy, birth outcomes and male fertility. Transport-related air pollution increases the risk of death, particularly from cardiopulmonary causes, and of non-allergic respiratory symptoms and disease (WHO, 2005). More recent evidence also suggests that exposure to air pollution can impact on cognition, cognitive decline (Shehab & Pope, 2019) and influence the onset of dementia (Moulton & Yan, 2012). In general, both long-term and short-term exposures have been shown to be associated with risk. However, few studies have explored in depth the impact air pollution exposure associated with transport can have on public health in East Africa.

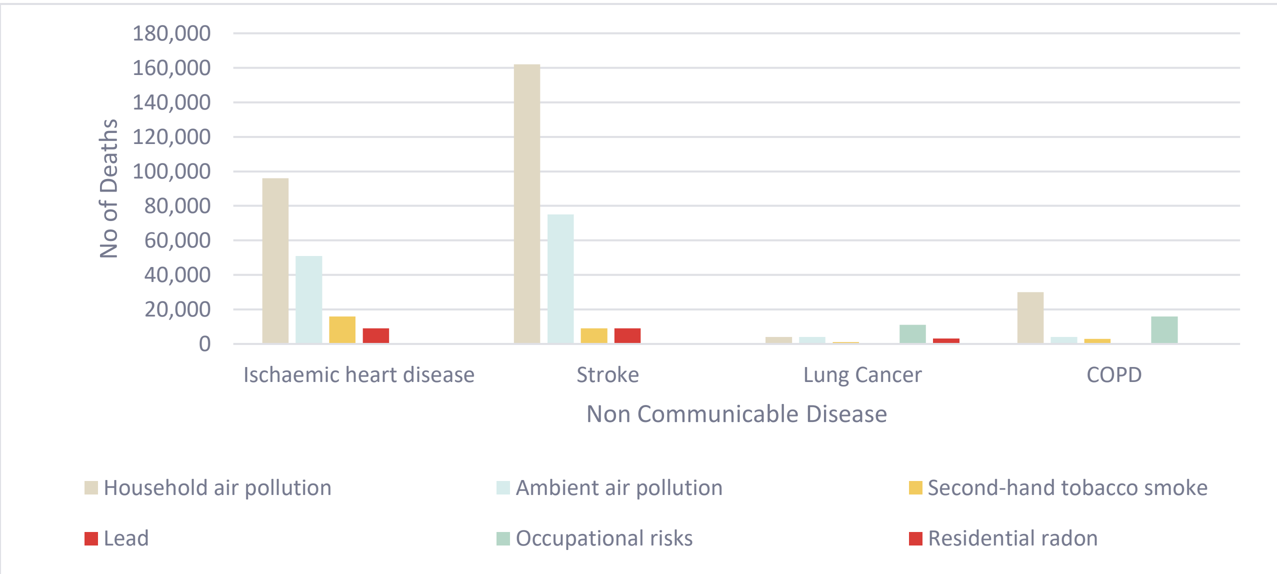
Air pollution from motorised transport in cities is considered to represent a large and increasing public health problem, particularly in the rapidly growing urban agglomerations of emerging economies. Outdoor air pollution, much of it generated by motorised transport (including suspended PM, sulphur oxides, carbon monoxide, nitrogen oxides and ozone) is thought to contribute to a range of cardiovascular, pulmonary and respiratory diseases (Zhang, Mauzerall et al. 2010), a significant contributor to the estimated 3.2 million deaths a year associated with ambient air pollution (OECD, 2014).

Bhalla et al. (2014) estimated that in 2010, total deaths attributable to transport-related air pollution were at a minimum of 184,000 a year, with the number of deaths increasing by over 10% in the previous two decades. A study by the International Council for Clean Transportation (ICCT) reached a similar conclusion, estimating mortality attributable to ambient particulate matter $PM_{2.5}$ from motor vehicles at 230,000 deaths per year in 2005 (Bhalla, et al., 2014). Cities are particularly impacted by transport-related emissions because high numbers of vehicles emit at ground level in areas that are densely populated. The growth in vehicle-derived urban air pollution in some cities has been particularly rapid: the city of Bengaluru, for example, experienced on average a 34% increase in air pollutants between 2002 and 2010 (Alpert, Shvainshtein et al., 2012), of which 41% of PM_{10} and 67% of NOx emissions were attributable to road vehicles (Bansai & Bandivadekar, 2013).

Whilst not definitively linked to transport related exposures, the Addis Ababa City Administration Health Bureau report that a number of illnesses have grown significantly in recent years. The diagnosis of respiratory disease has increased substantially, acute upper respiratory disease has increased from 4,539 (2003) to 212,590 (2017) an average increase of 47.18% per year. Similarly, acute bronchitis has increased annually by 55.62%. Respiratory diseases like Chronic Obstructive Pulmonary Disease (COPD) have a rate of annual growth of about 53.44%, whilst only 8 incidents were recorded in 2013, this increased to 1,871 in 2017. Similarly, the incidence of pneumonia was 575 in 2013 leaping to 29,844 in 2017. This may be a result of better reporting.

More broadly, worsening air quality has been associated with a range of health issues. Air pollution is the second leading cause of deaths from non-communicable diseases (NCDs) after smoking (WHO, 2019). Household and outdoor air pollution have been recognised as one of the risk factors for NCDs, alongside unhealthy diets, smoking, alcohol abuse, and physical inactivity. Worldwide, 24% of stroke cases, 25% of ischaemic heart disease (IHD), 28% of lung cancer and 43% of COPD were attributable to ambient and household air pollution in 2016, and evidence on additional NCDs is emerging (WHO, 2016; 2016a). In Ethiopia NCDs are estimated to account

Figure 7: ***Deaths from main NCDs in Africa attributable to environmental risks in 2012 (WHO, 2019)***



for 39% of all deaths with cardiovascular disease (16%), cancers (7%) and chronic respiratory diseases (2%) considered significant (WHO, 2018: 87).

Air pollution from transport also exacts a substantial economic cost: the OECD estimates that road transport accounted for approximately half of the total estimated annual cost of outdoor air pollution of US$1.7 trillion in 2010, in addition to representing a substantial percentage of the economic cost in China and India (US$1.4 trillion and US$500 billion respectively) (OECD, 2014). A recent estimate suggested that the heavy haze in China in January 2013 alone caused US$3.7 billion in direct losses to society (Mu & Zhang, 2013).

Occupational susceptibility

Several epidemiological studies showed associations between mortality and occupational exposure to transport emissions, though not all found a statistically significant increase in risk. A retrospective study of the effects of occupational exposure to carbon monoxide on mortality from heart disease (Stern et al.,1988) found that tunnel officers had higher mortality from arteriosclerotic heart disease than people in the general population of New York City (standardised mortality ratio (SMR): 135; 90% CI: 109–168). Tunnel officers also had a higher risk of mortality than the less-exposed bridge officers, which leads to the hypothesis that motor exhaust might increase the risk of death. A prospective study on mortality of professional drivers in London – particularly lorry drivers – showed excess deaths from stomach cancer, lung cancer, bronchitis, emphysema and asthma, although there were significantly fewer deaths than expected from all causes and circulatory diseases (Balarajan & McDowall, 1988). This pattern, however, could not be confirmed in taxi drivers.

