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P.O. Box 30030, Nairobi, Kenya
Website: www.unhabitat.org

Acknowledgements

Principal Author:	Prof. Dr. Rafael Borge Garcia
With inputs from:	Steven Bland, Stefanie Holzwarth, Robert Kehew, Sebastian Lange, Joyce Mavoungou
Project Supervisor:	Sebastian Lange
Editor:	Robert Kehew
Peer reviewers:	Bernhard Barth, Thomas Chiramba, Marcus Mayer, Abena Ntori, Paula Pennanen Rebeiro-Hargrave
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Foreword

Air pollution is a significant concern all over the world. In Africa, it is a major contributor to premature deaths and other health problems. The World Health Organization considers air pollution the single largest environmental health risk today, overwhelmingly affecting low- and middle-income countries, including most African countries.

We also know that Africa is one of the fastest urbanizing regions of the world. This rapid urbanization, often unplanned, exerts great pressures on local and national governments. As a former mayor, I can understand the pressing need to house, provide basic services and create jobs in the fastest and most efficient ways. Unfortunately, all of these human activities leads to even greater air pollution in our cities.

Air quality strongly depends on local factors. There are no quick fixes to address urban air pollution. The first step to deliver tangible urban solutions is to help decision-makers identify key factors and key drivers that is degrading air quality. This current report, ***Air Quality in African Cities***, helps to improve our understanding of Africa's urban air pollution problem, adding impetus to the air quality agenda on the continent. It is a comparative study of five very different cities across the continent, linking the findings to the implementation of the Sustainable Development Goals (SDG). It also offers guidance on how to improve air quality in Africa.

As the study shows, persistent poverty and air pollution are closely connected; hence, the causes of social inequity and environmental degradation must be dealt with simultaneously. Integrated strategies, at the national and local level, aiming at solving social issues and overcoming persistent poverty are essential to enable action. To effectively address air pollution in African urban areas, it is necessary to adopt a multi-level governance approach that considers local factors and communities' diverse needs and constraints. This requires involving relevant stakeholders, such as governments, businesses, and local communities, in developing and implementing strategies to improve air quality.

The COVID-19 pandemic over the past three years has stressed the need to urgently tackle sanitary conditions, improve waste management systems and address the lack of infrastructures that are also connected to poor air quality. This is fully consistent with the conclusions and recommendations in this report and reinforces the need to improve general living conditions in Africa.

I hope that the actions and recommendations of the report are taken onboard and implemented. We do not have much time left if we want to achieve our global goals and the vision of a better quality of life for all in a rapidly urbanizing world.

Maimunah Mohd Sharif
Under-Secretary-General
Executive Director of UN-Habitat

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Acronyms & Abbreviations

For symbols as well as acronyms for units, chemical compounds and currencies, see separate lists, below.

ADF	African Development Fund
AEIS	Atmospheric Emission Inventory System (South Africa)
AEL	Atmospheric Emission Licences (South Africa)
AFOLU	Agriculture, Forestry and Other Land-Use
AFTU	Association de Financement des Professionnels du Transport Urbain (Dakar)
AMA	Accra Metropolitan Assembly
AOD	Aerosol optical depth
AQ	Air quality
AQA	Air Quality Act (South Africa)
AQG	Air Quality Guidelines
AQI	Air Quality Index
AQMF	Air Quality Management Framework
AQMP	Air Quality Management Planning
ASN	Association Senegalaise de Normalisation
BnM	Basa njengo Magogo
BRT	Bus Rapid Transit
CACC	Climate and Clean Air Coalition
CADAK-CAR	Communauté des Agglomérations de Dakar - Communauté des Agglomérations de Rufisque
CAIP	Cairo Air Improvement Project
CBD	Central Business District (Nairobi)
CCT	City of Cape Town
CCTVA	Car inspection centre (Dakar)
CEHM	Centre for Environmental Hazard Mitigation (Cairo University)
CETUD	Conseil Executif des Transports Urbains de Dakar
CGQA	Centre de Gestion de la Qualité de l'Air (Dakar)
CGQA	Centre de Gestion de la Qualité de l'Air (Dakar)
CI	Confidence Interval
CMB	Chemical Mass Balance
CNG	Compressed Natural Gas
COVID-19	Coronavirus disease 2019 related to the pathogen SARS-CoV-2
CTT	Sorting and Transport Center (Dakar)
DACCIWA	Dynamics-aerosol-chemistry-cloud interactions in West Africa
DANIDA	Danish International Development Agency
DEA	Department of Environmental Affairs (South Africa)
DEA&DP	Department of Environmental Affairs and Development Planning (Western Cape)

DEEC	Department for Environment and Classified Establishments (Senegal)
DoE	Department of Energy (South Africa)
DUSP	Dakar Urban Strategic Plan
DVLA	Driver and Vehicle Licensing Authority (Ghana)
EC	European Commission
ECCAD	Emissions of atmospheric Compounds and Compilation of Ancillary Data
ECI	Environmental Compliance Institute
EEA	European Environmental Agency
EEAA	Egyptian Environmental Affairs Agency
E-MAGIN	E-waste Management in Ghana
EMCA	Environmental Management and Co-ordination Act (Kenya)
EMEP	European Monitoring and Evaluation Programme
EPA	Environmental Protection Agency
EPAP	Egypt Pollution Abatement Project
ESP	Emerging Senegal Plan
EU	European Union
FEM	Federal Equivalence Method
FRIDGE	Fund for Research into Industrial Development Growth and Equity
GAMA	Greater Accra Metropolitan Area
GASDA	Greater Accra Scrap Dealers Association
GCMA	Greater Cairo Metropolitan Area
GDP	Gross Domestic Product
GHCN	Global Historical Climatology Network
GHG	Greenhouse gases
GIDA	General Industrial Development Authority (Egypt)
HPAP	Health and Pollution Action Plan (Ghana)
ICHES	Integrated Household Clean Energy Strategy (South Africa)
IGSR	Institute of Graduate Studies and Research (University of Alexandria)
IISD	International Institute for Sustainable Development
INDC	Intended Nationally Determined Contribution
ITCZ	Intertropical Convergence Zone
ITDP	Institute for Transportation and Development Policy
IUESMP	Integrated Urban Environmental Sanitation Master Plan (Accra)
JICA	Japan International Cooperation Agency
KAPS	Khayelitsha Air Pollution Strategy
KMD	Kenya Meteorological Department
KPI	Key Performance Indicator
KURA	Kenya Urban Roads Authority
LCD	Low Carbon Development (Ghana)

LEZ	Low Emission Zone
LGMTEC	Local Government Medium-Term Expenditure Commission (South Africa)
LPG	Liquefied petroleum gas
MAB	Man & the Biosphere Programme
MEDD	Ministre de l'Environnement et du Developpement Durable (Senegal)
MEPC	Ministry of Economy, Planning and Cooperation (Senegal)
MEPN	Ministry of Environment and Nature Protection (Senegal)
MESTI	Ministry of Environment, Science, Technology and Innovation (Ghana)
MISR	Multi-angle Imaging SpectroRadiometer
MMDA	Municipal, Metropolitan, District Assemblies (Ghana)
MODIS	Moderate Resolution Imaging Spectroradiometer
MoEF	Ministry of Environment and Forestry (Kenya)
MoH	Ministry of Health (Egypt)
MoLD	Ministry of Local Development (Egypt)
MPDD	Ministère du Plan, du Développement Durable et de la Coopération Internationale (Senegal)
MRTS	Mass Rapid Transit System (Nairobi)
MSEA	Ministry of State for Environmental Affairs (Egypt)
MURHLE	Ministry for Urban Renewal, Housing and Living Environment (Senegal)
NACA	National Association for Clean Air (South Africa)
NAQS	National Air Quality Strategy (Egypt)
NASA	National Aeronautics and Space Administration (USA)
NCC	National Coordinating Committee (South Africa)
NCC	City Council of Nairobi
NDF	Nordic Development Fund
NDP	South Africa's National Development Plan
NEAP	National Environmental Action Plan of Egypt
NELI	National Efficient Lighting Initiative (Egypt)
NEM	National Environmental Management (South Africa)
NEMA	National Environmental Management Act (South Africa)
NEMA	National Environment Management Authority (Kenya)
NIUPLAN	Nairobi Integrated Urban Development Master Plan
NLTA	National Land Transport Act (South Africa)
NMT	Non-motorized transport
NOAA	National Oceanic and Atmospheric Administration (USA)
NSEC	National Strategy for Environmental Communication (Egypt)
NSSD	National Strategy for Sustainable Development (Senegal)
NUA	New Urban Agenda
OECD	Organization for Economic Co-operation and Development

PAEL	Provisional Atmospheric Emission Licences (South Africa)
PAMU	Programme d'Amélioration de la Mobilité Urbaine (Dakar)
PATMUR	Supporting Transport and Urban Mobility
PNUER	Programme National d'Urgence d'Electrification Rurale (Senegal)
PROGEDE	Projet de Gestion Durable et Participative des Energies Traditionnelles et de Substitution
PTB	Petit Train de Banlieue
QA/QC	Qualtity assurance / Quality control
RCI	Residential, Commercial and Institutional
RNA	Ribonucleic acid
SAAQIS	South African Air Quality Information System (South Africa)
SAAQIS	South African Air Quality Information System
SANS	South African National Ambient Air Quality Standards
SARS	Severe acute respiratory syndrome
SDG	Sustainable Development Goals
SE4ALL	Sustainable Energy for All
SEC	Supreme Energy Council (Egypt)
SEDAC	Socioeconomic Data and Applications Center
SEI	Stockholm Environment Institute
SLCP	Short-Lived Climate Pollutants
SMW	Solid Municipal Waste
TDA	Transport and Urban Development Authority (Cape Town)
UHI	Urban Health Initiative
UN	United Nations
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UN-Habitat	United Nations Human Settlements Programme
UNIDO	United Nations Industrial Development Organization
UoN	University of Nairobi
US	United States
USAID	United States Agency for International Development
USEPA	United States Environmental Protection Agency
WB	The World Bank
WHO	World Health Organization
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting model

Symbols, Units and Chemical Compounds

µg	Microgram ($1 \cdot 10^{-6}$ g)
BC	Black carbon (PM fraction)
BTX	Benzene, toluene and xylene
C_6H_6	Benzene
CO	Carbon monoxide
CO_2	Carbon dioxide
GJ	Gigajoule ($1 \cdot 10^9$ J)
H_2S	Hydrogen sulphide
HC	Hydrocarbons
Hg	Mercury
hr	Hour
kt	Kiloton ($1 \cdot 10^9$ g)
MW	Megawatt ($1 \cdot 10^9$ W)
NH_3	Ammonia
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides (NO and NO_2)
O_3	Ozone
OC	Organic carbon (PM fraction)
PAH	Polycyclic aromatic hydrocarbons
Pb	Lead
PM	Particulate Matter
PM_1	Particulate Matter of a size less than or equal to 1 micron
PM_{10}	Particulate Matter of a size less than or equal to 10 microns
$PM_{2.5}$	Particulate Matter of a size less than or equal to 2.5 microns
POPs	Persistent organic pollutants
ppb	Parts per billion
ppm	Parts per million (in mass when it refers to fuels composition; in volume when it refers to ambient air concentration for a given substance)
SO_2	Sulphur dioxide
SO_x	Sulphur oxides (SO_2 and SO_3)
t	Metric ton ($1 \cdot 10^6$ g)
TSP	Total Suspended Particles
UFP	Ultrafine particles (particulate Matter of a size less than or equal to 0.1 microns)
VKT	Vehicle·kilometres travelled
VOCs	Volatile Organic Compounds
yr	Year

Currencies

USD	US Dollar
EGP	Egyptian Pound (1 USD = 5.4 EGP)
GHS	Ghanaian Cedi (1 USD = 15.6 GHS)
ZAR	South African Rand (1 USD = 15.0 ZAR)
CFA	West African CFA Franc (1 USD = 607.0 CFA)
KES	Kenyan Shilling (1 USD = 101.2 KES)

Exchange rates as of 19/02/2020

Executive Summary

Motivation and scope

This publication represents an effort to raise awareness about the issue of urban air quality in Africa and add impetus to the air quality agenda in this continent. Despite limited availability of air quality monitoring data and specific epidemiological studies, current evidence suggest that the impacts of air pollution are more severe in the most socio-economic vulnerable communities. It is estimated that 94 per cent of the annual 8 million premature deaths related to poor air quality worldwide occur in low and middle-income countries. In addition, air quality is intimately related to global warming, identified as a major health threat in Africa, especially for the more vulnerable layers of society. Improving air quality in African cities may yield larger health benefits than most known health interventions.

Tackling air quality issues in African cities is particularly important. While Africa is currently the least urbanized continent, it is also the region experiencing the fastest rate of urbanisation in the world, with an average annual growth rate of 2.55 per cent in the period 2000 – 2015 that will likely rise urban population to 2.5 billion by 2050. Urbanization has historically meant better living standards for most. However, rapid demographic growth requires public policies to steer the urbanization process and to help ensure an equitable distribution of wealth in line with the UN New Urban Agenda and the Sustainable Development Goals. However, the urbanization process in Africa is widening social gaps and leading to "urbanisation of poverty". In this context, local and national governments are struggling to cope with air quality management in a region where nearly 60 per cent of the population live in slums. Policies and measures to abate emissions and reduce population exposure should be harmonized with other strategies to provide for public services including waste management, clean water and public transport, which are closely related. Coordinated and adequate urban and territorial planning may be the key to face this huge challenge. However, the complexity of air pollution and its implications with urban planning and multi-level governance deserves a more detailed analysis to identify the essential drivers and factors involved in the improvement of air quality in African cities.

Urban air quality depends on a large number of emission sources and pollution transport and transformation phenomena that occur at multiple temporal and spatial scales. Intertwined, often non-linear, physical and chemical phenomena determine ambient concentration levels of multiple harmful substances, including carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), volatile organic compounds (VOCs), ozone (O_3) and particulate matter (PM).

The scientific literature identifies household fuel burning as the largest contributor to $PM_{2.5}$ (the single most relevant pollutant from the health perspective) ambient concentration. This means that Africa needs to deal with both outdoor and indoor air pollution. Traffic is another relevant sector, and its relative importance is expected to grow substantially in the near future. Use of old cars, poor quality of fuel, underdeveloped infrastructures and unorganized public transport are common issues in African cities, contributing to worsen air pollution. Many cities in this region have the additional challenge of natural pollution due to windblown dust from deserts or sea salt that interact with anthropogenic emissions and cause large health impacts. Other studies have pointed out that open field burning adds considerable pressure to urban air quality.

Despite some common features, urban air pollution largely depends on local conditions, and it is essential to take into account the specific characteristics of each city, including the socio-economic and political context of their respective countries.

Five case studies

To help disentangling this complexity and to try to provide useful guidance, we look at the specific air quality issues and responses given by five African cities (in alphabetical order): Accra, Cairo, Cape Town, Dakar and Nairobi.

All these cities have recognized air quality problems and are beginning to take steps in addressing them in a context of rapid urbanization, population growth and social inequity. Being capital cities, they provide particularly interesting examples to study how multi-level governance can be incorporated in urban air quality management. Despite these commonalities, they cover a range of economic development stages, from lower-middle economies (Senegal, Kenya, Ghana) to emerging economies (Egypt, South Africa) and have different constrains and prospects. Their geographical and experience-diversity may provide illustrative examples for other African cities and provide them with valuable information on how to maximize initial efforts to tackle air quality issues. At the same time, we try to shed light on the lessons that they can draw from one another and can be used to make general recommendations and strategic advice for the whole continent as a first step in the elaboration of a more systematic Theory of Change for improved air quality in African cities.

We intend to provide a consistent view of the current stages of process towards a comprehensive air quality management strategy for the five cases studies included in this report. This is rather challenging considering their heterogeneity and the generalized scarcity of relevant data, e.g. air quality measurements, in African cities. We carried out a desk review in collaboration with local authorities and experts in each country to gather the most up-to-date information available. To provide the reader with a synthetic and harmonized view of the status of the five cities analysed, we tried to combine i) fully comparable, globally available data and ii) any other local or national specific data and references that may be relevant for our goal. This is deemed as a reasonable framework to discuss local-specific information while keeping a minimum comparability needed to gain a general perspective.

For each of the cities we include basic information from globally available databases conveniently documented, therefore traceable and perfectly comparable, to provide the necessary background. This includes population and population projection figures, economic indicators, health data as well as basic geographic and climatic features that have an influence on local air quality.

Impact and implications of the COVID-19 pandemic on air pollution

The recent pandemic provides an opportunity to contrast the general recommendations given in this document under a wider perspective of an unexpected and unprecedented health crisis. In addition, it allows to assess the potential of non-technical measures to curb emissions and improve air quality from examples all over the world.

Although our understanding is still limited, early research points out that health risks of COVID-19 and air pollution are tightly connected from the physical perspective. In general, poor air quality implies more COVID-19 cases and worse health outcomes. Lockdowns enforced in many countries provided an unparalleled demonstration of the potential contribution of non technical measures to abate emissions and improve air quality, alleviating the burden of disease, especially in highly polluted cities in economically developing countries. The linkage of the pandemic and atmospheric pollution has long-reaching social and economic implications that reinforces the need to improve general living conditions in Africa and opens a window of opportunity to accelerate action towards a more sustainable world by conciliating COVID-19 recovery programs with the climate agenda.

The lack of monitoring data and the scarcity of specific studies hinder the analysis of the impact of recent restrictive measures in Africa. The information available allowed us to perform a preliminary analysis only for Cape Town, suggesting that measures taken to control the spread of coronavirus in March 2020 and following months may have had a more limited effect on air quality than in Asian or European countries. Presumably, the largest effect was associated to a reduction of emission in road traffic that may have reduced NO_2 levels up to 25% during the lockdown.

Some lessons learned from the review of the evidence and studies available are as follows:

- Developing countries and specially deprived communities are much more vulnerable to the pandemics, as they are to air pollution
- Health and economic benefit of tackling air pollution and climate change may largely exceed the damage caused by COVID-19
- The pandemic provides an additional argument to strengthen emission abatement efforts and calls for a site-specific approach to take into account socio-economic issues and local particularities in Africa; e.g. stay-at-home policies may not be effective due to very high exposure to indoor pollution and high prevalence of communicable diseases
- The response to the pandemic through long-term plans and alliances may help improving air quality and exploit the potential for innovation in Africa

Conclusions and recommendations

The lack of consistent and comparable information prevents from a formal comparison of the status of air pollution in Africa as well as the air quality management framework across the continent. More research is needed to fully characterize the drivers of air pollution action in the region and formulate evidence-based plans to improve air quality in affected cities in coordination with climate policies and general development strategies. Nonetheless, we identified some communalities among the five case studies that allows us to draw some general conclusions and strategic advice based on the six framework areas proposed in the Guidance Framework for Better Air Quality:

1. **Air quality standards and monitoring**
    - Air quality standards are typically set up at the national level and most of the countries included in this report have moved from the air quality guidelines to formal and rather comprehensive air quality standards. Despite the absence of air quality standards in some African countries, the major problem seems to be the lack of effective enforcement of these standards.
    - Air quality data in the continent is very limited. Even where monitoring stations exist, maintenance or reliable power supply is lacking, and data is therefore of poor quality or consistency. International collaboration seems to be key for the initial development of monitoring capabilities, but it is essential to secure adequate funding to guarantee the sustainability of urban air quality monitoring networks.
    - New technologies based on low-cost sensors may help improve monitoring capabilities but significant investments for capacity building and maintenance and closer collaboration with local universities and research institutes are still needed.

2. **Emissions inventories and modelling**
    - While national GHG inventories are usually available, city-scale emission inventories are mostly missing and should be developed to prioritise action on the variety of emissions sources affecting urban air quality and to monitor progress and to assess the efficiency of plans and measures.
    - Some cities have been able to channel international cooperation into the development of incipient modelling capabilities. The literature discussed throughout this report illustrate relatively simple modelling exercises that may be useful as a first step to understand local air quality issues for specific sources or neighbourhoods. Further support and scientific collaboration is needed to move towards more complex tools to deal with emerging air quality issues such as tropospheric ozone or secondary aerosols.

3. **Health, COVID-19 and other impacts**
    - While some general estimates exist, more localised epidemiological and cost-benefit studies are needed to understand better the health impacts of poor air quality in African cities, prioritize measures and make a stronger case for action. Health impact models based on assumptions drawn from higher income countries may underestimate impacts in Africa due to synergies with weather risks, communicable diseases and food security issues. Meeting the WHO air quality guidelines, or even the national air quality standards, would bring extensive health benefits, especially for the most vulnerable communities.
    - The evidence offered by the case studies in this report point out that low-income citizens in African cities may disproportionally bear the impacts of air pollution. Emissions from indoor dirty fuels combustion, waste open burning and unpaved roads among others create pollution hot spots in informal settlements. Exposure to air pollution from traffic is particularly high among the poor as well, since they mostly rely on non-motorized transport routes along heavily polluted environments. Tackling these issues will contribute not only to improve air quality but also environmental justice.
    - There is clear evidence that pollution-related health effects build up with those from other diseases such as COVID-19 (and the other way around), while the urban poor are also more and most severely affected (as by the air pollution impacts). This underlines the need to foster emission abatement measures in Africa cities, while emission reduction strategies both for air quality and climate pollutants are to be favored in/by green post-COVID-19 economic recovery programmes. It would be counterproductive to relax air quality standards in favour of a faster economic recovery. In general, lessons learnt from the COVID-19 pandemic reinforces the air quality related recommendations made from the analysis of the five case studies in the report.

4. **Communication**
    - Education and public awareness towards air pollution processes and air quality health effects is alarmingly low in Africa and it may be a major hindrance to implement emission abatement measures. Any intervention or strategy needs to emphasise communication actions for a successful result.
    - Open access to air quality data, emission inventories and health indicators is an essential need to involve policy makers and to engage relevant stakeholders and the general public in improving air quality. Channels for communicating the impacts of poor air quality are also essential since only an informed citizenry can demand additional measures to preserve public health

5. **Clean Air Action Plans**
    - Air quality action can be driven by dedicated Air Quality Action Plans but also by integrating air pollution actions into national and city development plans that guide infrastructure development. The choice of adopting either approach will depend on the local context. While both approaches will yield positive effects, it is important to explicitly consider emissions and exposure in all the plans and strategies as an effective way to maximize health benefits.

- Ad-hoc experimental campaigns and research projects highlight that, despite the diversity of city-specific conditions, PM-related pollution is common factor to all of them and should be prioritized.
- For countries and cities in which data and financial resources are lacking, a strategic focus on domestic "no regrets" short-term actions to reduce air pollution may be a wise investment, even before the creation of long-term monitoring and management capacity. Effective banning of open burning, accompanied by a transition to a more responsible recycling local industry, or improved fuel standards may represent such an illustrative 'no regrets' actions.
- Road traffic is a key sector in all the cities analysed. Stronger emission inspection schemes and interventions to promote clean, affordable and efficient public transport must be prioritized. In this context, soft mobility offers significant health benefit potentials and it should be promoted in the local agendas.
- While rapidly growing cities pose a major challenge in terms of mobility demand and resource consumption, this also provides an opportunity to integrate air quality criteria in the general urban planning of new settlements and city enlargement.

6. Governance

- While multi-level governance and planning may be complicated at initial stages of air quality management, it is a powerful combination that matches the multi-scale reality of air pollution and may provide the most effective and sustainable response in the long term.
- While the magnitude of CO_2 per capita emissions varies widely in the 5 countries, switching to renewable energy sources constitute an example of national-scale strategy that will always report local air quality co-benefits. A harmonized and coordinated response to climate change and air quality is a pressing need to meet national climate commitments and local air quality standards.
- It is key to improve local governance to achieve real changes by strengthening institutions and solid collaborations among administrations, companies and other stakeholders. In addition to official plans and strategies, there is a breadth of projects and initiatives in collaboration with multiple international organizations that would benefit from a closer coordination. The creation of centralized emissions and air quality department in the cities may facilitate the allocation of responsibilities and an effective allocation of resources.
- Public-private partnerships have demonstrated to be an effective way to promote social development and air quality improvement in the cities analysed. The case studies also inform that involving actors of the informal economy is essential to provide a consistent response to air pollution and social issues in urban areas.
- Multi-national organizations to coordinate national air quality plans and measures into a common African strategy may be instrumental to boost cooperation among countries, share experiences, exploit synergies and to deal with transboundary pollution issues. This may provide a fruitful framework to exchange experiences and harmonize criteria and methodologies.
- This report may establish a solid foundation from which to tackle multi-level governance related questions and to address vertical and horizontal integration of planning frameworks. Under a wider perspective it may serve for the alignment of policies aiming at improving air quality, climate change mitigation, but also the localization of respective SDGs at city level. Besides the air quality work at national level, also city-level action needs to be taken into consideration more strongly, thus providing clear standards and incentives to reduce air pollution. This report takes a first step into this direction by aiming at clean air action plans.

Key findings from present report

- Air quality data in African cities are limited, but there is enough evidence to advocate form immediate action.
- Sources of pollution are diverse, and a one-size fits all approach from other countries is unlikely to succeed.
- The contribution of transport is growing in all the cities thus radical action linked to urban planning is needed in this sector.
- Localised health impact data are generally lacking, but the available evidence suggests that the most exposed and affected are typically those from lower socio-economic brackets.
- To act, local governments need to integrate air quality into infrastructure and development decisions, and, ideally, develop comprehensive Clean Air Action Plans in the context of a wider social and environmental sustainability strategies, including climate change policies.
- To succeed, national and local governments, stakeholders and citizens will have to work together, creating synergistic policies that enable action at the national and local level.

Chapter 1

Introduction & Conceptual Framework

Clean air is an essential need for life. However, according to the World Health Organisation (WHO), less than ten per cent of the world's total population breathes clean air. In 2016, ambient (outdoor) and indoor air pollution was deemed responsible for eight million premature deaths a year worldwide. A full 94 per cent of those deaths occurred in low and middle-income countries (WHO, 2018). Despite the scarcity of reliable air quality monitoring data and epidemiological studies for the poorest countries (Ostro et al., 2018), the scientific evidence suggests that the impacts of air pollution are most frequent and severe in the communities that are poorly equipped to address the problem and recover from the impacts (Ladrigan et al., 2017). Such impacts may be particularly pronounced in the concentrated confluences of people and economic activities that we call cities.

For such reasons, addressing air quality – particularly in urban areas – emerges as a priority in the Sustainable Development Agenda 2030. For example, Sustainable Development Goal (SDG) Target No. 11.6 commits the world's governments to: "Reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality…". At the same time, by improving urban air quality decisionmakers will help to ensure healthy lives (SDG 3) and combat climate change (SDG 13).

The UN New Urban Agenda (UN, 2017) helps to further position many of these developmental linkages in the urban context. For example, through the New Urban Agenda Member States commit to: "facilitate the sustainable management of natural resources in cities and human settlements in a manner that protects and improves the urban ecosystem and environmental services, [while] reducing greenhouse gas emissions and air pollution" (Para. 65). In such efforts, decisionmakers should "take into consideration air quality guidelines, including those elaborated by the World Health Organisation" (Para. 55). Africa – and, particularly, African cities – are not exempt from these global air quality concerns. While the major cities on the continent do not experience the same levels of chronic air pollution as some cities in Asia do (Lelieveld et al., 2015), available data suggests that African cities are bearing a considerable share of the global burden of air pollution-related disease. Air quality in major cities in Africa generally does not meet guidelines set by the World Health Organisation (WHO).

Data also suggest that the health impacts from poor air quality on the African continent are significant and increasing. Air pollution contributes to a significant number of non-communicable diseases including cancer, stroke, respiratory diseases and heart disease. In Africa, while deaths attributable to other risk factors such as unsafe water, unsafe sanitation, and childhood malnutrition have decreased markedly since 1990, air pollution-related deaths have risen (Roy, 2016). While these kinds of aggregate trends must be used with caution given inherent uncertainties and assumptions, comprehensive disease assessments do indicate an increasing health impact from air pollution on the continent (Stanaway et al., 2018).

Nor are the negative impacts of air pollution in Africa confined to the health sector alone. The World Bank estimates that, in 2013, air pollution costs in Sub-Saharan Africa totalled 3.8 per cent of GDP (WB, 2016). In addition, since the emissions of air pollutants often coincide with the release of greenhouse gases, worsening air quality is intimately related to global warming. The impacts of climate change have been identified as an additional, growing health threat in Africa, especially for the more vulnerable layers of society (Chersich et al., 2018).

Although air quality is deteriorating in many places, it lies in people's power to slow or even reverse this trend. Taking such steps will yield considerable benefits. Recent analyses point out, for example, that modest reductions in the levels of fine particulate matter ($PM_{2.5}$) in the air in African cities may have larger health benefits to infants than most known health interventions (Heft-Neal et al., 2018). Such positive health impacts also yield attendant economic benefits, e.g., in terms of increased worker productivity.

Bearing in mind this growing challenge and opportunity, the present publication seeks to add impetus to the air quality agenda in African cities. It endeavours to do so by providing both national and local-level policymakers, as well as citizens, business leaders and international donors, with insights into the drivers and levels of air pollution, as well as initial responses in the continent. From in-depth analyses of the current status and actions taken in five illustrative African cities (see below), we have extracted general conclusions, recommendations and strategic advice. It is hoped that these findings will offer insights not only in those representative cities, but also for other urban areas with similar air quality issues or comparable stages of maturity in their efforts to develop and implement comprehensive air quality management systems.

1.1 An Underlying Driver of Air Quality Concerns in Africa: Urbanisation Trends

Health impacts related to air pollution mostly occur in urban areas where both emissions and populations concentrate. Currently, 55 per cent of the world's population live in cities, a proportion that is expected to increase to 68 per cent by 2050 (UN, 2019a). Although at present Africa is the least urbanised of the settled continents, the African continent is experiencing the fastest rate of urbanisation in the world, with an average annual growth rate of 2.55 per cent in the period 2000 – 2015. Such trends are expected to cause the urban population of the continent to rise from 1.3 billion today to a projected 2.5 billion by 2050 (UN, 2019a). While there are several emerging megacities of greater than ten million population in the region (including one of the case studies in this publication, Cairo), the fastest growing urban centres are generally small and medium in size. At present, settlements with less than one million inhabitants account for 63 per cent of the urban population in Africa (UN Habitat, 2016).

Urbanisation has historically been accompanied by industrialisation, economic growth, rising incomes per capita and better living standards for many. However, demographic growth requires public policies to steer the urbanization process and to help ensure a more equitable distribution of wealth (UN Habitat, 2010). Many parts of Africa seem to be experiencing urbanisation without significant productivity increases or adequate service provision; rather than yielding positive outcomes, these circumstances can lead rather to the "urbanisation of poverty". At present in sub-Saharan Africa, 59 per cent of the urban population live in slums (UN Habitat, 2016), while only 45 per cent have access to basic sanitation facilities. Tragically, this percentage of coverage has only increased by eight per cent in the last 15 years; likewise, the poverty ratio (per cent of population with an income of less than USD 5.50 a day in 2016 dollar terms) has only modestly decreased during that period, from 89 to 85 per cent (WB, 2019a). The residents of African cities have failed to fully benefit from the economics of urban agglomeration at least in part because investments in infrastructure, industrial and commercial structures and affordable formal housing have not kept pace with burgeoning populations. Moreover, urban growth has not been well guided. Many cities have evolved as a collection of fragmented neighborhoods not connected by efficient transportation or other networked infrastructure; this results in congestion and other dysfunctions and limits job opportunities. The associated costs may well reduce or even overwhelm the economic benefits that should result from urban concentration, helping to make African cities unappealing for investors and disconnecting them from regional and international markets (Vinay et al., 2017).

African national and local governments and civil society therefore face an overarching task that can be described as the "synchronisation of development and environmental challenges" (Roy, 2016). While industrialised countries generally first transformed economically and only then began to tackle environmental sustainability, many African countries are faced with the challenge (and opportunity) of undertaking both at the same time. Air pollution, a risk traditionally associated with-industrial and post-industrial countries, is rising even in African countries where relatively little industrialisation has taken place. Given other pressing concerns, taking action on air pollution has not been as high on the political agenda as addressing other issues. However, as discussed below air quality is a growing concern that seriously threatens the wellbeing of urban dwellers of the continent. Guiding urban development into productive patterns now will save costly retrofits later.

1.2 Five African Cities

To help understand urban air quality issues in African cities, we examined specific air quality issues and responses in five cities on the continent: Dakar, Senegal; Nairobi, Kenya; Accra, Ghana; Cairo, Egypt; and Cape Town, South Africa (Figure 1).

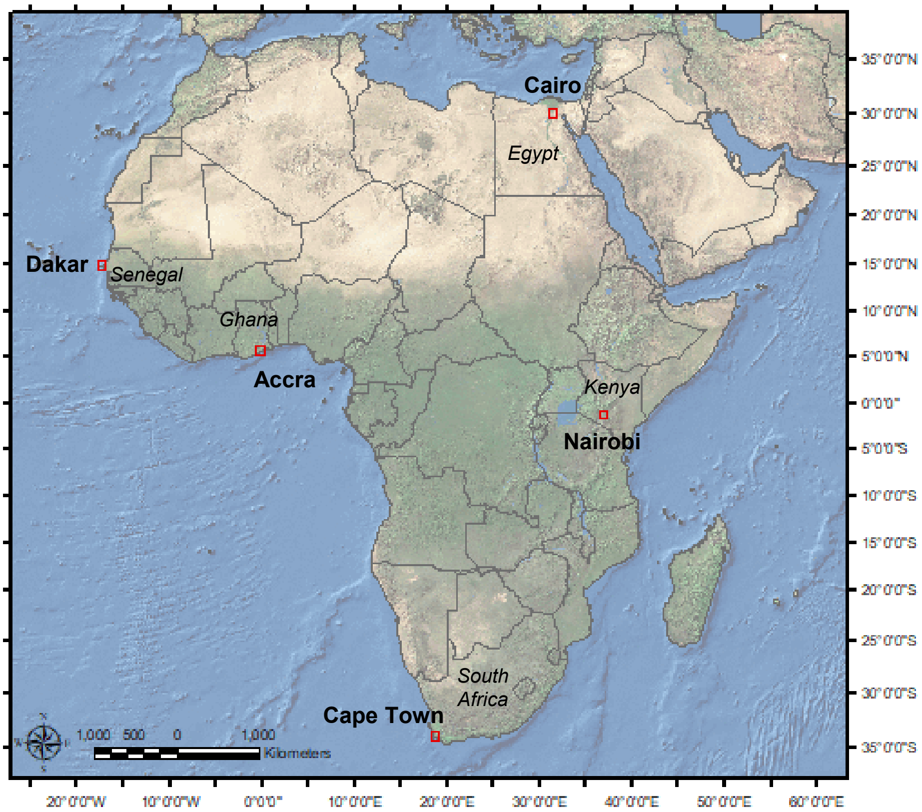
As shown, these cities are located across the African continent. Four of these cities are located in sub-Saharan Africa (in Senegal, Kenya, Ghana and South Africa), while one is located in North Africa, in Egypt.