The possible relationship between occupational exposure to vehicle exhaust and cancer risk has also been explored in a Danish cohort study (Hansen, 1993); lorry drivers were followed for cause specific mortality for a ten-year period. The study highlighted increased mortality from lung cancer (SMR: 160; 95% CI: 126–200), indicating that exposure to diesel exhaust may have contributed to the observed increased risk. Alfredsson et al. (1993) compared mortality from myocardial infarction and other causes for bus drivers in Sweden with that of working men over a fifteen-year period; they found a 50% increase in mortality from myocardial infarction among drivers in the areas with the largest cities. Another study identified a significantly increased risk of mortality from ischaemic heart disease in bus drivers working in areas with high traffic intensity (Netterstrom & Suadicani, 1993).

A cohort study in Rome explored the mortality pattern of taxi drivers exposed to vehicle exhaust (Borgia et al., 1994). An increased standardised mortality ratio (SMR) was observed for lung cancer (123; 95% CI: 97–154). Owing to statistical uncertainty, however, the results did not clearly indicate an association between the risk of lung cancer and exposure to vehicle exhaust among taxi drivers. In Italy, Lagorio et al. (1994) compared the mortality in a cohort of petrol station attendants with the regional population. Data analysis indicated some increased risks for oesophageal (SMR: 241; 90% CI: 82–551) and brain cancer (SMR: 195; 90% CI: 77–401). In summary, those studies that focus on transport-related air pollution indicate that it contributes substantially to the increased risk of death, particularly from cardiopulmonary causes.

A study of highway tollbooth workers reported an increased number of acute irritative symptoms such as headache, nasal congestion, eye irritation and dry throat (Yang et al., 2002). Bus drivers, conductors and taxi drivers in Shanghai showed higher prevalence of respiratory symptoms and chronic respiratory diseases than controls not exposed to vehicle emissions (Zhou et al., 2001).

A questionnaire-based study in Denmark (Raaschou-Nielsen et al., 1995) investigated the prevalence of respiratory diseases and other disease symptoms amongst Copenhagen's street cleaners. The street cleaners showed a significantly higher prevalence of chronic bronchitis and asthma than other outdoor workers such as cemetery workers, who were exposed to lower levels of pollution.

Commuter susceptibility

Whilst occupational exposure and its impact on health has garnered increasing levels of interest amongst public health professionals, the impact of commuting, personal exposure and impact on health has received substantially less attention. In many cities, the need for a mobile workforce entails that the length of the total work day (working and traveling time) has increased significantly, yet the health effects remain under studied. In contexts of rapid, urban and population growth where air quality has declined, exposure on daily commutes is an area that deserves more sustained attention, given the potential impact on public health. This is particularly needed given that many urban centres have expanded and populations have moved further away, with average commutes increasing. Historically, cities have been compact areas with high population densities, with the physical extent of cities growing slowly (Seto et al., 2010). Contemporary trends see a reverses, with urban areas expanding on average twice as fast as the populations that live within them (Angel et al., 2011).

Table 7: ***The Countries with the Longest Commutes (Dalia[1]) and survey responses to daily commute***

Country (and city)	Daily commute in minutes
Kenya	80
Ethiopia (Addis Ababa)	87.7
Hong Kong	90
India	91
United Arab Emirates	96
Israel	97

Globally, commuter times are increasing rapidly, Dalia (2018) estimates that commuter times in Kenya, Hong Kong, India, United Arab Emirates and Israel are, on average, well in excess of 60 minutes per day. Daily commute times in Addis, based on responses from participants in our survey, were circa 88 minutes. Many studies of commuting highlight the benefits of active travel (i.e. cycling and walking) and there is growing evidence demonstrating the detrimental impact of lengthy, non-active commutes on health and wellbeing (RSPH, 2016). Research indicates that commuting can reduce mental wellbeing, negatively impact physical health such as raising blood pressure and also, reduce the time available for health promoting activities. Whilst sedentary behaviour has long been identified as having adverse effects on cardiovascular and metabolic health, the impact of long commutes are less understood. Studies have shown that greater commuting distances are associated with decreased cardiorespiratory fitness, increased weight, and other indicators of metabolic risk. Studies of air quality have also shown that depending on the mode of transport, exposure to air quality will vary, with those dependent on slower forms often exposed to higher levels of pollution over longer periods. Broadly speaking commuting impacts on health in two ways:

- **Mental wellbeing**: A study using data from the British Household Panel Survey found that subjective health measures such as self-reported health status and satisfaction were lower for individuals who commute longer distances. This research also found a correlation between length of commute and increased visits to medical professionals, potentially as a result of perceptions of lower health status. Wong et al. (2018) exploring the psychological impacts associated with exposure to air pollution during the daily commute found commuters identified stress (13.0%), followed by insomnia (5.0%) and feeling moody and anxious (3.6%). Depression was reported by 1.1% of respondents. Although the proportion of psychological health effects experienced are lower than that of physical health effects, the authors assert that mental and emotional well-being is essential to overall health (Wong et al., 2018).
- **Physiological effects**: a study by White and Rotton (1998), found that commuting can lead to physiological effects, e.g. increased pulse rate and higher systolic blood pressure. Similarly, other studies have demonstrated a connection between commuting and a higher body mass index. A recent study of health and public transport in Malaysia explored physical health effects experienced from exposure to air pollution during daily commutes. Respondents reported physical fatigue or weakness (35.5%), followed by coughing (23.6%), a significant proportion also reported headache (16.1%), light-headedness (14.6%), and breathing difficulties (14.5%).

Overall, those analyses that have explored health impacts of daily commutes consistently identify that longer travel duration is likely have an impact of mental and physical health (Chatterjee et al., 2017). The majority of these studies originate from the global north with fewer exploring the issue in the global south.

It is also important to note that, globally there is a correlation between the transport mode and social class, with poorer groups reliant on public and non-motorised transport. Household travel surveys in Nairobi (Salon & Aligula, 2012) and Kampala, (Bryceson, Mbara et al. 2003) confirm that poorer groups rely on walking, cycling and (often informal) public transport. Lower-income households are also disproportionately affected by road accidents, air pollution and displacement related to transport projects (Vasconcellos 1997).

Perceptions of susceptibility to air pollution amongst older people in Addis Ababa

To explore perceptions of susceptibility to air pollution, survey respondents were asked to identify in what ways they thought air pollution adversely affected them or their city (see figure 8). Whilst survey respondents acknowledged that air pollution was an issue and had an impact on daily life, particularly long term respiratory health, responses suggest that there is dissonance between perceptions of air pollution and identification of its economic impact. This may in part stem from a lack of knowledge and sensitisation around the consequences of air pollution exposure. What was striking from the responses was the high degree of consensus across respondent replies with similar findings across all three groups.

To explore the health impacts of exposure further, survey respondents were asked to identify causes of illness during the last twelve months. Figure 9 provides an overview of survey respondents who recorded being sick and highlights significant differences across the surveyed groups. Of the bus driver group 100% reported having been sick during the last 12 months with eye irritation (40%) and sinus problems (30%) consistently identified. Of the street vendor group 70% of respondents recorded being sick, with eye irritation again identified as the main cause of illness. Finally, of the commuter group, 50% reported being sick, with eye irritation and sinus problems being cited as the main causes. Whilst these findings require further exploration, they highlight that bus drivers and street vendors are particularly susceptible to poor health related to air pollution.