Moreover, these cities represent a range of socio-economic development stages (see Figure 2). One of the countries represented, Senegal, is considered a Least Developed Country, a term that reflects not only income but also human assets and economic/environmental vulnerability criteria[1]. Two of the other countries represented are lower-middle income economies (Kenya, Ghana), while the remaining two are considered emerging economies (Egypt, South Africa). All five case study cities are capital cities.

Of the five cities, four are considered large cities, with populations between one and five million (see Figure 3), while the remaining city (Cairo) is a mega-city whose urbanized area is home to a population well in excess of ten million. As shown all five cities are growing rapidly, with growth rates above two per cent per annum. Nairobi, however, is in a class of its own, with a galloping growth rate in excess of four per cent per year; this poses additional challenges in managing urban growth.

1 See https://www.un.org/development/desa/dpad/least-developed-country-category.html.

Figure 1: Location of the 5 target cities in this report



While each of these five cities face similar challenges related to rapid urbanization, social inequalities and population growth, as discussed below each presents specific air quality issues and have different constraints and prospects.

When selecting case study cities, the criteria suggested above (geographic dispersion, socio-economic differences, varied population sizes, etc.) all came into play. We also considered cities' history of cooperation with UN-Habitat, together with the availability of information and on-the-ground presence; this criterion was deemed essential to undertake in-depth case studies on a limited research budget. Finally, all are vanguard cities on the continent, in the sense that they have all identified air quality as a concern and have begun to take steps to address this challenge.

Figure 2: Key country data (GDP per capita vs poverty headcount ratio). The size of the bubbles represent total national population as of 1 July 2019. The figures refer to that population (million inhabitants in each country)

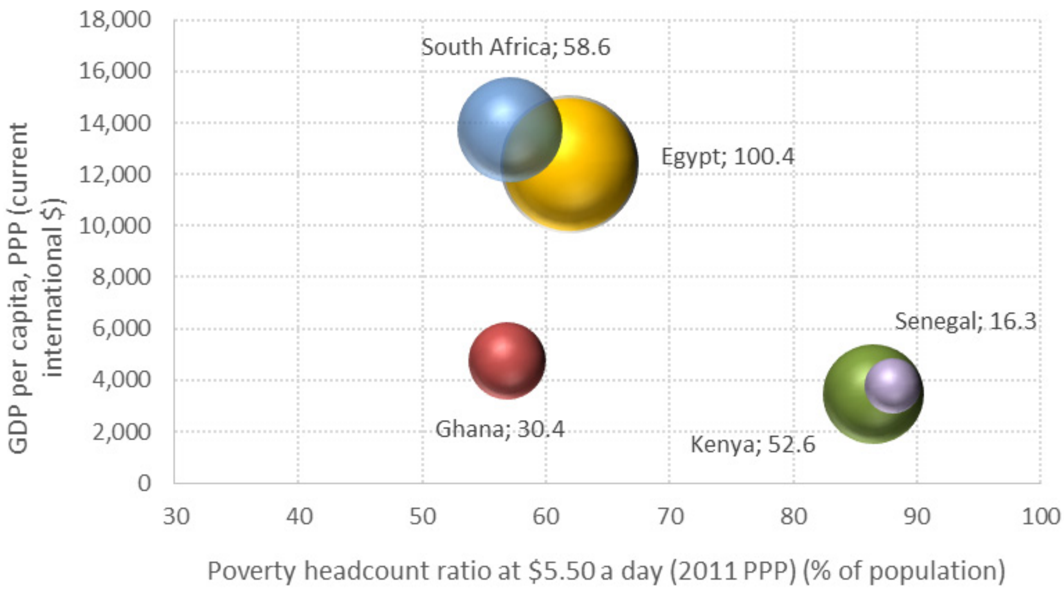
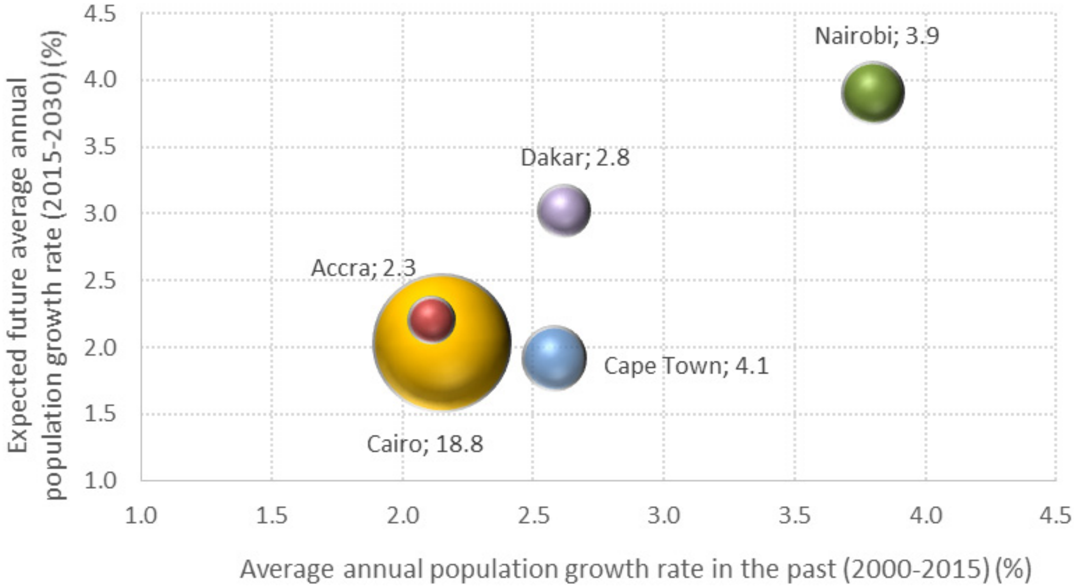


Figure 3: City population data (recent and expected population growth rates). The size of the bubbles represent total city population as of 1 July 2019. The figures refer to that population (million inhabitants in each city)



1.3 Conceptual Framework

The present review considers air quality issues and responses in the target cities according to a conceptual framework first utilised in the Guidance Framework for Better Air Quality in Asian Cities (Clean Air Asia, 2016), a publication developed by Clean Air Asia together with the United Nations Environment Programme (UNEP)[2]. This Framework includes major elements or components of a comprehensive system of air quality management or, expressed in more developmental terms, a theory of change for improved air quality. While originally developed for Asian cities, it can serve for broader, more global applications, including for the present review of cities in Africa. This Framework contains the following elements or components[3]:

1. Air quality standards and monitoring
Establishing ambient standards and robust national and local air quality monitoring systems enables countries and cities to understand air pollution levels and specific health impacts at different scales.

2. Emissions inventories and modelling
Understanding the sources of different types of air pollution helps to pinpoint targeted and relevant actions.

3. Health and other impacts
Conducting health and other impact assessments helps to build the policy case for action, engage stakeholders, and track the health benefits of action.

4. Communication
Including stakeholders in air quality management is vital; this includes the availability and accessibility of air quality data, and advice to citizens on staying safe in major air quality incidences.

5. Clean Air Action Plans
Developing both a stand-alone plan and strengthening air quality management in relevant policies and legislation at both the local and national level drives the delivery of air quality improvements.

6. Governance
Developing effective governance mechanisms ensures policy development and enforcement and provides a mechanism for stakeholder participation. Such mechanisms are particularly relevant when embracing multi-level governance as an enabling factor within a theory of change perspective, a point taken up below.

The authors of the present publication used this Framework firstly to gather and organize information on the air quality management systems, initiatives and practices in the five target African cities. For a complete discussion of the methodology and sources used in this review, see Appendix A; for the five city case studies, see Appendix B.

Then, secondly, after gathering and organizing this relevant descriptive information, the authors of the present publication tried to identify at what stage

2 For introduction, see https://www.youtube.com/watch?v=QsYNFt2S8S0.
3 For more complete descriptions of these components, see booklets Nos. 1-6 of Clean Air Asia/UNEP, 2016.

of the development the target cities' air quality management system was. Again, these stages came from the Clean Air Asia / UNEP Air Quality Management Framework. Overall descriptions of those stages per this Framework are as shown in Table 1[4]:

Finally, based on where a given country or city stood in terms of these stages, it was possible to generate a roadmap for how cities or countries could progress from one level to another[5]. Thus, taken together, this Framework can help countries – and cities – identify or diagnose where they currently stand in terms of the AQMF, and then tailor a roadmap for improving their system of air quality management over time.

Bearing in mind these considerations, the present publication proceeds as follows. Following the present Chapter 1 (introduction and conceptual framework), in Chapter 2 we summarize and synthesize findings from the five city-level case studies[6], and draw conclusions and recommendations. Then, in Chapter 3 we discuss improving air quality in cities in the context of undertaking a green recovery after Covid-19. Finally, we offer some brief remarks on 'the way forward' in addressing air quality in African cities.

Table 1: Stages of air quality management system

Stages	Indicators
Underdeveloped	There is generally little/no capacity, policies, information on, and mechanisms for AQM. The city's air quality is deteriorating due to the lack of control systems and mechanisms in place.
Developing	There is some capacity, policies, information and mechanisms for AQM in place, but this is insufficient. Consequently, while air pollution levels at this stage remain high with associated serious health and environmental impacts. These are stabilizing and the trajectory can be reversed.
Emerging	Air quality management activities, policies, and communications are starting to be put in place and are starting to be implemented more regularly and systematically. Some data are available and used and there is demonstrated capacity at the operational level of staff, stakeholders, and institutions/ structures that support implementation.
Maturing	Air quality management activities, policies, and systems are regularly implemented, with review and monitoring systems in place to ensure quality control and the accuracy of information. These are supported by policies and governance processes that are more inclusive and varied to suit the different contexts at the national and subnational levels. There is a certain level of transparency such that information is communicated to a wider audience using different communication channels. The improvement of air quality is being achieved with the implementation of effective policies to reduce emissions.
Fully developed	Where AQM activities, policies, and processes are in place, the focus is on ensuring the sustainability of the measures undertaken, the quality of the data and research studies generated, and continuous improvement to existing measures through the upgrading of review and monitoring processes, leading to further improvements in air quality. Public participation is strengthened and supported by transparency in governance processes, regulations, and frameworks.

4 For more detailed descriptions of these stages as they apply more specifically to the individual components of the Framework, see booklets Nos. 1-6 of ibid.

5. For more information on this generic roadmap, further developed for each of these six components, see booklets Nos. 1-6 of ibid.

6 For the full city case studies, see Appendix B.

Chapter 2

Main Findings, Conclusions & Recommendations from the City Case Studies

This chapter offers summary findings, conclusions and recommendations regarding addressing air quality in African cities. Following some (1) background in the form of key comparative findings for the continent as a whole and the five target countries, we present (2) synthesized findings from the five city case studies. For the in-depth city case studies for Dakar, Nairobi, Accra, Cairo and Cape Town from which these synthesized findings were drawn, see Appendix B.

2.1 Overview of the Continent & Five Target Countries

Review of global and regional air quality datasets for the African continent and the five countries[7] reveals the following:

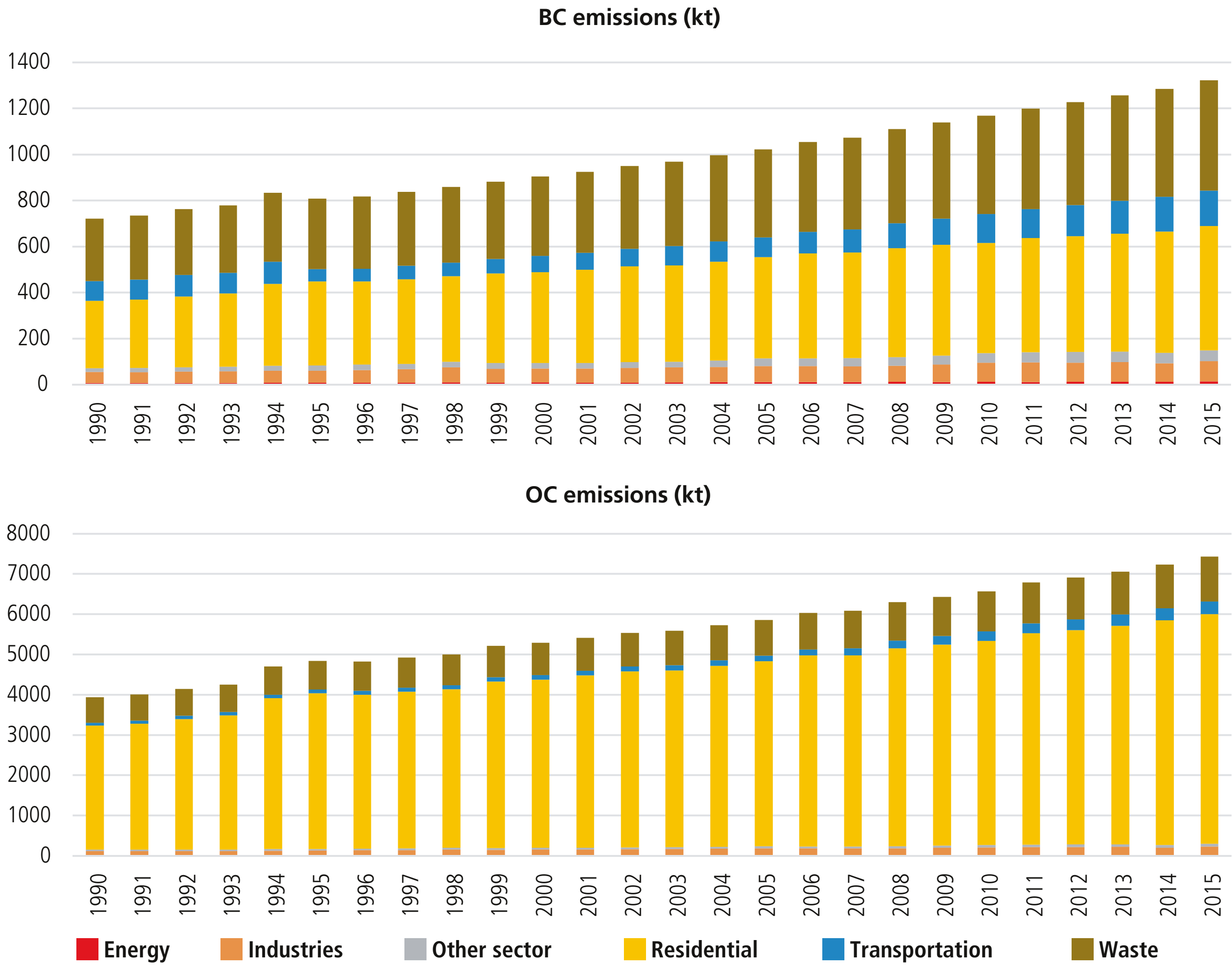
Particulate Matter emissions have risen steadily in Africa over the past quarter-century. The most updated and comprehensive regional inventory available[8] shows steady increases in emissions of particulate matter over the past twenty-five years (Figure 4). As discussed elsewhere, $PM_{2.5}$ represents the single most important pollutant from a public health perspective, while PM_{10} is also an important – and broadly tracked -- pollutant. From 1990 to 2015, these rising trends are similar for both major forms of PM, as well as organic carbon (OC) and black carbon (BC)[9]. For organic carbon, the residential sector is by far the largest source of emissions, while waste (including open air burning) and residential activities are the main sources for black carbon emissions. While the transportation sector is not the main source of black carbon, total BC emissions from this sector have steadily risen over the past twenty-five years.

Sources of air pollution in developing countries may not mirror those in industrialised countries. In Africa, reducing the household use of solid fuels, taking older private vehicles off the road, and preventing the importation ("dumping") of older and/or diesel-powered vehicles from the Global North, generally would represent priority actions. The review of PM source apportionment analyses carried out by Karagulian et al. (2015) identified eleven such studies for Africa (out of 419 for the entire world). As an average, the largest contributor to $PM_{2.5}$ ambient concentration is household fuel burning, responsible for 34 per cent of total concentration –the largest relative concentration in the planet. Natural sources (desert dust and sea salt) were the second source in importance, accounting for 22 per cent of $PM_{2.5}$. (For comparison, natural sources represent the largest share of ambient concentrations in Middle-eastern countries, as much as 52 per cent.) Traffic was identified as the third largest contributor to $PM_{2.5}$ levels in Africa, with a 17 per cent share. This sector was, however, the main cause of PM_{10} levels, contributing around 34 per cent of total ambient concentration of this pollutant on the continent. Other studies have identified open field burning activities as a major source of this pollutant in Africa (Naidja et al., 2018). These findings must be used with caution given the highly locally specific nature of urban pollution. Nonetheless, they highlight two factors that any comprehensive air pollution response in African cities will likely have to take into account, as follows:

- According to the most updated and comprehensive African inventory (Keita et al., 2018), PM emissions from the residential sector, mostly related to household solid fuel combustion, represent more than 70 per cent of

7 For discussion of the global and regional datasets used, as well as the methodology followed for the city-level case studies, see Appendix A.
8 See Appendix A.
9 Directly emitted anthropomorphic particles are largely made of OC and BC (Bond et al., 2004), therefore together they make a good proxy for combustion-related emissions.