Figure 8: ***Survey respondent's perceptions of air pollutions adverse impacts on individuals and Addis***

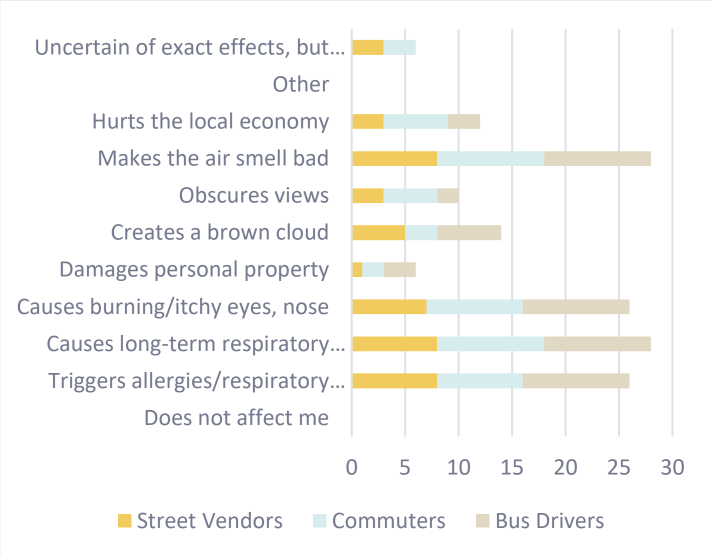
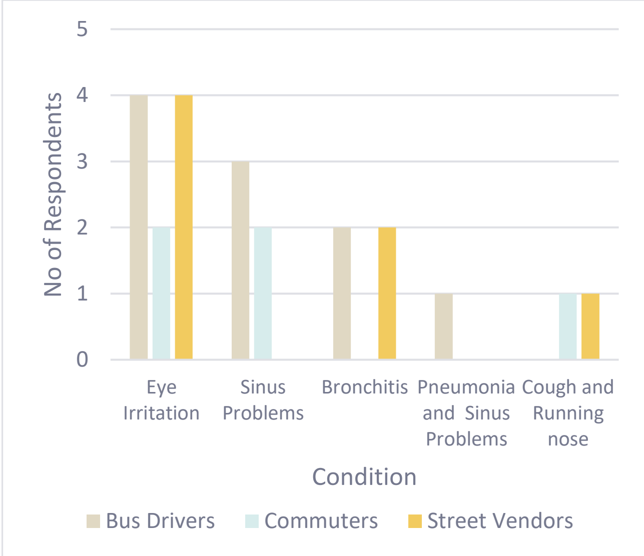


Figure 9: ***Survey respondent's identification of causes of illness (last 12 months)***



Adaptive capacity

The concept of adaptive capacity remains contested, but can broadly be defined as the ability of individuals, communities, organisations, nations or other actors to take actions to either reduce or avoid risk. While greater exposure and higher susceptibility to air pollution increase vulnerability, adaptive capacity refers to the means by which people can reduce their vulnerability. The concept of adaptive capacity is important because while exposure and susceptibility characterise vulnerability in a negative way, adaptive capacity recognises the ability of actors to learn and change behaviour.

Whilst many studies of air pollution focus on efforts to reduce pollution levels and improve air quality (i.e. mitigation), some recent literature has explored how various actors can protect themselves against the impacts of pollution by means of adaptation. This focus on adaptation stems from an awareness that due to a lack of air quality regulations, enforcement institutions or effective agreements on air quality management, improvements may be difficult to achieve (Ebert & Welsch, 2011; Lankao & Tribbia, 2009). Indeed, mitigation requires consensus and cooperation across a number of stakeholder groups (public and private sector and civil society) and levels (local, regional, national and global). In contrast to mitigation, adaptation requires less consensus and some actions may be taken at an individual, organisational or city level.

In the context of rapid urbanisation in Addis Ababa, those who are have long commutes or work close to or on congested roads are likely to be most affected by increases in pollution levels. Consequently, a key focus of 'soft' actions for adaptation should be directed at developing the adaptive capacity of groups such as bus drivers, commuters and street vendors in the environments in which they spend significant periods of time.

Finding reliable ways to measure adaptive capacity, particularly of these groups, is challenging and remains a priority for researchers and policymakers. Numerous indicators have been developed, including education, income and health, as well as access to financial, technological and institutional resources. More broadly, recent literature has attempted to identify determinants of adaptive capacity and specify the processes through which those determinants interact. Eakin et al. (2014), for example, explore the relationship between socioeconomic development and, in the context of their research, climate risk reduction, as an interaction between 'generic' and 'specific' capacities and explore how those capacities might complement or undermine each other. In a similar vein, the Local Adaptive Capacity (LAC) framework, seeks to understand how different determinants of adaptive capacity influence each other at household and community levels.

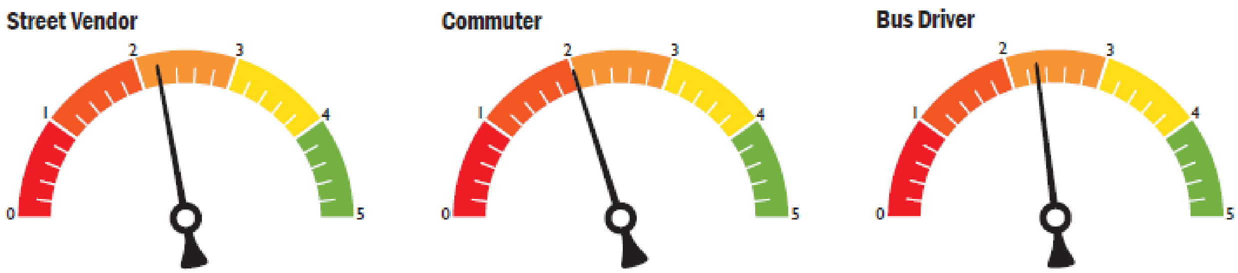
Common across both approaches is an agreement that knowledge represents an important determinant of adaptive capacity (Williams et al., 2015). The LAC framework identifies knowledge as both a dimension of adaptive capacity, but also an element within other dimensions. Similarly, the Intergovernmental Panel on Climate Change (IPCC) considers a 'lack of knowledge' to be a possible constraint on adaptation.

Whilst some studies have suggested that East African's possess a high level of awareness regarding air pollution and its impact (Omanga et al., 2014), others report low awareness. A study conducted in the informal settlement of Mathare (Nairobi) found that most residents lacked extensive awareness about air pollution and its effects on health, with some citing smoking and poor sanitation as the main pollutants (Ngo et al., 2017). Similarly, a study by Egondi et al. (2013) in Nairobi's Viwandani and Korogocho informal settlements identified residents as having low perceptions of air pollution levels and related health risks despite high levels of exposure. Similar findings have been recorded in Ethiopia. Tamire et al., (2018) found that economic status, lack of commitment, cultural views along with safety and security issues were found to be barriers to change. This ASAP-East Africa study found that whilst survey respondents perceived air pollution as a risk and identified themselves as vulnerable, knowledge regarding its sources and impact was mixed.

Studies that have sought to determine the influence of age, education, employment status and income on risk of mortality associated with ambient air pollution have found that Interquartile increases in particulate matter (PM_{10} and $PM_{2.5}$), sulphur dioxide, nitrogen dioxide, carbon monoxide, and elemental and organic carbon were associated with a 4–7% increase in mortality among those who did not complete primary school. Among those aged 85 years or older, estimates of increased mortality were 2–7%. However, among this age group, those who did not complete primary school, estimates of increased mortality were 11–19%. Cakmak and Vidal (2011) suggest that education has more of an influence than income or employment and that sex had no impact.

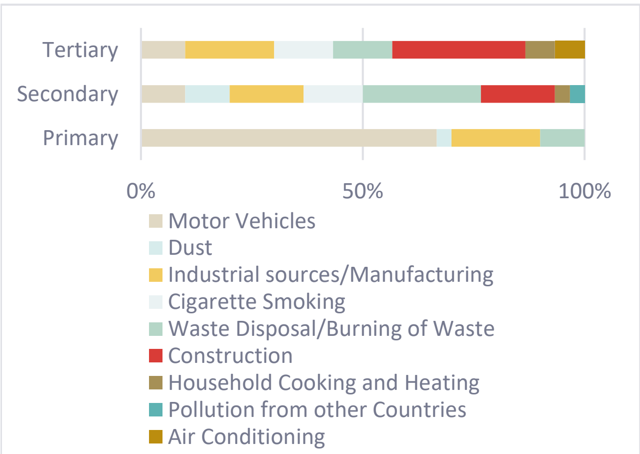
Participants in our survey where asked to assess "how they rated their ability (as an individual) to take actions to improve air pollution or minimise exposure (1 being no ability at all, 5 being very able)". Respondents across the survey groups recorded similar perceptions, bus drivers reported marginally higher ability 2.3/5, followed by street vendors 2.2/5 with commuters reporting the lowest ability 2/5. As commuters often have to travel large distances to access employment opportunities and are dependent on transport providers, this may explain their perception of dependence on actions taken by others to minimise exposure to air pollution (i.e. governmental policies and initiatives by public transport providers).

Figure 10: ***Survey's perceptions of ability to take actions to improve air pollution or minimise exposure***



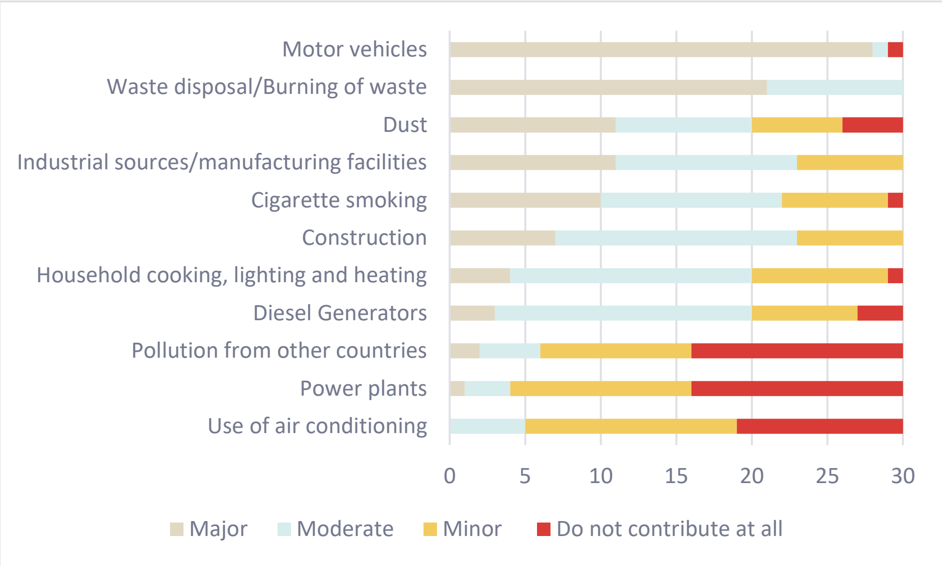
Survey respondents were also asked to rank what they considered the primary, secondary and tertiary sources of air pollution (see figure11). Respondents identified an array of sources with motor vehicles (20), industrial sources (6), waste disposal/burning of waste (3) and dust (1) identified as primary sources. This is unsurprising considering the focus of the study.

Figure 11: ***Survey respondent's perceptions of sources of air pollution (Primary, Secondary and Tertiary)***



To explore this issue further, survey respondents were asked to specify sources of air pollution and to rank their relative contribution (major, moderate, minor or whether they did not contribute at all). Respondents identified a broad range of sources (see figure 12. Findings can be contrasted with EU research that identified population-weighted averages for relative source contributions to total $PM_{2.5}$ in urban sites in Africa. These included domestic fuel burning (34%), natural sources including soil dust and sea salt (22%), traffic (17%), unspecified sources of human origin (17%) and industry (10%) (Karagulian et al., 2015).

Figure 12: ***Survey respondent's identification of sources of air pollution and relative contribution***



There also exists a relationship between socioeconomic status and adaptive capacity. According to the IPCC, socioeconomic factors that determine adaptive capacity include access to technology and infrastructure, information, knowledge and skills, institutions, equity, social capital, and economic development (IPCC 2014).

There is a dearth of evidence that explores the impact of socioeconomic status, ambient air pollution exposure and adaptive capacity in Addis Ababa. Some studies have found that occupation influences level of exposure with studies in Kenya indicating that bus drivers and street vendors are often exposed to high levels of pollution (Ngo et al., 2017). There is a more established evidence base that highlights household income, indoor air pollution exposure and cooking fuel use. Whilst the survey sample (both in size and scope) limits the ability to make concrete assertions regarding this issue, some interesting findings do emerge. Survey respondents were asked to identify their educational level, in some instances this has been used as a proxy for poverty. Of the sample, those who reported having the lowest level of education (i.e. primary education only) considered themselves the most vulnerable to air pollution (4.5/5), figures for secondary education were 3.3/5 and tertiary education 4/5. Interestingly those who reported having a tertiary education reported the second highest level of vulnerability. In terms of adaptive capacity, findings were more mixed with those with lowest levels of education reporting the highest levels of adaptive capacity. Average scores for adaptive capacity across educational levels were as follows primary (2.6/5) secondary (2/5) and tertiary (2.1/5).

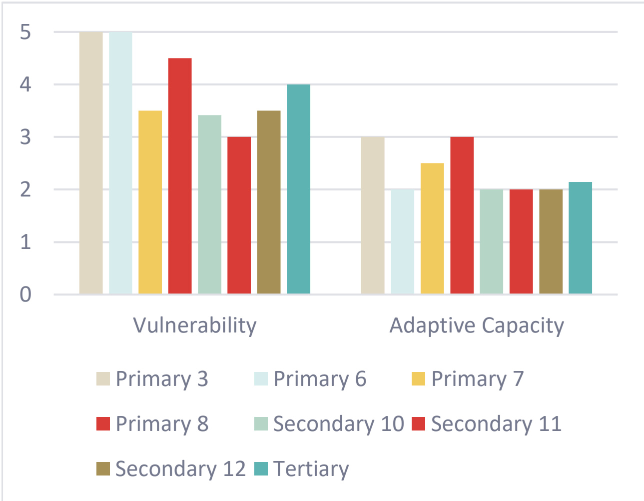
Survey respondents were also asked to identify steps they took to address air pollution or to minimise their exposure. Survey responses and personal testimony from participants highlighted the degree to which a sense of impotence was the recurrent response.

Bus drivers reported the highest levels of impotence. Of the responses received, 9/10 reported taking no action with only 1 bus driver reporting taking any action (opening the bus window).

Street vendors reported similarly low levels of action, with 6/10 reporting taking no action. However, four street vendors reported that they would actively clean areas surrounding their stores and homes to minimise air pollution, with two identifying the spraying of water as a tool used to minimise the resuspension of dust. These responses may indicate the links between waste management and air pollution.

Commuters, in a similar vein to the above, identify high levels of inaction, with 6/10 identifying taking no action. Of the four that indicated taking actions, two identified the covering of mouth and nose, one the opening of windows on buses. Interestingly one highlighted the need for proper waste management and a reduction in charcoal use in the city.