Figure 4: PM emission trends for the African continent[10]



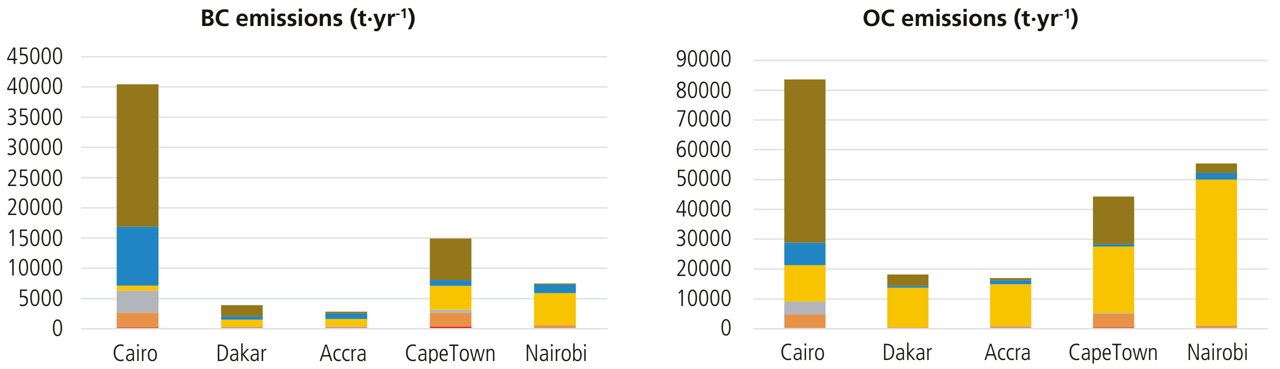
total combustion sources on the continent. As a consequence, African cities need to deal with both indoor and outdoor air pollution, in contrast with OECD country cities, where indoor air quality is driven by outdoor concentration levels (Tang et al., 2018).

- Traffic is a relevant polluting sector in nearly all African cities, and its relative importance is expected to grow substantially in the near future (Liousse et al., 2014). Use of old cars, poor quality of fuel or diesel fuel, underdeveloped infrastructures and unorganized public transport (Assamoi & Liousse, 2010) are common challenges in African cities, contributing to worsening air pollution (Mbow-Diokhane, 2019). It should be noted that exhaust emissions are not the only source of PM from mobile sources – abrasion (road, brake and tyre wear) and dust re-suspension can be even larger contributors to PM emissions. Non-exhaust emissions are particularly relevant in Africa where unpaved roads make up the majority of the road network (Naidja et al., 2018).

The sources of emissions vary considerably from city to city. While our five case study cities share some commonalities with these overall continent-wide emission patterns, at the same time they show some considerable variations (see Figure 5). The residential sector does indeed appear to be the main source of emissions of organic carbon for four of the five cities (Dakar, Accra, Cape Town and Nairobi); however, in the megacity of Cairo the waste sector predominates. For black carbon, the dual importance of the waste and residential sectors appears evident in Dakar and Cape Town. In Cairo, however, the waste sector dominates BC emissions, with the residential sector assuming little importance, while the reverse is true in Nairobi. The reasons for such differences are complex but have to do in part with the varying levels of socio-economic development achieved in those countries. The main implication of these marked differences is that, when addressing air quality at the city level, one size doesn't fit all: baseline emissions inventories and source apportionment studies must be undertaken as a basis for formulating customized, well-targeted clean air action plans.

10 *Ibid.* Source: Borge, elaborated from the gridded inventory of Keita et al. (2018).

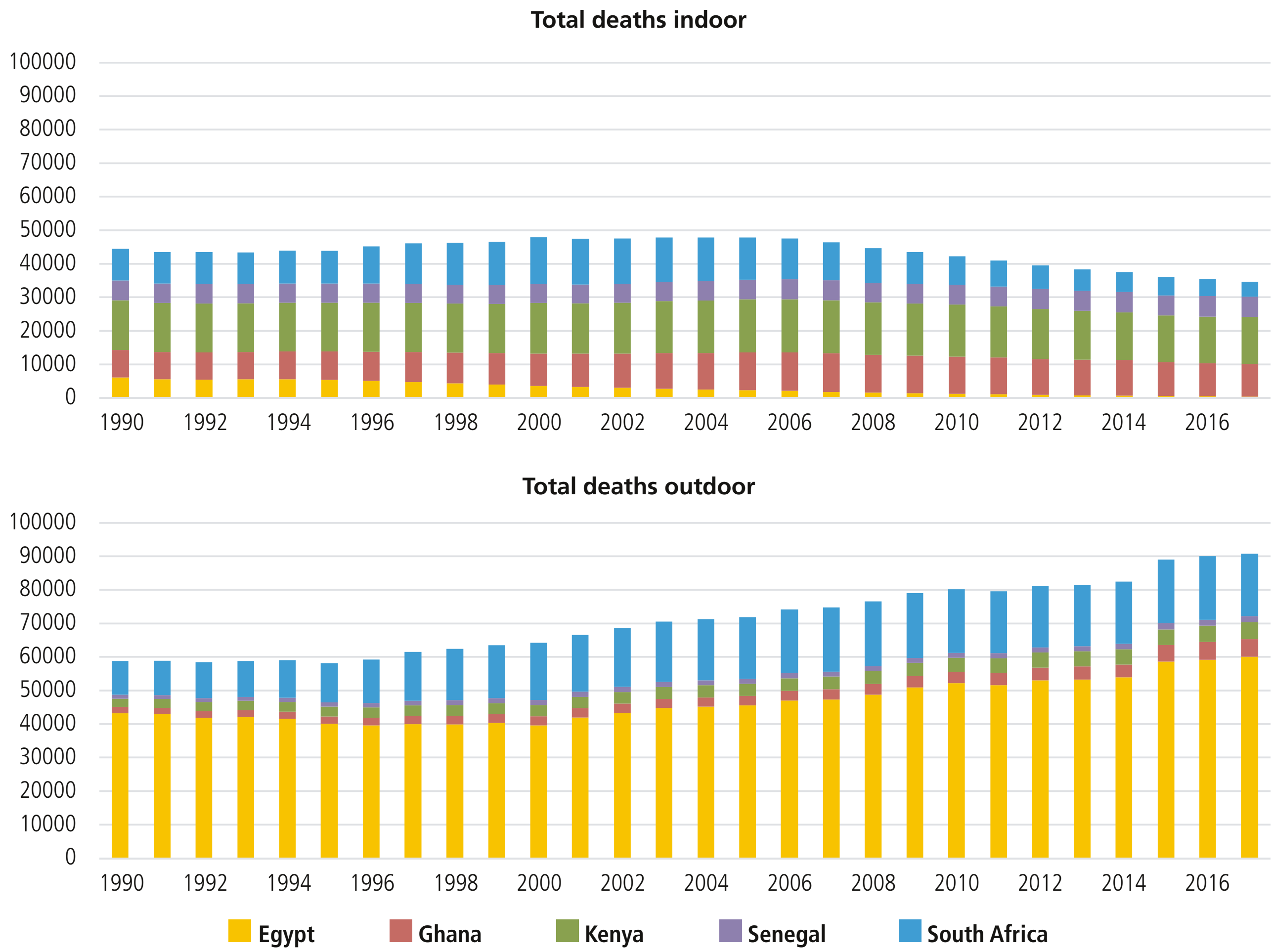
Figure 5: PM emissions in the 5 target cities (t) in 2015[11]



In the five case study countries, total premature deaths per annum from outdoor (ambient) air pollution are on the rise. This unfortunate pattern seems to hold true for all five target countries (Figure 6). In all five countries, premature deaths from air pollution per annum outstrip deaths from unsafe water, sanitation and underweight childhood (Roy, 2016).

Since about 2005, the five countries under review have collectively had some success in curbing premature deaths from indoor air pollution. More specifically, available data (Stanaway et al., 2018) suggest that household air pollution is generally a larger health concern in the lower income countries; ambient air conditions assume greater relative importance in

Figure 6: Total deaths associated to air pollution in the countries where the five case study cities are located, according to the global burden of disease 2017[12]



11 Source: Borge, elaborated from Stanaway et al., 2018.
12 Source: Borge, elaborated from Stanaway et al., 2018.

emerging economies. The trends in Egypt and South Africa clearly show that the burdens of disease have shifted towards outdoor (ambient) air quality over the last years while per capita GDP has grown; meanwhile, indoor air quality still dominates health impacts in Senegal, Kenya and Ghana.

Mortality rates attributed to the joint effects of household and ambient air pollution vary considerably among countries, as well as in the diseases that cause those death (Figure 7). According to the latest information from the Global Health Observatory data repository (WHO, 2016), lower respiratory infections are the leading cause of air pollution-related mortality in Ghana and Kenya, while ischemic heart disease dominates such deaths in Egypt. These two conditions have a similar contribution to premature deaths in Senegal and South Africa. Overall, Senegal presents the highest mortality rate due to air pollution.

With those sobering trends and individual differences between countries in mind, we turn to the city case studies.

2.2 Five African cities: Status of progress in addressing air quality & promising practices

Based on our five in-depth city case studies (see Appendix B), below we (1) summarize the status of progress in the five cities (and countries) in addressing air quality, while highlighting promising practices. Then we (2) offer some reflections and recommendations on improving air quality in these and other cities. These discussions are organized per the Air Quality Management Framework (AQMF) summarized in Chapter 1, above. Finally, we (3) discuss the implications of the findings for donors and the development communities, in terms of 'theories of change'.

Status of Progress in Addressing Air Quality

The overall status of cities' (and countries') progress in addressing and managing air quality is shown in Table 2. As shown, the countries at higher levels of socio-economic development (i.e., Egypt and South Africa) have generally achieved more 'mature' or 'developed' ratings for their air quality management systems, as indicated by the 'green' cells. At the same time, the table suggests that all five countries and cities have some areas where further work is needed, as shown by 'yellow' or 'red'. It should be noted that the lack of fully consistent and comparable information prevents a more formal comparison of the status of air quality management in the cities under review. The goal here is not so much to try to 'rank' the cities in this study but rather to identify the most promising practices as well as important areas for future improvement.

Table 2 also shows, encouragingly, that all five cities (and countries) offer some promising practices or measures that have yielded at least some initial positive results. These practices may offer replicable examples for other African cities faced with similar air quality issues or at similar stages of development in their air quality management systems.

Figure 7: Mortality rates attributed to joint effects of household and ambient air pollution, according to the Global Health Observatory data repository (WHO, 2016). The bars show the 95 per cent confidence intervals

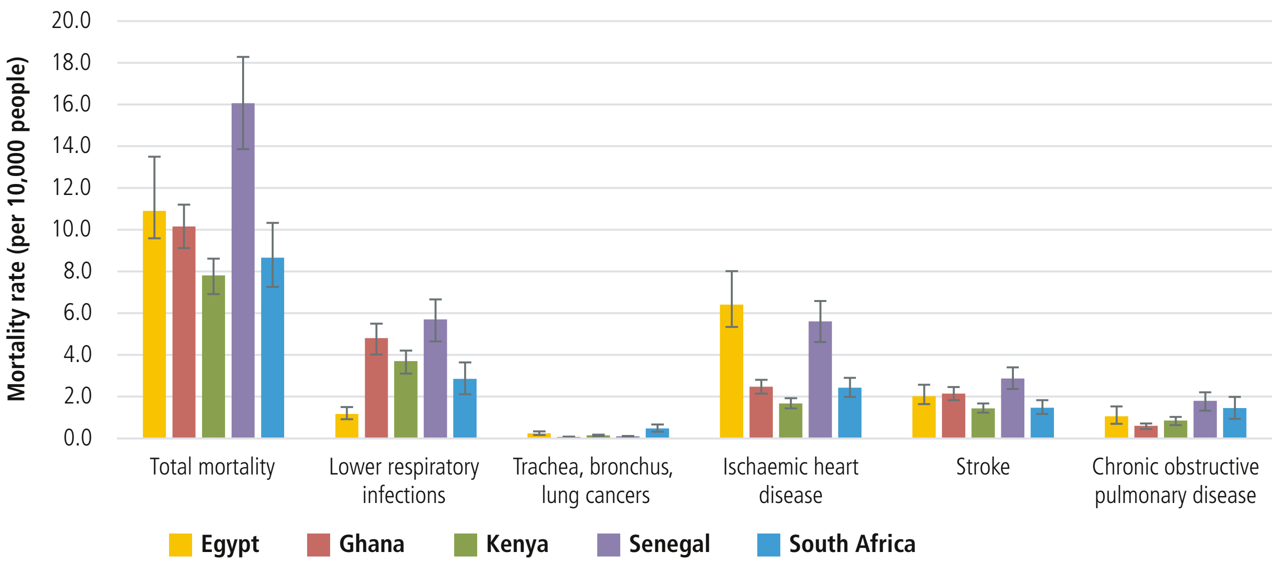


Table 2: City level air quality management assessment summary according to the Air Quality Management Framework[13]

City (Country)	Stage in Air Quality Management Process						
	Air quality standards & monitoring		Emissions inventories and modelling	Health (and/ or other) impact assessments	Communication	Clean Air Action plans	Governance
	Monitoring (# and type of stations)	National air quality standards**					
Accra (Ghana)	5 fixed reference stations*, 23 low-cost monitors	Air Quality Guidelines proposed only for PM10	Some research-oriented emission estimates. Limited modelling capabilities	Some studies focussing on indoor air quality issues. Relevant impact from e-waste open burning traffic too	AirNow-Ghana system being developed to share AQ data	2018 Greater Accra Metropolitan Areas Air Quality Management Plan (Ghana's EPA)	Comprehensive legal and institutional framework. Lack of integration and operational capacity
Cairo (Egypt)	42 fixed reference stations and 25 sampling stations in GCMA	TSP, PM10 NO_2, SO_2 O_3 and Pb ($PM_{2.5}$ missing)	Urban emission inventory available for 2010, need to be updated. Limited modelling capabilities	Some studies highlight the impact of traffic	AQ reports issued but data not publicly available	Several national plans and instruments but no AQ-specific strategy	Poor ministerial coordination and lack of a clear institutional framework for local AQ management
Cape Town (South Africa)	17 fixed reference stations*	SO_2, NO_2, PM_{10}, O_3, C_6H_6, Pb, CO and $PM_{2.5}$	Some research-oriented emission estimates and industrial inventories. Limited modelling capabilities	Some studies quantify the impact of meeting air quality standards, particularly beneficial for vulnerable groups	South African Air Quality Information System (SAAQIS) and National Association for Clean Air (NACA)	2016 Western Cape Province Air Quality Management Plan along with many other national and local strategies	Multi-level distribution of competences and profuse regulation. Lack of centralized local AQM authority.
Dakar (Senegal)	5 fixed reference stations*, 1 mobile lab,	SO_2, NO_2, CO, PM_{10} and Pb ($PM_{2.5}$ missing)	Some research-oriented emission estimates. Limited modelling capabilities	Studies point out that indoor air quality is a major health issue. Traffic is also particularly relevant in Dakar.	Centre de Gestion de la Qualité de l'Air (CGQA) oficial AQ data, forecast and information	National development strategy (ESP) and several relevant local instruments but no specific AQ strategy	Comprehensive strategy to keep strengthening administrations and increase cooperation. Limited integration.
Nairobi (Kenya)	2 fixed reference stations*, 1 mobile lab, 6 low-cost monitors	SO_x, NO_x, CO, O_3, Pb, PM_{10} and $PM_{2.5}$. (Not effectively enforced)	Some research-oriented emission estimates. No modelling activities	Some studies highlight the impact of traffic household combustion and open burning	Clean Air Nairobi platform to share AQ data. Small-scale demonstrative projects	Air Quality Action Plan (2019-2023), complementary to other local and national relevant plans	Instruments and structures available. Institutional weakness and corruption

*Despite the existence of these stations, data is often outdated, inconsistent or missing
**Not in cities' control; included to indicate existing enabling/legislative framework at national level.

13 In Table 2, columns correspond to the 'elements' or 'components' of the AQMF. As explained in the Key, the colour coding corresponds (in a consolidated way) to the several 'stages' of the AQMF, as follows: 'green' shows a component at a maturing or fully developed stage, 'yellow' indicates a component at a developing or emerging stage, while 'red' suggests a component that is underdeveloped.

Key:

Colour	Monitoring	National air quality standards	Inventory	Health and /or other impact assessments	Communication	Action plan	Governance
Green	A relatively comprehensive air quality data monitoring system returning data usable by WHO database	Existing	Detailed inventory of emissions and their sources conducted	Localised health (and/or other) impact assessments exist – by local government or other body	Stakeholder/ community outreach, awareness raising happens regularly	Air Quality Action Plan exists and is current or being updated	Capacity for AQ management activities within the city, dedicated staff/ structures/ integration with city development plans
Yellow	Partial data monitoring, patchy coverage, reliability or quality	Guidelines being converted into standards	Some partial studies of pollution sources & types conducted, limited or dated	Partial estimates of air pollution impacts, not fully localised	Some outreach and awareness activities, dated or partial	Partial plan exists, in progress, or outdated	Limited capacity, partial integration with city development plans
Red	No/very little air quality data monitoring	No national standards	No inventory of emissions conducted	No studies of the health impacts are available	No outreach and awareness activities on air quality	No AQ action plan exists	No dedicated air quality capacity or management structures

Sources: Framework: Clean Air Asia (Clean Air Asia, 2016). Assessment: authors of present report.

These encouraging practices, the most promising of which are shown with a 'green' rating in Table 2, include the following:

1. **Air quality standards and monitoring**
   - South Africa has comprehensive and stringent national air quality standards (SANS), and a schedule in place to progressively tighten $PM_{2.5}$ standards in the future. This can be regarded as an ideal situation for mature stages of air quality management.
   - Cairo (Egypt) has been able to channel international collaboration (DANIDA, USAID) to develop a full-scale urban air quality monitoring system. Similarly, the support of NDF and USAID has helped Dakar and Accra, respectively, to kick-start their monitoring capabilities. Accra in particular has proved successful in attracting international cooperation for a range of activities related to improving air quality management.