Figure 13: ***Survey respondent's identification of level of education and perception of vulnerability and adaptive capacity***



Facilitating adaptation

Whilst understanding the adaptive capacity of bus drivers, street vendors and commuters is fraught with issues, it is clear that the most effective pathways for adaptation are likely to arise out of an informed evolution of existing institutions and the participation of civil society groups, public and private sector actors. A number of studies emphasise the importance of the support and political will of local public officials in developing successful solutions to environmental issues such as air pollution (Slovic et al., 2016). Others emphasise the need for communities to build from and integrate modern techniques into air quality management practices and for local networks to effectively collect and disseminate data needed for assessing impact. This may provide a means to facilitate public participation processes in formulating policy.

In practice, this is often challenging, with the public often excluded from decision making processes. An opportunity exists in Addis Ababa given the predominance of public and non-motorised transport. It is a site where targeted investment in transport can have a significant impact on air pollution levels and the exposure of particularly vulnerable groups. In the Ethiopian context, efforts should be focused on developing public transport and environmental health protection policies and air quality campaigns. Given that bus station locations and bus routes are often the product of historic factors and sited in areas where sources of air pollution may be prevalent, interventions must adopt a multifaceted approach that supports vulnerable groups minimise their exposure:

- Adopt a holistic approach to transport investments, supporting walking and cycling, integrating transport modes (i.e. light rail and bus etc.) and providing for 'last mile' transport solutions.

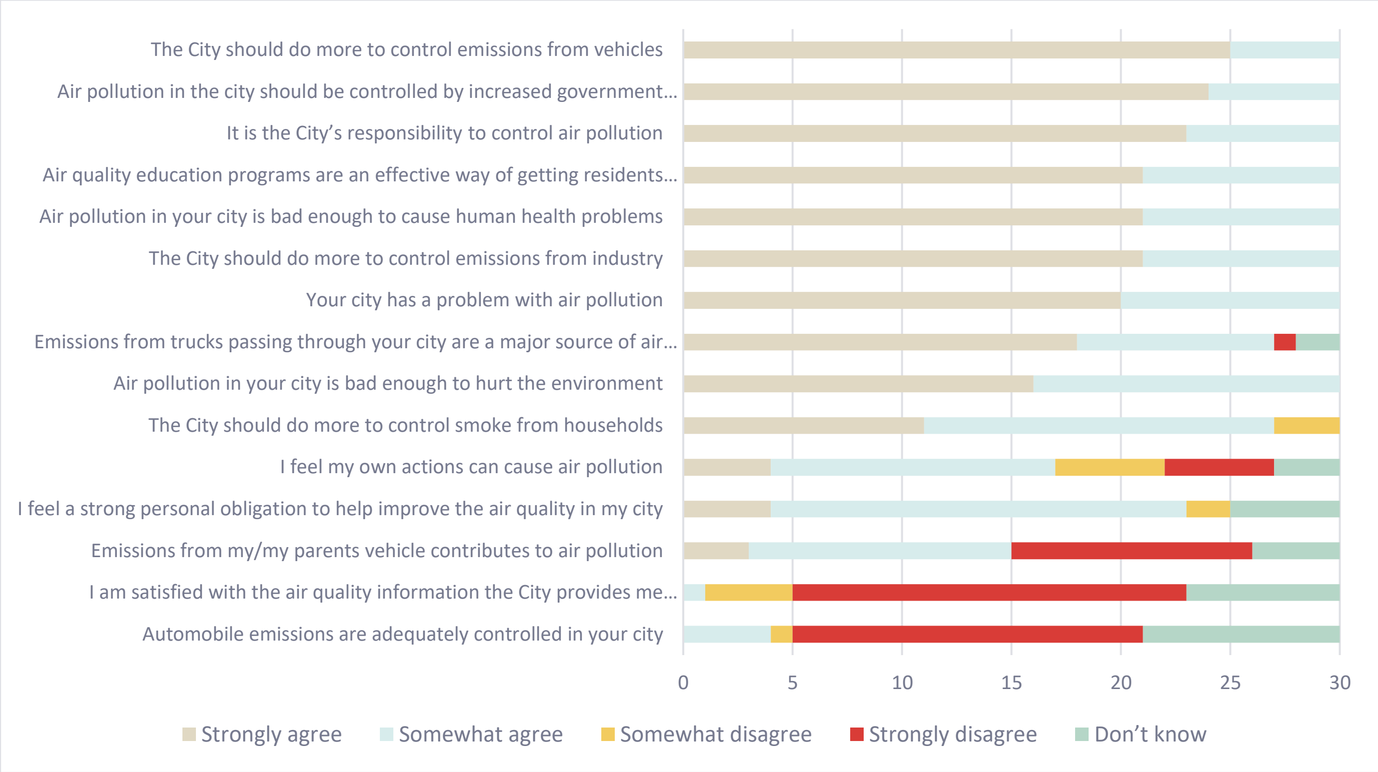
- Ensure that major infrastructure developments avoid displacement of residents and livelihoods. When considering such investment, efforts must be made to minimise disruption to particularly vulnerable groups. Experiences of BRTS development in Ahmedabad (India) indicated that vulnerable groups are often impacted most by such initiatives i.e. displacement of street vendors and exclusion of low income neighbourhoods from transport routes.
- Provide for the formalisation of employment opportunities around transport hubs through the provision of safe and well maintained spaces for street vendors to ply their trades. This can be accomplished by including street vendors in design decisions.

The case for taking action is increasingly compelling. A European study assessing the public health impact of urban air pollution in 25 cities showed that the monetary gain of complying with the WHO guidance for PM concentration would be 31 billion Euros (Pascal et al., 2013). Shifting from private motorised transport to rapid transit/public transport, such as rail, metro and bus, is associated with a wide range of potential health and climate benefits, including: lower urban air pollution concentrations, lower rates of traffic injury, less noise and improved access for people without cars.

- Public transport modes reduce total traffic emissions of air pollutants and climate change agents. Public transport use is also associated with more physical activity and less obesity, since public transport services are often accessed by walking and cycling.
- Comprehensive public transport systems often reducing traffic intensity, associated with road traffic injuries and noise-related health impacts. In the global north the injury risk for public transport users is much lower than the risk for car users.
- Investment in mass public transport can also yield equity benefits by improving the mobility of women, elderly and the poor, who often lack access to private vehicles. This, in turn, provides access to employment, education, health services and recreational opportunities.

Given the need for policy interventions to be publicly acceptable it is important to identify how receptive groups would be to certain interventions. This can be accomplished through participatory consultative processes. The rationale for consultation is clear, it aides government in garnering views and preferences, understanding possible unintended consequences of a policy or getting views on implementation. Increasing the level of transparency and engagement with interested parties also seen to improve the quality of policy making. Figure 14 below provides an overview of how strongly survey participants agreed or disagreed with a series of statements about actions to curb air pollution and provides insight into areas policy makers may wish to explore

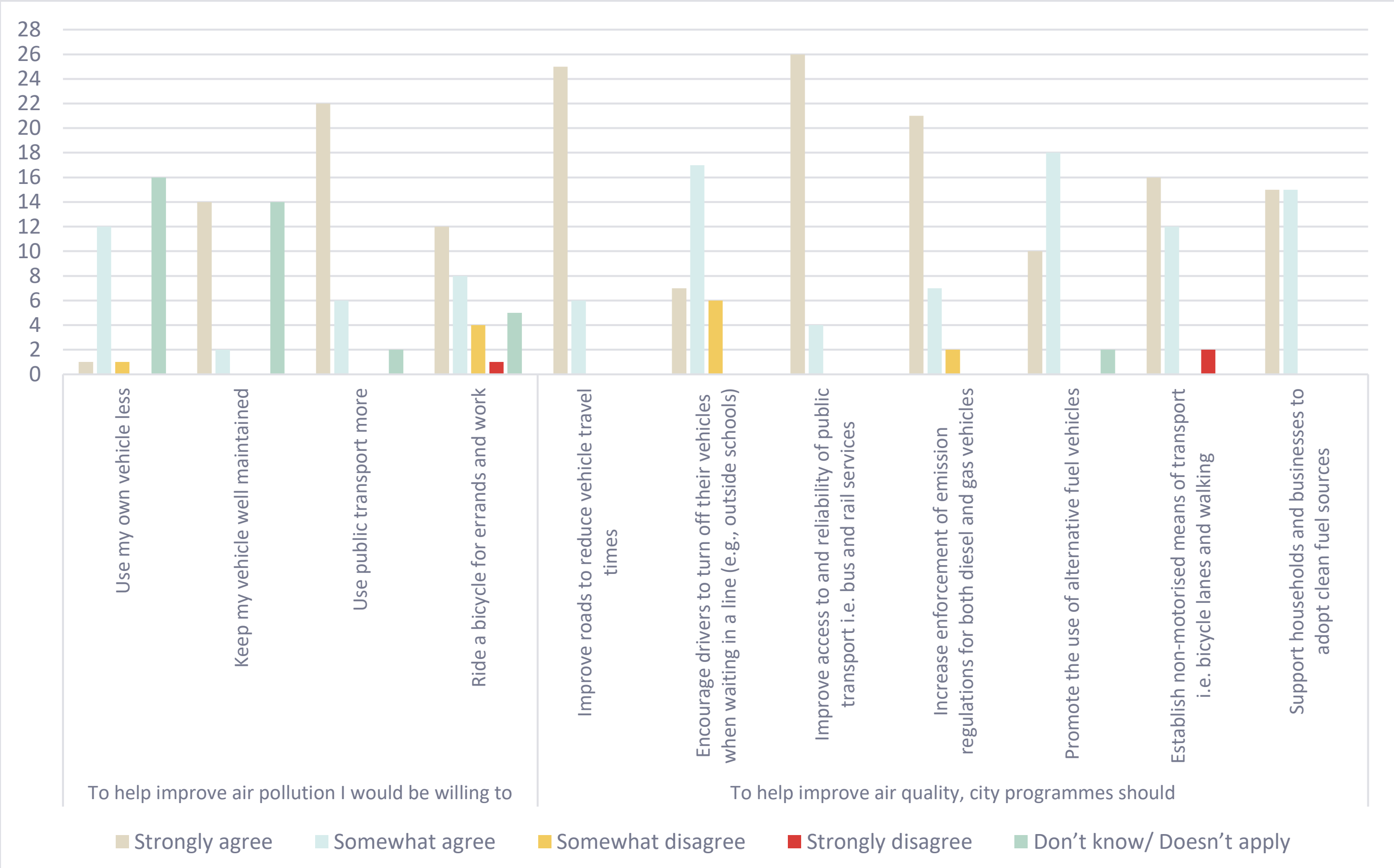
Figure 14: **Survey respondent's perceptions of actions to curb air pollution**



Survey respondents were also asked to identify how acceptable a number of potential policy interventions would be. Responses pertaining to individual actions whilst supportive, were mixed. Responses pertaining to government led air quality interventions were broadly in favour.

Adaptable, affordable and acceptable initiatives to improve the quality of air should be prioritised when considering how best to address air pollution in pollution hotspots through both preventive and remedial actions. Relevant national, state, and local stakeholders, including bus drivers, commuters, street vendors, transport bureaux and authorities, health officials, community and industry leaders, environmental scientists and transport providers need to work together to develop policies that ensure safe transport environments. This can often be challenging given competing agendas and priorities. To achieve the goal of improving air pollution levels in Addis Ababa this report identifies a number of options targeted at individuals (i.e. commuters, bus drivers and street vendors), organisations (transport providers) and government (local, regional and national)

Figure 15: ***Survey respondent's perceptions of policy interventions***



Conclusions and recommendations

The unprecedented urban growth that Addis Ababa will face over the coming decades could create the agglomeration of people and economies of scale that can contribute to the city's long-term development goals. However, if not well managed, this growth could exacerbate existing shocks and stresses, undermine access to basic services, increase congestion, hinders economic opportunity and impacts on individual well-being and health. As noted by the World Bank (2014), enhancing resilience in Addis requires actions and investments that are oriented toward implementing existing plans and regulations, establishing clear and capacitated leadership and investing in infrastructure that meets existing and, importantly, future needs. Assessing the population's exposure to transport-related air pollution and how this can be minimised is an important component of this process.

This study has explored air pollution exposure at an air pollution hotspot and on public transport via the deployment of low cost sensors in a bus station (outdoor) and on buses (indoor). The study also probed perceptions of commuters, bus drivers and street vendors. Findings underscore the vulnerability of these three groups to air pollution and suggest that those from low socioeconomic backgrounds are likely to face a triple burden of exposure both at home and in work or commuter environments. Data gathered during this study indicates that air pollution levels in bus station and bus settings regularly exceed WHO guidelines. Bus station air pollution exposure averaged 113 ± 99 µg/m^3 and peaked at 323 ± 203 µg/m^3 during days monitored. Further to this, air pollution levels tend to peak during early morning and evening rush hours and consistently record unhealthy levels throughout the day. Levels recorded on buses were equally concerning, across the journey's monitored air pollution levels ranged between 49 ± 19 µg/m^3 (unhealthy for sensitive groups) and 105 ± 45 µg/m^3 (unhealthy).

Survey findings suggest that commuters, bus drivers and street vendors are relatively cognisant of their inherent vulnerability to air pollution, perceiving their vulnerability on a scale of 1-5 at an average of 3.87/5 (five indicating extreme levels of vulnerability). This may in part be explained by survey participant's spending significant periods of time in highly polluted environments. Respondents demonstrated a mixed understanding of the potential sources of air pollution, though this may be a product of the relative lack of knowledge regarding air pollution. This study underscores that good air quality is inextricably linked to the provision of safe, healthy and efficient transport services for commuters, street vendors and bus drivers. Identification of susceptible subgroups is important for the generalisation of air pollution health effects measured in one location to another where different sociodemographic factors exist. Knowing that certain population subgroups are more susceptible may also influence policy decisions about setting 'acceptably safe' levels (Cakmak & Vidal, 2011). Given the inherent vulnerability of bus drivers and street vendors to air pollution exposure, coupled with the significant proportion of time spent by commuters at bus stations and on buses, it is clear that there is a need to develop proactive policies that protect these groups from exposure to unhealthy levels of air pollution in such settings. This report generates a series of recommendations targeted at individuals, organisations and government.

Individual (bus drivers, street vendors and commuters)

While effective policies to reduce emissions at their source must be the focus, some evidence supports the effectiveness of individual action to reduce exposure and minimise health risks. As noted, commuters, street vendors and bus drivers often have little or no say in where they work or the periods of time they spend in highly polluted environments. This is principally a product of the location of livelihood opportunities and the available transport infrastructure that connects the city, making them particularly dependent on actions taken by others to minimise exposure to air pollution (i.e. transport and infrastructure initiatives and governmental policies). Despite this, knowledge and attitudes towards air pollution can enhance the adoption of adaptive strategies and encourage others to change their behaviours.