2. **Emissions inventories and modelling**
   - Cairo is the only city in this study that, in cooperation with international institutions, has completed an urban emission inventory and has undertaken strategic analysis of future emission scenarios. Although the city has not succeeded at in regularly updating its inventory, it does offer a useful example of the efforts needed to compile at least an initial comprehensive inventory in the African context.
   - The modelling activities within the Khayelitsha Air Pollution Strategy (KAPS) in Cape Town are a good example on how local authorities can acquire some basic modelling tools and capabilities.
   - Despite the technical limitations of CGQA, Dakar produces air quality forecasts that can contribute significantly to limit the negative health effects of poor air quality.

3. **Health and other impacts**
   - Specific health impact assessments in Cape Town have provided clear evidence of the critical need of public health interventions and the establishment of pro-equity policies to improve air quality in low-income areas.
   - Similar studies for Cairo provide information about the benefits of complying with national air quality standards. In addition, analysts made a clear economic case for emission abatement by estimating that the cost of air pollution represents three to six percent of the GDP.
   - Studies in Senegal revealed that improving indoor air quality would not only result in significant health benefits but would also yield remarkable climate and gender co-benefits.
   - Recent research in Dakar clearly highlights the health effects related to traffic and provides compelling arguments to reduce emissions from traffic.

4. **Communication**
   - The South African Air Quality Information System (SAAQIS) is exemplary at disseminating air pollution information to the public – a necessary first step to raise awareness. In addition, the National Association for Clean Air (NACA) provides a reference for the dissemination of studies and activities related to air pollution in Africa, including the Clean Air Journal, a publication that focuses on air quality management and the impacts of air pollution in Africa. Initiatives such as these can also help to build technical capacity and to foster collaboration. Cape Town was the only city in this report where a quantitative analysis of the impact of recent COVID-19-related measures was feasible due to air quality data availability and accessibility from the monitoring network (see Chapter 3, below).
   - Dakar's air quality network represents a model of transparency and effective environmental data dissemination, even though monitoring capabilities are in incipient stages.
   - In Accra, we see the fledgling work of the WHO/CCAC's Urban Health Initiative in raising the necessary awareness through community-based actions and campaigns. Other collaborative initiatives such as the "Clean Air Nairobi" platform can be instrumental for involving people.
   - In general, all the air quality plans, projects and sectoral strategies consulted in this report recognized the essential role of communication and stressed the need to accompany any intervention with an intense dissemination and awareness-raising campaign.

5. **Clean Air Action Plans**
   - The Greater Accra Metropolitan Areas Air Quality Management Plan, recently launched by Ghana's EPA, includes clear measures, with the accompanying indicators, time frames, responsibilities and collaborations needed to comply with national ambient air quality standards. The plan addresses all the relevant sources and contemplates the involvement of stakeholders and residents. More importantly, it identifies the capacity gaps that should be addressed for a successful implementation. All these features should be included in an ideal urban air quality plan.
   - Despite the lack of a specific plan per se, the massive introduction in Egypt of natural gas in the domestic, industrial, power generation sector, along with the development of large-scale engineering projects, has allowed officials to improve air quality in Cairo despite rapid population growth. Although this strategy may not be sustainable or adequately climate-friendly in the long run, it does demonstrate that investments in transportation infrastructures and fuel switching schemes can be very effective at cutting down emissions in initial stages of air quality management.

6. **Governance**
   - The cases of Senegal and Ghana show that strengthening administrative capacities and consolidating robust democracies provide the preconditions and necessary enabling environment (i.e., appropriate institutional, legal, and regulatory structures) for the successful development and implementation of air quality management systems.
   - The administrative decentralization in South Africa has allowed the development of a multi-level regulatory scheme that provides the necessary framework for the regulation and allocation of responsibilities among national, regional and local administrations. While this is the ideal situation for the implementation of advanced air quality management systems, the experiences from Cape Town also expose the difficulties and potential shortcomings of this approach. On the other end of the spectrum, Egypt demonstrates that a strongly centralized management may be more effective, at least in the initial stages of air quality management.
   - The development of a comprehensive regulatory framework, along with the effective implementation of an operational control and inspection system, has enabled South Africa to make significant progress in curbing industrial emissions.
   - Local initiatives such as the Greater Accra Scrap Dealers Association (GASDA) in Agbogbloshie provide good examples of effective ways to simultaneously eradicate bad practices (inadequate waste management in this case) while introducing new business models into the informal economy. Both factors redound to better living conditions for the most vulnerable strata of society.
   - Experiences in Cairo have demonstrated the potential of agricultural waste valorisation in cement plants to alleviate the black cloud issue in the region. This innovative business model approach illustrates the benefits of cross-sectoral measures to prevent pollution, while at the same time improving the local economy and yielding climate co-benefits.
   - We note the opportunity to link air quality management to overarching development strategies, either at the national (e.g., the Emerging Senegal Plan) or the local level (e.g., OneCape 2040 in Cape Town, or the Nairobi Integrated Urban Development Master Plan). Such linkages can not only improve social and economic conditions but also bring about greater environmental justice.

Reflections and recommendations to improve air quality in Africa

From the data and relevant information discussed for these five cities, some general recommendations and strategic advice for African cities can be tentatively offered, as follows[14]:

1. **Air quality standards and monitoring**
    - Most of the countries examined in this report have moved from more voluntary and limited air quality guidelines to formal and more comprehensive air quality standards, typically set at the national level. At the same time, according to the information available, the main issue confronting African countries at present is not the lack of air quality standards per se but rather the absence of their effective enforcement. As much as possible, it would be advisable to include $PM_{2.5}$ in such standards, since this is the most relevant pollutant from a public health perspective. Given the strong influence of natural sources in the continent, e.g., windblown dust from deserts, air quality standards should be reviewed to consider such factors when assessing compliance and air quality trends.
    - Air quality data on the continent is limited and this makes assessing the scale of the challenge difficult. Even where monitoring stations exist, adequate maintenance or reliable power supplies are lacking, and data are therefore of poor quality or consistency. International collaboration has proven to be an effective way to kick-start monitoring capabilities, but at the same time research shows that adequate training and dedicated funding is essential to guarantee the sustainability of those networks over time. Evidence from the cities analysed points out that providing for a dedicated source of funding and establishing mechanisms to operate and maintain monitoring infrastructures is critical.
    - New technologies based on low-cost sensors may help improving monitoring capabilities, but significant investments in capacity building and maintenance are still needed.
    - It is also important to increase the collaboration of cities with local universities and research institutes, to involve scientists in this process.

2. **Emissions inventories and modelling**
    - Emissions inventories are an essential input to prioritise action on the range of emissions sources affecting urban air quality, and are a key piece of any air quality management system. They are also useful to monitor progress and assess the efficiency of plans and measures. While national GHG inventories are usually available, city-scale emission inventories are mostly missing; they should be developed as a first step to tackle air quality issues. Emission estimates have been made for all the cities analysed in this report as a result of ad-hoc scientific studies or sectoral plans, but they are usually not exhaustive and typically are not regularly updated. As a complement to such specific studies, mobility strategies or master plans developed for the cities usually contain some of the data needed to compile a reliable emission inventory for key sectors such as traffic or domestic emissions. In addition to this information, local universities and research centres often possess the capabilities to address this task in cooperation with the local administration.
    - Further collaborative efforts should be directed at the development of air quality modelling tools. The literature discussed throughout this report illustrate relatively simple modelling exercises that may be useful as a first step to understand local air quality issues for specific sources or neighbourhoods. Cities or regions with a stronger modelling experience may keep working on more complex tools to deal with emerging air quality issues such as tropospheric ozone or secondary aerosols. Investing in the development of modelling tools will increase the ability to anticipate the effect of emission abatement measures, and provide the basis for the cost-benefit analyses that must constitute the basis of subsequent urban air quality plans.

3. **Health and other impacts**
    - While some general estimates exist, localised epidemiological and cost-benefit studies are needed to better understand the health impacts of poor air quality in African cities and make stronger cases for concerted multi-level policy action. Extreme weather, communicable diseases and famine may increase the vulnerability of certain population groups to the impacts of air pollution more than conventional health impact models (based on assumptions drawn from higher income countries) might suggest. Such localised findings would better inform the prioritisation of actions.

14 More research is needed to fully characterize the drivers of air pollution action in the region and formulate evidence-based plans to improve air quality in the individual affected cities, in coordination with climate policies and general development strategies; such lies outside the scope of the present review. At the same time, the lack of consistent and comparable information prevents a more formal comparison of the status of air pollution or definitive assessment of the air quality management framework(s) in countries and cities

- The evidence offered by the case studies in this report point out that low-income citizens in African cities may disproportionally bear the impacts of air pollution. Emissions from the burning of dirty fuels indoors, the open burning of waste, and unpaved roads, among other sources, create pollution hot spots in informal settlements. Exposure to air pollution from traffic is particularly high among the poor since they mostly rely on non-motorized transport routes along heavily polluted environments. Such factors mean that air quality is not only an environmental but also a social justice concern. All the case studies without exception underscore this circumstance. Therefore, any serious, broad-based efforts to improve the lives and living conditions of the urban poor necessarily must consider how to improve air quality in their environs. At the same time, general efforts to meet WHO air quality guidelines or even national air quality standards would confer extensive health benefits, especially for the most vulnerable communities.
- All the evidence suggests that developing countries and specially deprived communities subjected to inadequate air quality conditions are much more vulnerable to synergetic negative health outcomes as those of the COVID-19 pandemics. This circumstance provides an additional argument for more decided action towards rapid reduction of air pollution.

4. **Communication**
    - Education and public awareness towards air pollution processes and air quality health effects is alarmingly low in Africa; this may hinder the uptake of emission abatement measures. Any intervention or strategy needs to emphasise communication measures for a successful result.
    - Open access to air quality data, emission inventories and registers is an essential precondition to engaging relevant stakeholders and the general public in improving air quality. Channels for communicating the impacts of poor air quality are also essential since only an informed citizenry can demand additional measures to preserve public health.

5. **Clean Air Action Plans**
    - Air quality action can be driven by dedicated Air Quality Action Plans, but also by integrating air pollution actions into national and city development plans that guide infrastructure and socio-economic development. The choice of adopting either approach will depend on the local context. While both approaches will yield positive effects, it is important to explicitly consider emissions and exposure in all the targeted plans and strategies as an effective way to maximize health benefits.
    - Improving air quality in these five cities and those like them requires a comprehensive and diverse response to multiple pollution sources, covering both indoor and outdoor pollution. This is because the sources of air pollution (as well as local meteorological features) in the selected cities are varied and diverse, including the burning of waste (especially Accra), indoor fuel burning (everywhere but Cairo), Saharan dust (mainly in Cairo, Dakar and Accra), industry (Dakar, Cairo) and agricultural crop burning on the outskirts of cities (Cairo). Ad-hoc experimental campaigns and research projects highlight that a diversity of air quality issues remain in these urban areas. At the same time, PM-related pollution is a common factor to all of the case study cities; action to address this pollutant should be prioritized.
    - For countries and cities in which data and financial resources are lacking, a strategic focus on domestic “no regrets” short-term actions to reduce air pollution may be a wise investment, even before long-term monitoring and management capacity is established. Effective banning of open burning, accompanied by a transition to a more responsible local recycling industry and improved fuel standards, are examples of such ‘no regrets’ actions.
    - The transport fleet in many cities on the continent is increasing rapidly, and therefore transport is likely to become the main focus of air quality action in many cities. In addition to higher emission standards, fuel regulation, stricter regulation of imports to prevent the ‘dumping’ of older or diesel-powered vehicles on the continent, as well as complementary measures to manage transportation demand, are all needed for urban areas. In particular, ‘soft’ mobility measures such as those that encourage the use of non-motorised transport offer significant health co-benefits. Such investments should be prioritized in local agendas to provide safe, accessible alternatives to motorized transport.
    - The integration of public transport policies and cleaner mobility with urban development and land use plans is vital. Achieving more balanced urban growth is not only key to reduce harmful emissions from transport but is also of paramount importance to reduce persistent and generalized social inequities. While rapidly growing cities pose a major challenge in terms of mobility demand and resource consumption, this also provides an opportunity to integrate air quality criteria in the general urban planning of new settlements and city enlargement. Local officials and planners should strive for compact urban development with a balanced land use mix that provides adequate, proper sanitation and public transport infrastructures.

6. **Governance**

- While effective multi-level governance and planning may be difficult to achieve, particularly at initial stages of air quality management, it is a powerful combination if properly resourced and vigorously and coherently implemented. A coordinated, multi-level governance approach to air quality is vital since air quality is a multi-scale problem. On the one hand, national governments often have exclusive legislative power over issues such as air quality standards, industrial emissions and cleaner vehicles and fuels. On the other hand, sub-national governments can often take complementary actions such as developing public transportation infrastructure and periodically checking vehicle emissions; such measures typically lie under the purview of local authorities.
- The need to coordinate the COVID-19 response in low-income areas has demonstrated the advantages of multi-level governance mechanisms that provide for flexibility when designing local interventions. Inflexible, top-down directives have proven to be particularly counterproductive when trying to engage with residents of informal settlements.
- The coordination of air quality and climate change policies needs to be improved. While the magnitude of CO_2 per capita emissions varies widely in the five countries, switching from carbon-based to renewable energy sources represents an example of a national-scale climate strategy that can be counted on to always confer local air quality co-benefits. A harmonized and coordinated response to climate change and air quality is a pressing need to meet national climate commitments and local air quality standards.
- Some countries and cities have been very active in developing plans and regulations but, regrettably, air quality has not always improved accordingly. This is very likely due to deficient implementation and control. Strengthening institutions and reinforcing collaborations among administrations, companies and other stakeholders is key to improving local governance and achieving real changes. In addition to official plans and strategies, there is a breadth of projects and initiatives undertaken in collaboration with multiple international organisms that would benefit from a closer coordination.
- Air quality has multiple ramifications and requires close collaboration among different branches of the administration as well as with external stakeholders. At the same time, the creation of centralized emissions and air quality departments in local administrations may bring to bear greater focus on this issue, while facilitating a more effective allocation of responsibilities and resources.
- Public-private partnerships have proven to be an effective way to promote social development and improve air quality in the cities analysed. The case studies also show that involving actors in the informal economy is essential to provide a consistent response to air pollution and social issues in urban areas.
- A multi-national organisation (or organisations) at the continental or sub-continental scale may be instrumental to boost cooperation among countries, share experiences, jointly monitor air quality, exploit synergies and address transboundary pollution issues. Such bodies have proven effective elsewhere[15]. Such could be established either at the pan-African scale or, perhaps more easily, as a function of existing regional bodies such as the East African Community. This may provide a fruitful platform for countries to exchange experiences and harmonize criteria and methodologies. At the same time, a body such as United Cities and Local Governments of Africa (UCLG-Africa) can serve as a platform for sharing experiences in air quality management amongst African cities.

Towards a Theory of Change for improved air quality in African cities

Despite the communalities found for the five case studies included in the present report and the general recommendations made, it should be noted that air pollution strongly depends on local factors. There is no quick, one-size-fits-all fix to address urban air pollution. More research is needed in different types of cities and urbanizing contexts to draw more general conclusions and provide specific guidance for the wide range of issues that African cities face in terms of air pollution.

15 E.g., the UN Economic Commission for Europe's Task Force on Hemispheric Transport of Air Pollution, or a commission established to support cooperation in implementing the North American Agreement on Environmental Cooperation.

That being said, it might be helpful to provide a comprehensive description of the key drivers and factors for an effective air quality and climate action, along with a conceptual framework for future research in this area. Moreover, given the multi-scale nature of air pollution, it may help to link this framework with the role of multi-level governance as an enabling condition to deliver health and climate benefits from effective air quality management systems. Developing such a theory of change may help developing economies at taking the necessary steps to reduce the burden of disease brought by poor air quality in a context of rapid urbanization. From the limited vision provided by the cities analysed, it is not possible to propose a robust analytical framework suitable to deal with such complexities and to catalyse policy change; it's not even clear that successful strategies can be reduced to a particular linear, one-direction sequence of steps. Nonetheless, based on the evidence reviewed, we can provide some reflections towards that goal.

It is generally accepted that the first step towards change consists of building evidence about the problem and the benefits derived from tackling them – one of the main objectives of the present report. Giving residents access to that evidence is essential to create 'bottom-up' pressure that can mobilize local governments to act. However, we learned from the case studies in this report that citizens in African cities, even – and especially – the poor most directly affected by air pollution, often face more pressing concerns such as livelihoods, housing, sanitation and waste management. This suggests that general strategies at both the national and local levels that aim at solving social dysfunctionalities and persistent, structural poverty represent an essential enabling factor and precondition for action. Furthermore, such general strategies provide an opportunity to introduce bold policy scenarios to bring about profound, transformative changes that go beyond slow, incremental improvements.

To elaborate on this latter point: taking a transformative, multi-level governance approach helps to establish the enabling conditions that foster air quality action. Urban air quality management is in effect a shared responsibility between national and local levels, and multi-level governance provides for sharing responsibilities (e.g., related to regulation, planning, implementation and control) in a more effective and flexible way. This approach to air quality allows for both: (1) defining, at the national level, a common vision, set of goals and general instruments needed to support emissions abatement strategies, as well as (2) enabling, at the subnational level, regions or cities to address their specific pollution issues and find synergies with other local cross-sectoral strategies. The achievement of ambitious goals requires strong action at national level, typically in the scope of the energy sector, coupled with local measures able to provide solutions to each city's specific needs.