Personal exposure to air pollution can be reduced by avoiding locations with poor air quality or minimising periods of time spent in such locations. As noted this is often challenging when ones occupation or travel needs necessitate working near or passing through such hotspots. In order to most effectively adjust behaviour, individuals must be able to anticipate when and where air pollution is likely to be elevated above levels thought to increase risk. This requires providing individuals, in this instance bus drivers, street vendors and commuters, with the information they need to make informed decisions. Such information would allow individuals to better understand when and where exposure is likely to be highest and whether they are more likely than the general population to be susceptible to the harmful effects of air pollutants. This would require publically available air quality data in near real time.

Efforts must also be made to improve environmental health literacy. Environmental health literacy is a measure of individual understanding of specific risks, which then leads to broader understanding, including strategies that empower people to eliminate, reduce or minimise environmental exposures harmful to health. For commuters individual choices could include avoiding peak travel hours (often unavoidable) or altering routes to bypass certain areas. For street vendors, they may consider locating stores or conducting activities away from areas where pollution is likely to be elevated (again difficult considering the preference for areas with high concentrations of customers). For bus drivers, they may consider taking actions such as avoiding vehicle idling when waiting at bus stations which may reduce the amount of emissions - this could be supported by the development of guidance for drivers.

One option, common in many countries in South East Asia, that commuters, bus drivers and street vendors could adopt is the use of air pollution masks. One such example is the N95, a US government-certified mask that is estimated to block 95% of PM including $PM_{2.5}$ (Wong et al., 2018). Given the consistent identification of eye irritation reported across the survey responses, eye protection is another option. Both of these strategies would imply a cost which may deter take up as well as there being a cultural determinant which may also reduce uptake.

More broadly, it is important to ensure that sustained efforts are made to encourage city residents to prioritise public and non-motorised transport for their travel needs. Co-benefits of this will include improved air quality, reduced congestion and the development of more equitable cities.

Organisational (Anbessa bus company)

Whilst the ability of individuals to address air pollution or minimise their exposure may be limited or constrained, there are a number of opportunities available to public transport providers to support air quality improvement and minimise the impact of air pollution on commuters and bus drivers but also to reduce air pollution at hotspots such as bus stations which will have broader societal benefits. The ability to act is often dependent on financial resources and broader support from local and national governments is often a central component of this.

Public transport providers can actively invest in improvements to bus fleets. This involves both the retrofitting of old buses with new, greener technologies and the transition to electric or other less polluting engines. Examples of pilot projects can be found across the global south and north, however, it is in China that the adoption of electric buses has proceeded most rapidly. Shenzhen has emerged as the first city in the world to operate a 100% electric bus fleet. Case studies produced by the World Resource Institute (2019; 2019a) highlight opportunities and barriers to this transition, noting that whilst transport providers can advocate for improved bus fleets, this requires collaboration and support from both local and national government. Options for transport providers include technological measures such as catalytic converters, and improved fuels and engine design. These have effectively reduced exhaust emissions and contributed to improved air quality, despite the increasing traffic volume.

Transport providers can provide a public service by educating groups about air pollution and its health impacts. Indeed, transport companies have a captive audience for health promotion during both journey and waiting times in transport hubs. However, these opportunities are often underutilised. Anbessa could be positioned and supported to provide an educational service in Addis via on bus adverts or the distribution of information during journeys. Travel awareness campaigns, such as 'Travelwise' and 'In Town Without My Car', provide examples of how campaigns can be structured around transport choices and how individuals can change behaviour. Such campaigns often compete with commercial advertising campaigns, especially by car manufacturers, aimed primarily at selling cars. As well as focusing on local environmental and health impacts, travel awareness campaigns can also aim to improve informed knowledge of the facilities available for walking, cycling and public transport use (Sloman et al., 2004). In some contexts, public transport providers could also play a public information role regarding air pollution levels. Flag programmes deployed in the US and India could be adopted a bus station i.e. raising a flag that corresponds to pollution levels.

Public transport operations must focus increased efforts to support effectiveness and address user needs. Major suppliers of public transport services often orient these around minimising costs. Those cities that are most successful at integrating public transport services with urban development ensure a focus on user needs i.e. are effectiveness-driven. Transforming urban public transportation into a service that is responsive to the needs of users is, however, a complex undertaking. For Anbessa, being able to pursue the above means strengthening its operations in four key areas:

- Computerisation of operations.
- Improved management capabilities.
- Improved maintenance facilities for the transport fleet.
- The deployment of tools to ensure comprehensive operational analysis.

It is important to note Anbessa is already investing in some of the above and requires support from both government and donors. This study has demonstrated the potential of GPS enabled monitoring data to ascertain journey time and pollution levels. This data could be augmented with information on customer numbers and used to inform the development of a more responsive bus route system. Indeed identifying areas where congestion is endemic, or where demand is limited would make bus service provision more effective and efficient. This data driven approach to planning can be supported by academic organisations such as AAIT. This information could also be shared with government to inform road infrastructure or traffic management investments.

Public transport providers should undertake an assessment of sources of air pollution that originate within bus station environments and identify those that can be reduced or eradicated. Pragmatic steps that can be taken include; prohibiting vehicle idling when waiting at bus stations or at bus stops for prolonged periods, adopting less polluting fuels or transitioning to green technologies. There also exists some and potential in the strategic deployment of green infrastructure that may reduce the dispersion of pollutants. A co-benefit of this is that green spaces may improve the general appeal of public transport hubs.

Public transport providers should also encourage regular maintenance of bus station areas and buses to support healthy and clean environments. This is particularly pertinent in contexts where the resuspension of dust may be a significant contributor to air pollution. Interventions to improve the areas that buses pass through, or where customers may be particularly useful.

Governmental

Given the multi-scalar and interdependent nature of urban air pollution it is clear that government must play a key role in supporting efforts to address this issue. The focus must be on promoting efficient urban accessibility pathways based on compact, public transport oriented city forms. Such city-level policy initiatives must be accompanied by concerted efforts at a national and sectoral level. Within urban transport policy, three key principles are commonly recognised - usually summarised as 'avoid, shift, improve' (UNEP, 2011):

- **Avoid**: reduce travel intensity in cities through greater physical proximity and co-location of different urban functions;
- **Shift**: move from spatially inefficient and energy intensive private motorised modes to public, shared and non-motorised transport;
- **Improve:** improve the efficiency of road-based vehicles.

Interventions must also be cognisant that future travel mode distributions are expected to change with regional and local land use changes, as well as changes in transportation systems and personal choice.

Decision makers in Addis Ababa should support the development of an efficient, effective and capacitated transport authority. This involves both supporting existing staff and identifying where improvements can be made. Conducting a skills audit of Addis Ababa's transport authorities may provide a means of identifying strengths, weaknesses and areas for improvement and investment. The World Bank (2017) identifies four key areas that will be critical to success:

- creating an effective public transport authority,
- setting fares appropriately,
- adopting a transparent approach to subsidies,

- planning, managing, operating and maintaining the system, including the LRT, in an integrated and effective manner.

All the above should be based on a coherent strategic vision and plan for the public transport sector, particularly one that builds upon existing mass transport investments to help create an integrated network and lays out a realistic development program to achieve this. In addition, having an effective communications strategy so that the public can be on board with changes being made, is crucial.

Box 4: ***Bus rapid transit***

Pioneered in South America, bus rapid transit (BRT) is a solution developed in emerging markets that can be exported. It is a bus-based transport system, using segregated bus-only lanes along dedicated corridors, requiring ticket purchase at the platform or station to speed up boarding, and giving priority to intersection crossings. BRT buses can move as many people as subway systems, with a lower infrastructure load and cost. In Bogota, the BRT system can, at its peak, cater to over 2 million passengers per day on over 100 km of bus lanes.