It can be rightly argued that comprehensive clean air action plans, based on evidence, offer a central tool for cities to take effective air quality action. Nonetheless, we see that some cities have not managed to improve air quality even though they have developed such plans and strategies. In fact, examples exist of cities that have achieved significant progress in this area in the absence of a specific local air quality and climate change strategy. This raises the question about the factors or drivers that actually underpin effective action. We see that all measures that have proved effective, either at the national or the local scale, with plans or without, are based on solid business models, developed via engagement with relevant stakeholders. It is essential, therefore, to identify ways to transform the economy that provide both economic benefits as well as environmental gains.

Chapter 3

COVID-19 & Air Pollution

Impact and implications of the pandemic on air quality and climate

As a complement to our in-depth analyses of the status and policies of the five case study cities, below we discuss the undeniable implications and impacts of the current, ongoing pandemic on our conceptions and attitudes towards urban air pollution, with a focus on Africa. Under a broader perspective, this analysis helps us to stress-test and validate our recommendations regarding improving air quality in African cities. Given current information shortages, we proceed as follows. Firstly, we review recent scientific research on the links between air quality, health and COVID-19 (CCAC, 2020). Then, to bring the focus down to Africa, we undertake a quantitative analysis for Cape Town. Despite its limitations, this analysis helps us to understand the effect on air quality of the lockdown and other measures taken to contain the spread of the SARS CoV-2 coronavirus during the initial response in the first half of 2020, and consider its implications vis-a-vis the diagnoses and recommendations made for the five cities reviewed in the present report.

Highlights

- Initial research indicates that elevated levels of ambient air pollution correlate with, and likely contribute to, higher numbers of COVID-19 cases and worse health outcomes.
- Measures taken to slow the spread of the coronavirus provided an unprecedented demonstration of the potential of non-technical measures to curb the emissions of pollutants and improve urban air quality worldwide.
- The co-benefits of the lock-down measures originally intended to slow the transmission of COVID-19, in terms of improved air quality and in turn improved human health, may actually surpass the benefit resulting from the COVID-19 lock-down.
- The pandemic provides an additional argument to strengthen emission abatement efforts. A site-specific approach that takes into account the local particularities of Africa and its sub-regions and cities is called for.

3.1 Are COVID-19 and air pollution related?

The outbreak of the Coronavirus disease 2019 (COVID-19, related to the pathogen SARS-CoV-2) was first identified on 30 December 2019 and declared as a global pandemic by the World Health Organisation (WHO) on 11 March 2020. Symptoms of CoVID-19 are non-specific and can range from none (asymptomatic) to severe pneumonia and death (Wu, D., et al., 2020). This crisis, which has a strong sanitary dimension (see below), has had undeniable implications on our conception and attitude towards air pollution. While the COVID-19 emergency has overshadowed most other issues, climate change and air quality remain huge threats to public health. Consequently, the scientific community has been actively trying to identify the linkages between air quality and COVID-19 (CCAC, 2020) and, ultimately, deal with both issues in an integrated and comprehensive manner.

Although our understanding is still limited, recent research highlights that these two health risks, COVID-19 and air pollution, are tightly connected from the physical perspective. Although no definite conclusions are available yet, several studies suggest that meteorological variables such as temperature or humidity play a role in the spread of the SARS CoV-2 coronavirus (Gutiérrez-Hernández and García, 2020; Bherwani et al., 2020a; Xu et al., 2020). However, contrasting trends have been reported as well. At the same time, most studies to date focus on countries with low temperatures, so future research should consider locales that experience high temperatures and humidity (Shakil et al., 2020). Other researchers point out that the combined effect of meteorology and air pollution should be taken into account when assessing the influence of environmental variables on COVID-19 transmission in particular locations (Adhikari and Yin, 2020; Zhang, Z., et al., 2020).

There is a strong consensus regarding the relationship between COVID-19 incidence and air pollution. Viruses are not commonly airborne as individual organisms and are more likely attached to suspended particles. Hence, the concentrations of air pollutants such as $PM_{2.5}$ and PM_{10} may affect the aerosol transmission of SARS-CoV-2 (Xu et al., 2020). This has been confirmed by studies such as that of Setti et al. (2020), who found presence of SARS-CoV-2 viral RNA on coarse particulate matter. Other studies likewise have found a positive correlation between air pollution and COVID-19 transmission (Bashir et al., 2020; Filippini et al., 2020; Zhang, Z., et al., 2020; Zhu et al., 2020). Therefore, a cleaner environment could well prove to be an effective way to reduce the transmission of viral infections (Fattorini and Regoli, 2020; Kotnala et al., 2020). However, most of the early research on this topic relies on statistical evidence and inference; there is often a lack of hard biomedical or chemical evidence (Delnevo et al., 2020). This circumstance means that early, tentative findings regarding the correlation between the coronavirus spread and atmospheric factors eventually may be found to be spurious. In addition, some of the papers published on this topic under emergency conditions may not have gone through a rigorous review process (Heederik et al., 2020).

Regardless of the potential role of air pollution in the spread of SARS-CoV-2, many studies argue that, as happens with other respiratory viruses, chronic exposure to certain air pollutants might lead to more severe health effects of COVID-19 and/or a more complicated recovery of patients (Domingo et al., 2020). This is because the presence of particles may exacerbate patients' susceptibility (Han et al., 2020). For instance, Frontera et al. (2020) posit that chronic exposure to high levels of $PM_{2.5}$ as well as NO_2 in the most polluted Italian cities may increase viral load and impair host defences, resulting in higher mortality rates in those cities. Along those lines, Conticini et al. (2020) identified the relatively high levels of pollution in northern Italy as a co-factor of the high level of lethality resulting from COVID-19 infection recorded in that area. According to the study of Wu, X., et al. (2020), in the United States an increment of 1 µg/m^3 in $PM_{2.5}$ ambient concentration would increase the COVID-19 death rate by 15% (5%-25% 95% confidence interval). Such results indicate that cleaner air would put us in a better position to minimize the effects of COVID-19 or other respiratory viruses.

3.2 Short-term impact on emissions and air quality

Beyond the uncertainties regarding the relationship of coronavirus and air pollution, 2020 provided an unparalleled demonstration of the potential contribution of non-technical measures to abate emissions. The virus is efficiently transmitted among humans (Morawska and Cao, 2020; Prather et al., 2020), therefore, in 2020, generalized lockdowns and social distancing were adopted all over the world in an effort to slow down transmission rates. As a consequence, economic activities in many places have been markedly decreased (Anjum, 2020). Although activity rates may have increased in the residential (Le Quéré et al., 2020) and agricultural sectors (Manut et al., 2020), many measures taken to control the virus's spread have resulted in a substantial reduction of activities in key sectors responsible for air pollution. It is estimated, for example, that restrictions globally induced a 75% decrease in the aviation sector, and reduced urban traffic congestion by 50% (Le Quéré et al., 2020). Lockdowns in China reduced human mobility by 70% (Bao and Zhang, 2020) and resulted in reductions up to 40% in the activity of key industrial sectors (Anjum, 2020). Similar figures regarding traffic reduction have been reported for European cities, i.a., in Italy and Spain (Baldasano, 2020; Muhammad et al., 2020). A reduction of around 80% in traffic flow due to restrictive measures was observed in Rio de Janeiro, Brazil (Dantas et al., 2020). In Auckland, New Zealand, traffic flows reduced by 60–80% as a result of a government-led initiative to contain the virus by limiting all transport other than essential services (Patel et al., 2020). The effect of stay-at-home policies has also substantially reduced activity rates in North America. Xiang et al. (2020) estimate that, in Seattle (US), the median traffic volume and road occupancy decreased by 37% and 52%, respectively.

These changes in our production and mobility patterns brought about unprecedented reductions of anthropogenic emissions. Le Quéré et al. (2020) estimate that daily global CO_2 emissions decreased by 17% in April 2020 compared with the mean 2019 figures, with reductions of up to 26 % in certain countries. This is consistent with estimates for China, where measures to minimize the spread of SARS-CoV-2 led to a 25% reduction of CO_2 emissions (Dutheil et al., 2020; Wang and Min, 2020). GHG emissions also fell in other countries with less restrictive measures, such as the US. For instance, at the outset of the pandemic New York reduced emissions of CO_2 by five to ten per cent, along with other greenhouse gases such as methane (Anjum, 2020).

The implications for air quality of such unprecedented reductions in CO_2 emissions are even stronger. China was the first country to implement restrictions and arguably has imposed the most stringent measures. In Central China, NO_2 emissions fell by as much as 30% (Dutheil et al., 2020). Li et al. (2020) estimated that $PM_{2.5}$ and NO_x emissions dropped by close to 50% in the Yangtze River Delta Region; this brought about air quality improvements of around 33% and 27% for those two pollutants, respectively. He et al., (2020) attribute counter-COVID-19 measures to an average 25% reduction of $PM_{2.5}$ ambient concentrations in China, even while they point out that the effects are larger in colder, richer, and more industrialized cities. Ma and Kang (2020) reported decreases of 30% and 53%, respectively, of average $PM_{2.5}$ and NO_2 levels in Wuhan, the province where the pandemic originated, a month after lock-down. Chu et al., 2021 obtained very similar results when compared air quality in Wuhan with that same period of the previous year. Chu et al. (2021) estimated that, on average, air quality in China improved by 19 % and 30%, for $PM_{2.5}$ and NO_2, respectively. Shi and Brasseur (2020) found even more dramatic reductions in pollution levels: they estimated that the average concentration levels of $PM_{2.5}$ and NO_2 in China decreased by approximately 35 and 60 percent, respectively, during the lockdown. In yet another study, Wang and Min (2020) estimated that NO_2 concentration levels fell by 50% in 2020 compared with the same period in 2019, after the Spring Festival holiday. Finally, a study involving 367 Chinese cities (Chen et al., 2020) found reductions in NO_2 and $PM_{2.5}$ ambient concentration levels of 12.9 μg/m^3 and 18.9 μg/m^3, respectively, from Jan 1, 2016, to March 14, 2020. On average, the composite Air Quality Index (AQI) over the main urban areas in China improved by 20%, mainly due to reduced emissions from the transportation and industrial sectors (Wang, Y., et al., 2020).

All studies suggest that the measures taken were less effective in relative terms for PM than for NO_2, due to specific meteorological constraints, long-range transport and the non-linearity of aerosol chemistry (Le et al., 2020). While the $PM_{2.5}$ emission decrease in China may have been around 40%, $PM_{2.5}$ average ambient concentration levels were only reduced by 20%, and severe PM pollution events persisted during the Covid-19 outbreak (Wang, P., et al., 2020). In fact, PM concentrations actually may have increased due to enhanced secondary PM formation as well as unfavourable meteorology (Huang et al., 2020).

Turning to secondary pollutants, they present a contrasting trend with that noted for primary pollutants. Shi and Brasseur (2020) report an increase, by a factor of 1.5 – 2.0, of tropospheric O_3 in China during the lockdown period; this is consistent with the findings of other studies (Chu et al., 2021; Huang et al., 2020; Le et al., 2020). This increase was particularly high in urban areas, such as Hangzhou (Wang, L., et al., 2020), in contrast with more rural environments where NO_x was reduced to a lower degree. This phenomenon is due to the non-linearity of O_3 (Le et al., 2020), and has been observed in cities all over the world, including Rome (Sicard et al., 2020), Barcelona (Tobías et al., 2020) or New York (Adhikari and Yin, 2020; also see below).

Notwithstanding such special circumstances, net positive impacts on air quality have been broadly reported all over the world. Social distancing and other measures implemented after the COVID-19 outbreak in Korea in March 2020 reduced nationwide $PM_{2.5}$, PM_{10}, NO_2, and CO ambient concentration levels by 45%, 6%, 20%, and 17%, respectively (Ju et al., 2020). A comparison of the average $PM_{2.5}$ and NO_2 of a month before and after the COVID 'self-reflection' in Daegu (South Korea) shows a decrease of 21% and 19% respectively (Ma and Kang, 2020). This study found lower yet significant improvements for Tokyo (four percent and ten percent, respectively, for these pollutants). According to Abdullah et al. (2020), the Malaysia Movement Control Order achieved a reduction up to 58% in $PM_{2.5}$ concentrations in the country. Other studies report more modest reductions for this pollutant, around 23-32% (Kanniah et al., 2020), while the reduction of NO_2 concentration may have reached as high as 64%. Scientists point out that COVID-19 restrictions in Asia not only alleviated air pollution in major urban areas but in other locales as well. For example, significant air quality improvements in Hat Yai, a medium-sized city in Thailand, have been reported by Stratoulias and Nuthammachot (2020). NO_2 concentrations in this location decreased by 34% during the lockdown, while $PM_{2.5}$ and PM_{10} levels both decreased by more than 20%. This contributed to reach the lowest April averages for NO_2, CO and $PM_{2.5}$ levels reported during in the past decade.

Due to the COVID-19 pandemic, human activities were largely restricted in many regions in India beginning in mid-March of 2020. On average, for 22 cities throughout the country, around 43, 31, ten, and 18% decreases in levels of $PM_{2.5}$, PM_{10}, CO, and NO_2, respectively, were observed during the lockdown period compared to previous years, even while O_3 levels increased by 17% (Sharma et al., 2020). As a result, air quality in about 70% of the cities across India have returned to either 'good' or 'satisfactory' levels during the lockdown episode (Mahato and Ghosh, 2020).

These improvements were drastic in major urban areas like New Delhi (Kotnala et al., 2020), where the combined AQI evolved from 'unhealthy' or 'very unhealthy' to 'satisfactory' or 'healthy' (Srivastava et al., 2020). In that city, Mahato et al., (2020) report reductions of levels of PM_{10} and $PM_{2.5}$ as high as 60% and 39%, respectively, along with a 53% decrease of NO_2 concentrations[16]. Similar improvements – and up to 78% for NO_2 -- have been estimated for Mumbai (Kumari and Toshniwal, 2020). Among other environmental benefits (i.a., better water quality), a reduction of 85.1% in $PM_{2.5}$ concentrations have been recorded for Ghaziabad, one of the most polluted cities in India (Lokhandwala and Gautam, 2020). Of note, air quality also improved in larger, relatively industrialized areas such as in Gujarat State, where an

16 One study that adjusted for possible effects due to favourable meteorology suggested that, while still significant, the improvements in $PM_{2.5}$ pollution levels in New Delhi attributable to lockdown are actually more modest, around 33% (Sharma et al., 2020).

overall improvement of 58% in the AQI was observed during the first four months of 2020 relative to the same period of 2019 (Selvam et al., 2020).

Air quality improved during the COVID-19 shutdown in other parts of southern Asia as well, e.g., in Bangladesh, mainly due to lower ambient concentrations of $PM_{2.5}$ (Masum and Pal, 2020). In Almaty (Kazakhstan), the average $PM_{2.5}$ concentration was reduced by 21% during lockdown compared to the average on the same days in 2018–2019 (Kerimray et al., 2020). There were also substantial reductions in CO and NO_2 concentrations (49% and 35%, respectively), but again an increase in O_3 levels, by 15%. The authors of this study, however, suggest that reductions may not be directly attributed to the lockdown but rather due to favourable meteorological conditions during the period.

Despite regional differences, lockdowns have brought about significant NO_2 ambient concentration reductions in European countries, at approximately 25, 30 and 30% in Spain, France and Italy, respectively (Gautam, 2020). Overall, reductions in $PM_{2.5}$ and PM_{10} concentrations at urban locations in Europe were overall much smaller both in magnitude and relative change (around eight %) than in China or India. In at least some European cities the reductions in PM levels due to reduced transportation as well as decreases in fuel combustion in institutional and commercial buildings were partly offset by increases of PM emissions from activities in homes (Sicard et al., 2020). According to Muhammad et al. (2020), transport in some Italian and Spanish cities reduced by nearly 90%, but residential activities increased by more than 20%. A modelling assessment for Western Europe that assumed no meteorological biases suggested that NO_2 concentrations during March 2020 may have been reduced in the 30-50% range from historical levels, while reductions for $PM_{2.5}$ were estimated at five to 15% (Manut et al., 2020). However, BC levels – a fraction of PM, mostly related to diesel vehicles in Europe -- were found to diminish by 45% in Barcelona (Tobías et al., 2020). By contrast, O_3 levels in that city increased (up to 57% for the eight hour daily maxima), probably due to lower titration of O_3 by traffic NO emissions. Meteorologically normalized estimates by Petetin et al. (2020) propose that lockdown measures may be responsible for a 50% reduction of NO_2 levels on average over Spain.

A series of more or less restrictive measures intended to control the spread of coronavirus have been applied in the United States, too. Relative to the same dates in recent years, NO_2 and $PM_{2.5}$ ambient concentration levels in the continental US have seen reductions up to 27% and 11%, respectively during an initial COVID-19 restriction period (March 13 – April 8, 2020)[17]. A study by Muhammad et al. (2020) estimates that NO_2 was reduced by up to 30% in north-eastern US. Nonetheless, by using linear time lag models to account for both short- and longer-term changes in air quality. On the other hand, Zangari et al. (2020) argue that $PM_{2.5}$ and NO_2 concentration changes from January 2020 to May 2020 in New York City did not significantly differ from those observed during the same time in the previous five years. They conclude that the COVID-19 government-backed shutdowns had no or minimal effects at reducing air pollution in New York.

As this review has suggested, at least some of the changes in pollution levels observed before and after the onset of COVID may be related to the effect of weather. Controlling for meteorological conditions, the COVID-19 responses were associated with modest decreases in median levels of traffic-related pollutants in Seattle. Nitrogen Oxide (NO) showed reductions up to ten percent, while $PM_{2.5}$ concentration diminished around two percent; reductions in concentrations of BC and ultrafine particles ranged between five and eight percent (Xiang et al., 2020). The results of the analysis, however, were completely different in scenarios where meteorology was not adjusted for. This finding highlights the importance of taking meteorological factors into account when assessing the impact of emission reductions on air quality.

A few papers from South America find that local measures to contain COVID-19 may have had a considerable effect on air quality. An average 13% reduction in NO_2 concentrations was observed as a consequence of the COVID-19 lockdown in Ecuador. This reduction was more pronounced in the two most populated cities, Guayaquil and Quito, where NO_2 decreased more than 22% (Pacheco et al., 2020). Dantas et al. (2020) estimate that vehicular flow decreased by 80% in Rio de Janeiro; this reduced CO, NO_2 and PM_{10} median concentration values by 48.5, 53.9 and 33.3%, respectively. As observed in many other cities worldwide per above, O_3 levels in those cities increased during lockdown, by up to 63%.

In New Zealand, transport was limited to essential services only. Observations from Auckland suggest a consequent reduction in NO_2 of 34–57% and a reduction in BC of 55–75% over pre-COVID levels. The observed reductions in $PM_{2.5}$ and PM_{10} were found to be significantly less (eight to 17% and seven to 20%, respectively) (Patel et al., 2020).

17 The percent change of $PM_{2.5}$ is thought to be smaller than NO_2 because $PM_{2.5}$ emissions arise from multiple sources, including non-transportation sources such as emissions from food industries and biomass burning. Those sources were not affected by COVID to the same degree as was transportation (Berman and Ebisu, 2020).

3.3 Health implications

It is premature to evaluate the aftermath of the ongoing SARS-CoV-2 pandemic. However, scientists and researchers have begun to consider the implications of the unprecedented air quality improvements discussed above. Among others, a series of studies put in perspective COVID-19 effects when considering the negative health outcomes due to air pollution.

China locked down one-third of its cities and strictly restricted human mobility and economic activities. Assuming that those measures reduced $PM_{2.5}$ concentrations by 25%, He et al. (2020) estimate that such improvements in air quality would avert 24,000 to 36,000 premature deaths per month. According to official deaths reported in China from COVID-19, less than 5,000 during the first wave (Dutheil et al., 2020), this would mean that, paradoxically, the net number of deaths during the lockdown period may have been drastically reduced from business-as-usual. According to other estimates, in normal years air pollution in China is responsible for 4,000 preventable deaths each day, or around 1.6 million fatalities a year. This implies that cleaner air during lockdown may have prevented 100,000 premature deaths in China over two months (Dutheil et al., 2020). Moreover, the reduction in air pollution could also have yielded other positive benefits, in terms of reducing preventable non communicable diseases (Dutheil et al., 2020).

Chen et al. (2020) used short-term concentration-response functions from a previous study involving 272 Chinese cities. They estimate that air quality improvements in China during the initial (early 2020) quarantine period avoided a total of 8,911 NO_2-related deaths (95% CI 6950–10 866) and 3,214 $PM_{2.5}$-related deaths (95% CI 2340–4087). Those are much lower estimates, but still suggest that, in China, the health benefits from cleaner air could have outnumbered the confirmed deaths attributable to COVID-19 during that period (4633 deaths as of May 4, 2020). Similarly, Sharma et al. (2020) conclude that PM-related health risks were reduced by 52% in India due to COVID-19 restrictions, and that may have averted around 0.65 million premature deaths a year in the country.

These results contrast with the findings of studies in areas where far less strict measures were enforced, such as in the US. Stay-at-home measures resulted in $PM_{2.5}$ concentration reductions around 4 μg/m^3 in urban areas of California, avoiding 483 (95% CI: 307, 665) $PM_{2.5}$-related deaths in that state (Son et al., 2020). In contrast with China (Chen et al., 2020), this would mean that the public health burden of COVID-19 overwhelmingly outweighed avoided mortalities from reduced air pollution.

From the economic perspective, Bherwani et al., (2020b) aver that the trade-offs between the benefits due to reduced air pollution and the economic damages due to implementation of restrictive measures is particularly favourable for economically developing, highly polluted cities such as Wuhan or Delhi, in comparison with other large metropolises in developed countries such as London or Paris.

Besides the direct implications of the dramatic reduction in air pollution due to COVID-19, there are other factors to be borne in mind when considering the net effect. As suggested above, stay-at-home policies imply spending more time at home, a context in which poor household indoor air quality, a long-standing public health issue in some countries, gains increased relevance (Nwanaji-Enwerem et al., 2020). In highly dense areas this may increase contagion (Morawska and Cao, 2020). In addition, mobility restrictions can make it more difficult for infected people to access hospitals to receive treatment and proper medical care (Isaifan, 2020).

Whether or how long lockdown measures will continue in time is another critical issue. We have seen how the concentration of short-lived pollutants have been reduced by half after just a few days of commencing lockdown (Mahato et al., 2020). However, even in areas such as East Asia with emission reductions as high as 50%, emissions went back to normal soon after restrictions were removed (Zhang, R., et al., 2020). Further (and better) research is needed (Heederik et al., 2020), but the preliminary consensus is that a long-term benefit from cleaner air will be achieved only if emission reduction efforts are sustained over time (Isaifan, 2020; Muhammad et al., 2020). Regarding long-term human health hazards, the threat of air pollution can be much greater than that of COVID-19. That finding should be a wake-up call to seriously consider pursuing a more sustainable lifestyle after the end of the COVID-19 pandemic (Ma and Kang, 2020). In the meantime, it is important to enforce air quality regulations to broadly protect the public, while continuing to investigate the interlinkages between COVID-19 and air pollution (Berman and Ebisu, 2020).

More importantly, investigations of the linkages between the pandemic and atmospheric pollution should consider their far-reaching social and economic implications. For instance, climate-related risks such as heat waves, floods or wildfires may exacerbate the effects of coronavirus pandemic, potentially acting to increase already significant socioeconomic disparities (Phillips et al., 2020). In spite of recent emissions reductions and the temporary alleviation of the most serious air quality concerns, a rebound of emissions can be expected as economies reopen, and polluting activities resume (McNeill, 2020). This is particularly the case since a rebooting of primary sectors to compensate for economic loss is projected (Sarkodie and Owusu, 2020); this would likely result in levels of energy consumption and emissions that exceed levels before this extraordinary event (Wang and Min, 2020). Other authors warn that short-sighted responses may jeopardize the imperative decarbonization of the economy and transition to clean energy (Steffen et al., 2020), and thus be counterproductive in the long run. Potential relaxations in the implementation of environmental policies and regulations (McNeill, 2020) so as to achieve what some would hope would be a faster economic recovery may result in even higher emissions (Le Quéré et al., 2020), compromising progress towards air pollution targets. Barreiro-Gen et al. (2020) claim that the COVID-19 outbreak has shifted the priorities of organizations worldwide, as they try to maximize social and economic benefits, often at the expense of environmental considerations.

However, despite such pressures and concerns, a renewed commitment towards a low-carbon economy can certainly be justified from an economic perspective. In fact, it has been argued that the investment needed to adapt to climate change globally, from 2020 to 2030, represents a relatively small fraction of the global expenditure during the last few months as a response to the COVID-19 crisis, and that such investments made now may prevent further health disruptions of incalculable magnitudes in the future (Herrero and Thornton, 2020). In addition, this crisis has demonstrated that drastic behavioural changes are possible and can be broadly accepted by the population (Howarth et al., 2020). Finally, the present crisis offers an opportunity to accelerate action towards a more sustainable world by harmonizing and reconciling COVID-19 recovery programs with the global climate agenda (Rosenbloom and Markard, 2020).

3.4 How about Africa?

Measures to contain the spread of the coronavirus outbreak such as physical distancing or travel restrictions have been imposed in many African countries including South Africa, Rwanda, and Uganda (Mbandi, 2020). However, the lack of monitoring data and the scarcity of specific studies hinder the analysis of the impact of such measures. According to Rodríguez-Urrego and Rodríguez-Urrego (2020), the prohibition of vehicles and the closure of all stores except food suppliers achieved a $PM_{2.5}$ concentration reduction of 35% in Kampala (Uganda), giving rise to an improved, more moderate AQI level during the quarantine period. Otmani et al., (2020) report air quality improvements in a Moroccan city of 75%, 49% and 96% for PM_{10}, SO_2 and NO_2, respectively, during a lockdown period in 2020.

Of the five African cities reviewed in the present report, only Cape Town provides the minimum publicly available air quality data necessary (together with other data) for a preliminary analysis of the impact of COVID-19 measures upon air quality. We downloaded hourly air quality information from the South African Air Quality Information System (SAAQIS) (https://saaqis.environment.gov.za) and selected a number of monitoring stations with a minimum data availability of 75% for the most relevant pollutants during the first half of 2020 (January 1st to July 30th). A summary of the available data is shown in Table 3 and the selected locations are presented in Figure 8. In total, we processed nearly 90,000 hourly observations to provide an overview of the temporal variations observed in the Cape Town area and to examine if any pattern or correlation with COVID-19 measures exists.

A national state of disaster was declared in South Africa on March 15th, 2020, around ten days after the first confirmed case in the country. Self-isolation recommendations and a series of restrictions regarding gatherings (e.g., schools were closed on March 18th) and travelling followed this declaration until March 26th, when a complete lockdown was enforced in the country. This corresponded to the alert level five according to a five-level COVID-19 alert system introduced at the national level to manage restrictions during the pandemic.[18] We follow the color code used in this system (shown in Figure 9) when presenting and discussing concentration plots below.

Of note, this preliminary analysis lacks the necessary rigour to extract solid conclusions due to the qualitative and quantitative limitations of the data used and methodological issues (e.g., we did not control for the influence of meteorology or isolate typical seasonal patterns). Therefore, the results presented below are not necessarily comparable with those discussed earlier in the present chapter.

Below, average time plots by AQMS location type (residential, urban or traffic) are presented along with a non-linear trend based on non-parametric methods (Hastie and Tibshirani, 1990), to yield a more intuitive interpretation of the evolution of pollution levels. All plots were produced with the openair R package (Carslaw and Ropkins, 2012).

Under a business-as-usual scenario, concentration levels of all pollutants, except O_3, would be expected to increase from summer (January to March) to fall (April to June) in the Western Cape Province (DEA&DP, 2019a). The present review examines changes in pollution levels for this six-month period in 2020 but particularly from March 26th on, to see if those trends correlate with changes in COVID alert levels and resulting behavioural changes.

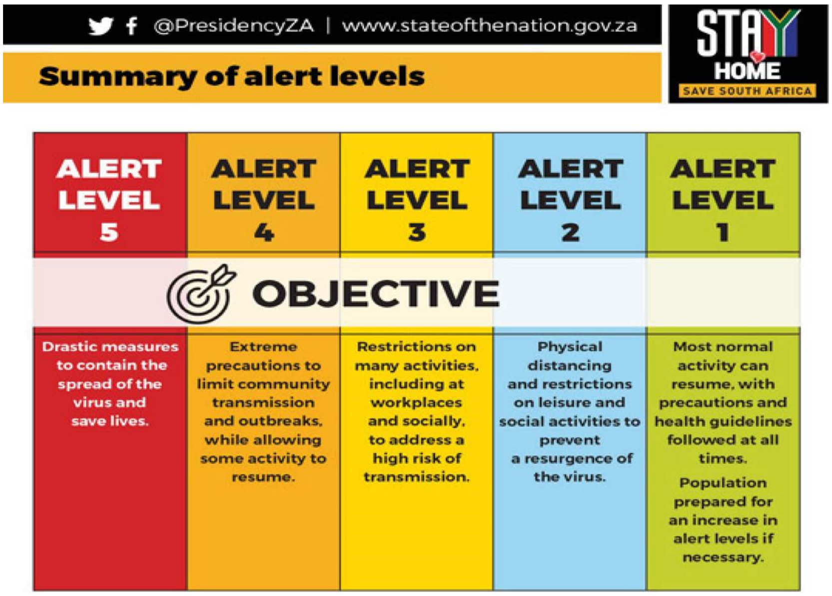
18 Source: (https://www.gov.za/documents/disaster-management-act-regulations-address-prevent-and-combat-spread-coronavirus-covid-19).

Table 3: Data availability of ambient concentration observations in the Western Cape (South Africa) monitoring network (%) in the first half of 2020. Selected datasets are highlighted in bold

Type	AQMS	SO_2	NO_2	NO	NO_x	O_3	CO	$PM_{2.5}$	PM_{10}	Benzene	Toluene	Xylene	Ethyl Benzene	CO_2	H_2S
Background	Cape Point	33.2	32.4	34.2	35.0	63.1	0.0	46.0	44.0	0.0	0.0	0.0	0.0	0.0	0.0
Industrial	Bellville South	63.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Postdam	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	69.9	72.5	70.1	63.2	0.0	0.0
Residential-Low Income	Hout Bay	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	69.0
	Khayelitsha-CT Metro	0.0	0.0	0.0	0.0	0.0	0.0	55.9	21.1	0.0	0.0	0.0	0.0	0.0	0.0
Residential-Medium/ Upper income	Atlantis	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Residential-Medium/ Upper income	Goodwood	31.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Hermanus	56.0	49.0	49.7	50.9	0.0	26.4	0.0	9.7	0.0	0.0	0.0	0.0	51.1	0.0
	Khayelitsha-WC Province	55.3	93.9	95.7	99.0	92.3	99.0	0.0	80.3	0.0	0.0	0.0	0.0	0.0	0.0
	Malmesbury	76.0	77.4	76.8	77.9	78.9	78.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Molteno	0.0	77.7	35.0	65.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Plattekloof	0.0	88.8	64.4	88.7	55.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Somerset West	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Wallacedene	33.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Worcester	89.5	97.8	97.8	97.8	85.0	58.2	18.8	18.8	0.0	0.0	0.0	0.0	0.0	29.4
Traffic-Roadside	Foreshore	37.4	0.0	0.0	0.0	0.0	0.0	44.2	86.6	0.0	0.0	0.0	0.0	0.0	0.0
Traffic-Street Canyon	Bothasig	0.0	86.2	20.2	65.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Urban	Athlone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Driftsands	0.0	77.6	73.4	77.6	53.9	0.0	0.0	0.0	6.6	6.9	4.6	3.0	0.0	0.0
	Paarl	66.5	82.1	87.6	87.7	87.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Stellenboch	58.5	87.4	86.9	86.9	88.1	84.3	88.7	89.0	0.0	0.0	0.0	0.0	89.2	0.0
	Table View	62.6	67.3	73.1	68.9	0.0	0.0	92.2	93.8	0.0	0.0	0.0	0.0	0.0	0.0

Figure 8: Location of the air quality monitoring stations (AQMS) used to analyse the effect of COVID-19-related measures in Cape Town

Figure 9: Summary of alert levels and relevant dates during the first half of 2020. Source: South African Government (https://www.gov.za/covid-19/about/about-alert-system)



See, for instance, the evolution of SO_2 levels depicted in Figure 10. A time plot of SO_2 ambient concentrations in Cape Town from January 1st to June 30th 2020 (two residential AQMS) show slight decreases right after the declaration of national state of disaster and the enforcement of alert level five. However, from the scarce data available, it is unlikely that COVID-related measures may have had a significant effect on this pollutant, since the average SO_2 level during the lockdown period was around 40% higher than the month before. This may be related to increased emissions from households, but it is difficult to extract definite conclusions since SO_2 levels are highly dependent not only on local activities but also on distant sources and meteorological conditions (Jenner and Abiodun, 2013).

In contrast, the trends observed for NO_2 (Figure 11) indicate that mobility restrictions may have contributed to reduce ambient concentration of this pollutant for certain areas during the lockdown period. The time plot corresponding to residential areas (upper panel) does not show a clear trend. However, NO_2 average levels from the two urban monitors selected (middle panel) show a clear decrease, around 25%, during the lockdown, and particularly during its initial phase; this effect is observed in the traffic station as well (lower panel). Of note, the constant values close to zero from mid-May on at this location are presumably due to a monitor malfunction. The limited data available point out that this decrease did not produce a significant increase in O_3 levels (Figure 12).