For cities that struggle with issues around infrastructure funding, planning, execution, or upkeep, a BRT system can be up and running in less time, with less cost, and less disruption to busy thoroughfares than building or expanding a traditional underground rail system. This can make it easier to deploy a BRT, and provides additional flexibility to change routes, allowing fast-growing cities to more easily service new neighbourhoods and commuting corridors.

Government at national and local levels can support innovations or interventions that improve the environmental performance of vehicles such as adoption of new technologies or improved fuels. Cities in particular have the opportunity to improve the environmental performance of vehicle fleets involved in municipal services such as waste collection and public transport. They can also encourage moves to more efficient commercial and private vehicles through regulatory and fiscal measures. Policy measures such as fleet emission regulations foster economies of scale, and thereby contribute to reducing the production cost of new technologies. For public bodies, implementation of regulatory measures is cost-effective, whereas upfront investments for the purchase of new public transport fleets may be prohibitive. From the perspective of the transport operator, enhancements can be cost-effective under specific conditions i.e. dependent on retail and fuel costs. For users, the health and environmental benefits of investment must be balanced against economic costs. However, such benefits tend to be excluded from benefit cost calculations of individual users (Bartle et al., 2016). A menu of options is available for Ethiopian policy makers drawn from global experience and can include vehicle: emission standards, fuel quality standards, scrappage programs, and tax incentives. When adopting these, it is important to develop a national policy road map for cleaner vehicles and fuels that provide a clear and predictable course for technology and fuel adoption by private and public stakeholders. Such interventions must be accompanied by communication and education campaigns that highlight the co-benefits of such programmes:

- **Environmental improvements**: Enhancements to vehicles which improve energy efficiency can help to reduce local air pollution, noise levels and CO2 emissions, with benefits for human health and the environment.
- **Road safety**: Technologies that improve safety (e.g. braking distance) also offer benefits in the form of fewer road casualties.

- **Passenger satisfaction**: Improved technologies may contribute to better passenger experience for example, lower noise, fuel smell and vibrations. Such enhancements could then help encourage increased passenger levels and have an impact on commuter wellbeing

Cities can encourage more efficient or alternative uses of road space by dedicating space specifically for use by public transport, cycles and high occupancy vehicles. They may also narrow carriageways to improve public spaces. Schemes in which general traffic lanes are re-allocated to alternative uses can be expected to reduce traffic volumes, improve journey times for the modes given additional priority (e.g. bicycles or buses), increase the use of non-car modes and reduce casualty numbers. In countries where the last mile of journey is often dependent on informal transport, public transport systems could better integrate the informal transport sector. This may also create more reliable employment and livelihoods for the informal suppliers of small and low-performance vehicles, while improving operational efficiency and improving service quality for kilometre. For example, in Mumbai and New Delhi, there are designated spaces for informal rickshaws to park and line up for customers at stations; and in the city of Ahmedabad in India, the G-Auto rickshaw service, designed like a dial-a-ride taxi service, is proving to be successful.

Cities can encourage greater use of public transport through more reliable, frequent or quicker services, by increasing network coverage, or making improvements to the quality of vehicles and facilities. Such improvements are likely to be more significant in the longer rather than the shorter-term. Benefits of supporting public transport providers include:

- **Social Inclusion**. Enhancing public transport can bring social inclusion benefits by providing new or additional services to areas not well-served, as well as improving accessibility levels for less able travellers. Free or concessionary fares can also help address affordability issues for some groups.
- **Air quality**. Levels of emissions and air quality improvements can be delivered by moving to newer, better quality, public transport vehicles.
- **Congestion / Modal shift**. The provision of affordable travel can contribute to reductions in congestion and some transfer from car use.

Efforts must be made to link national and local initiatives that address rapid urban growth by focusing on the implementation of Integrated Development Plans. A challenge here, is effective implementation and prioritisation of interventions for short, medium and long term. These plans must ensure; coordination at multiple levels and a balanced focus between the city centre and peripheral areas to ensure that growth is orderly and that viable and affordable transportation options are available. The development of transportation infrastructure can be used to guide urban growth through the establishment of mass transport skeletal services e.g. bus services could be established along future BRT, LRT, and MRT routes.

Policy integration across urban planning, design and transport is frequently compromised by sectoral and disciplinary silos, fragmented governance and a lack of coordination between national and local policy frameworks for urban form and transport. The World Bank (2014) highlight six factors that are key to Addis Ababa developing more effective transport institutions:

- **Institutions should be organised effectively**. Functions of a strategic, tactical and operational nature should be incorporated into an institutional framework that makes sense in the local context, even though all these functions need not be performed by a single entity.
- **Human capital needs to be mobilised and engaged**. The challenge in Addis Ababa is not necessarily that skilled individuals are not available, but rather ensuring that the right people are in the right jobs.
- **Social capital needs to be created and then exploited**. This means developing the know-how to sequence evidence-based solutions in the right order.
- **Lead institutions should create "public value" in a visible way.** The World Bank recommends supporting this through a corridor-specific approach.
- **High level political support** can ensure that the lead agency will be able to carry out its mandated functions, obtain the financial resources needed to support high-calibre staff, and manage internal opposition to reform programs.
- **Communications and ICT functions need to be an integral part of the institutional arrangements for transport.** Managing public expectations – helping the public to understand the benefits of using new transport services or how and why fares or services are changing – is critical.

Raise the priority given to traffic management and road maintenance. It is critical to undertake measures to obtain the greatest possible efficiency out of current networks. Traffic management investment in improving the existing network is likely to produce better traffic results per unit of expenditure than investment in expanding road networks.

Government should analyse current and future transport hub sites and design. Transport hubs must be attentive to shifting urban realities and should be designed to protect users from exposure to pollution. However, many countries lack adequate regulations or enforcement powers related to siting policies, or the required skills to support the design of hub facilities to minimise air pollution exposure. Governments at local and national level should draw on existing best practice to develop policy and design where they are absent and consider how these could be applied retrospectively for existing transport hubs. It is acknowledged that this will often be challenging given the locked-in nature of much existing transport infrastructure. In existing hubs, environmental quality should be evaluated and steps taken to address poor conditions. Remedial or mitigating steps may include the strategic deployment of vegetation or buildings to act as a barriers to improve near-road air quality (see Baldauf, 2016 and the Trees & Design Action Group, 2017)

The location of new transport hubs should also be thoroughly analysed. The analysis should include testing air quality and providing an inventory of nearby sources of pollution, such as highways, industrial facilities, power stations and airports as well as studying the local climate i.e. characteristics such as usual wind direction and wind tunnels, topography as well as other physical aspects of the site.

Government should encourage greater cooperation between agencies. Oversight and enforcement at national, regional, and local levels is needed to ensure better urban environments. Regional and local actors interested in creating healthier environments can benefit from the application of scientific knowledge, technical expertise and environmental data. Government environmental agencies should cooperate closely with other departments to better manage city development.

Ideally, infrastructure developments will be directly linked to strategic planning policy, which in turn informs local planning and regulation. While this approach to planning is commonly adopted in the global north, it is far less effective in the global south, where there is typically limited institutional capacity and a high degree of informal urban growth.

Governments at local and national levels should also provide support to public transport providers who can be at a central to initiatives addressing air pollution. Anbessa, for example, have consistently upgraded bus fleets, improved maintenance of existing fleets and sought to develop and deliver a more efficient service. Government could incentivise public transport providers to identify and cost their own air pollution mitigation plans and support those that demonstrate most impact.

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