Figure 10: Time plot of SO_2 ambient concentration in Cape Town from January 1st to June 30th 2020 (two residential AQMS)

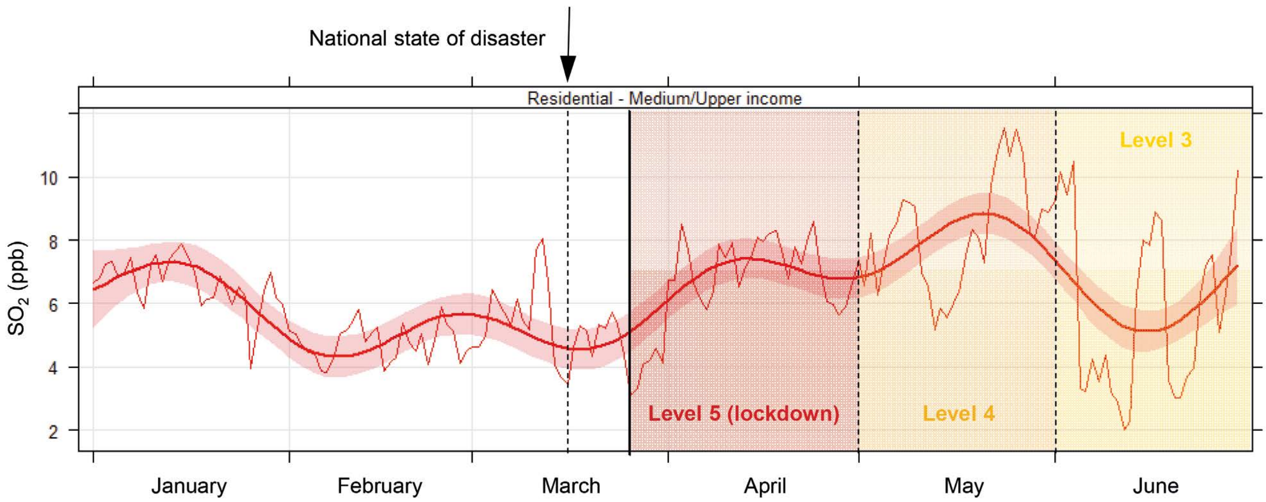
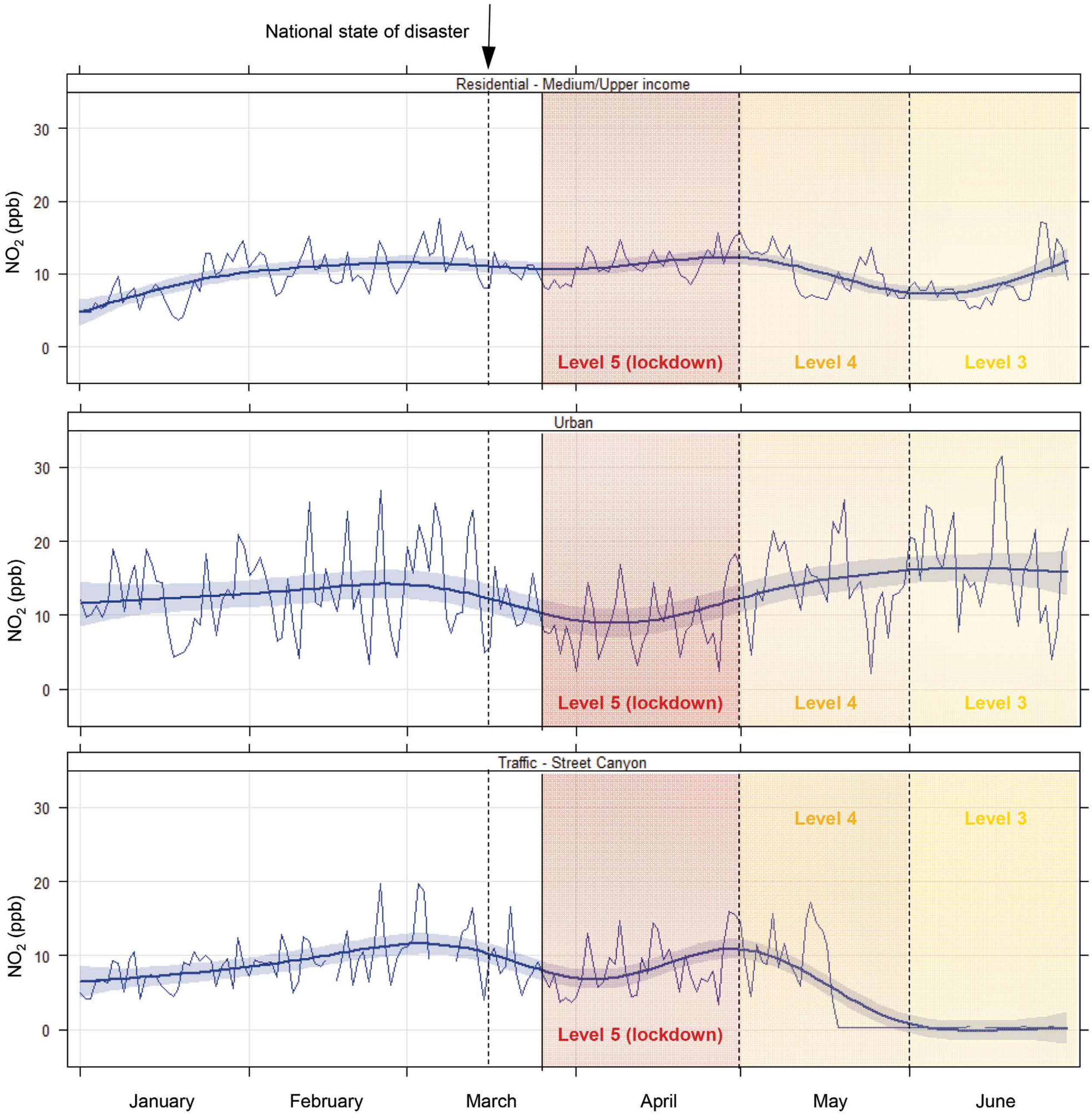


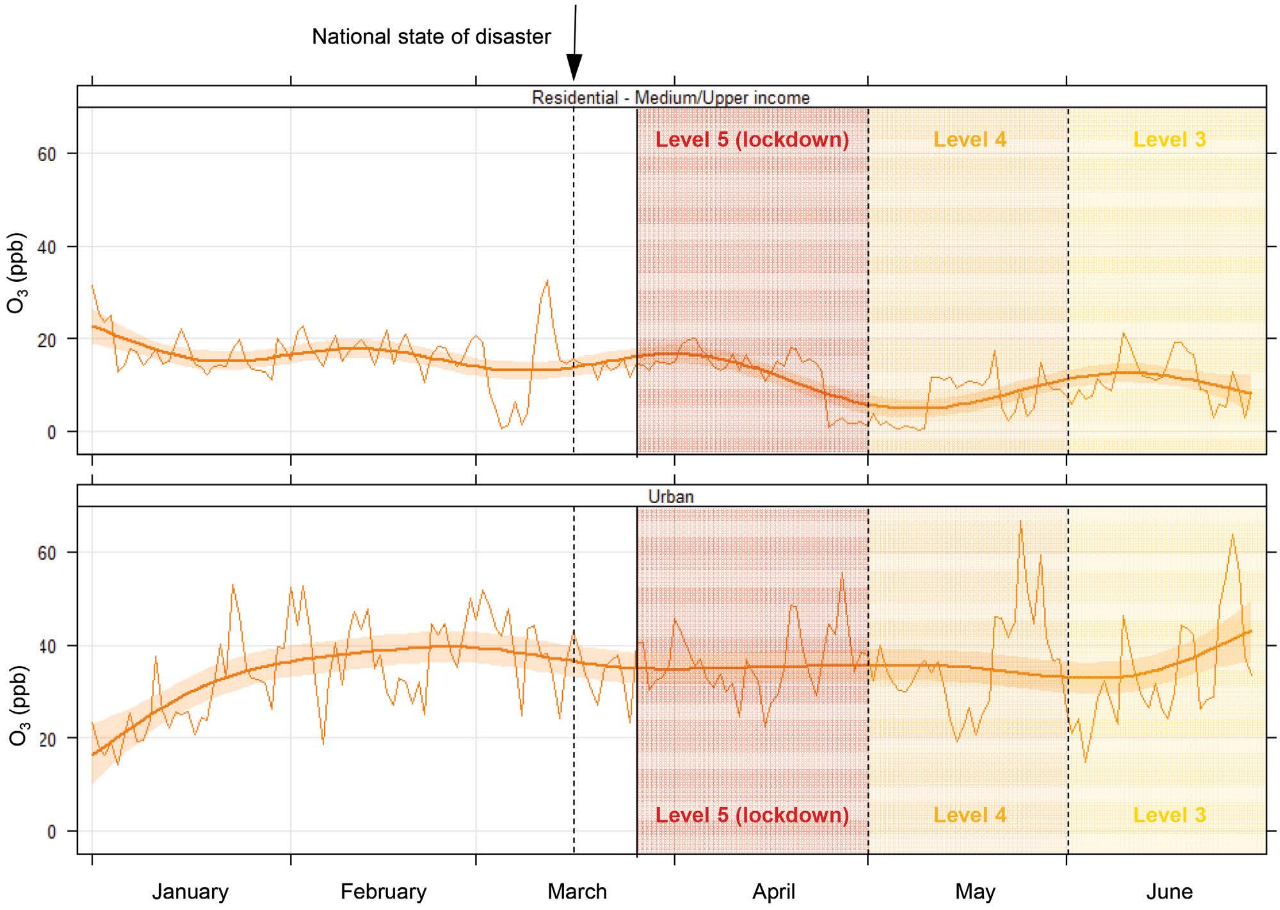
Figure 11: Time plots of NO_2 ambient concentration in Cape Town from January 1st to June 30th 2020 (three residential, two urban and one traffic monitors, AQMS)



Relatively low $PM_{2.5}$ levels (daily average below 15 μg/m³) were recorded at urban monitoring sites during the lockdown (Figure 11). It is hard to link these acceptable air quality levels with the COVID-19 related measures since a declining trend is observed from late February, before the lockdown or even the state of disaster declaration; this trend is therefore most likely related to meteorological factors. $PM_{2.5}$ concentrations are considerably higher during periods of less restrictive alarm levels in May and June. While this change could be attributed to increased activity following the end of the lockdown period, it might just as well be related to the typical seasonal patterns of this pollutant.

A similar trend is found for PM_{10} (see Figure 14). Time plots show PM_{10} ambient concentration in Cape Town from January 1st to June 30th 2020 (one residential, two urban and one traffic AQMS) at urban and residential locations, where the highest concentration values are found. This is consistent with previous studies that link high PM levels with residential wood burning, waste burning and dust from unpaved roads, among other sources (DEA&DP, 2016). However, the PM_{10} trend observed at the traffic monitoring station (lower panel) resembles that of NO_2; this may indicate that lower traffic intensities during the lockdown may have effectively curbed pollution levels during that period.

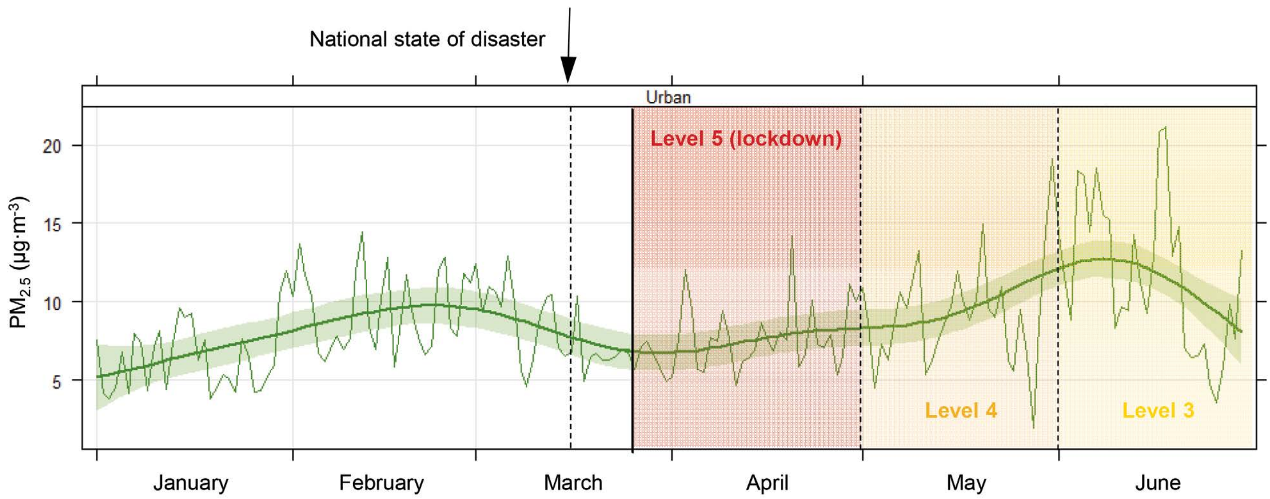
Figure 12: Time plots of O_3 ambient concentration in Cape Town from January 1st to June 30th 2020 (three residential and two urban AQMS)



As for CO (Figure 13), a tracer of incomplete combustion, a decrease in levels after the enforcement of the level five alarm can be seen both in residential and urban areas. However, the subsequent increase and larger oscillations during the following months prevent us from clearly identifying the impacts of restrictive pandemic measures upon this pollutant.

Carbon dioxide (CO_2) is not a relevant specie from the air quality perspective. Observed levels of this greenhouse gas are strongly conditioned by global average CO_2 background concentrations due to the very long lifetime in the atmosphere of this gas. However, CO_2 levels can be used to track the activity rates of local combustion sources and to

Figure 13: Time plot of $PM_{2.5}$ ambient concentration in Cape Town from January 1st to June 30th 2020 (two urban AQMS)



identify changes on meteorological conditions. A sudden concentration drop like the one observed in late February 2020 (approximately from 490 ppm to 410 ppm) (Figure 14) may indicate a change in general circulation patterns that correlate with better ventilation conditions in the city. That would explain the declining trend observed for all the pollutants analysed around those dates. From a low point observed sometime during March, the concentration steadily builds during the remaining reference period to stabilize around 450 ppm.

This overview of pollution levels in Cape Town during the first half of 2020 suggests that measures taken to control the spread of coronavirus in March and in the months following may have had a more limited effect on air quality than in Asian or European cities. Presumably, the largest effect was associated with a reduction of road traffic; that may have reduced NO_2 levels up to 25% during the lockdown. However, this finding should be confirmed by a more rigorous analysis that can remove the influence of meteorological conditions, a critical factor to explain pollution trends (Borge et al., 2019).

Figure 14: Time plots of PM_{10} ambient concentration in Cape Town from January 1st to June 30th 2020 (one residential, two urban and one traffic AQMS)

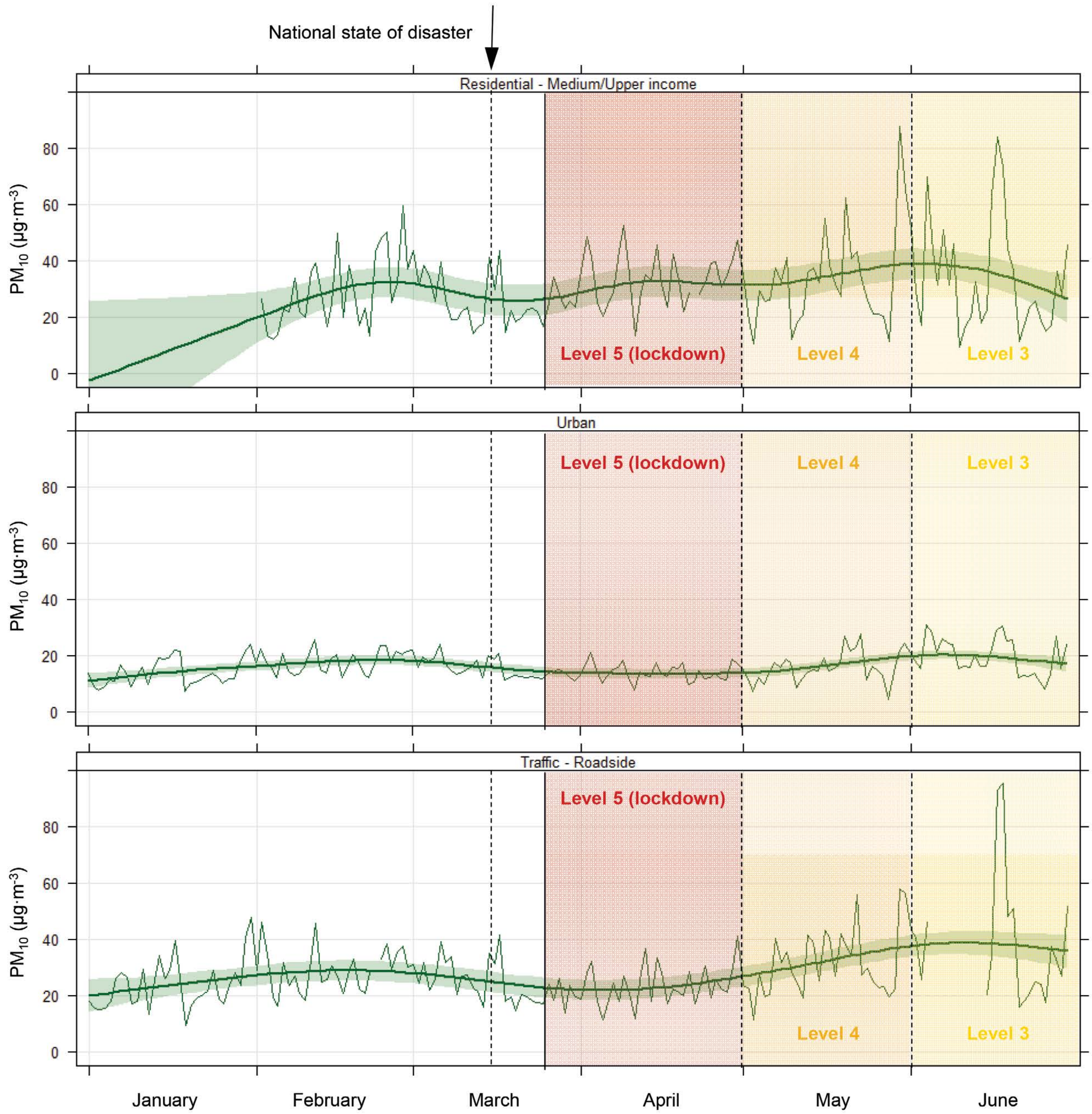


Figure 15: Time plots of CO ambient concentration in Cape Town from January 1st to June 30th 2020 (two residential and one urban AQMS)

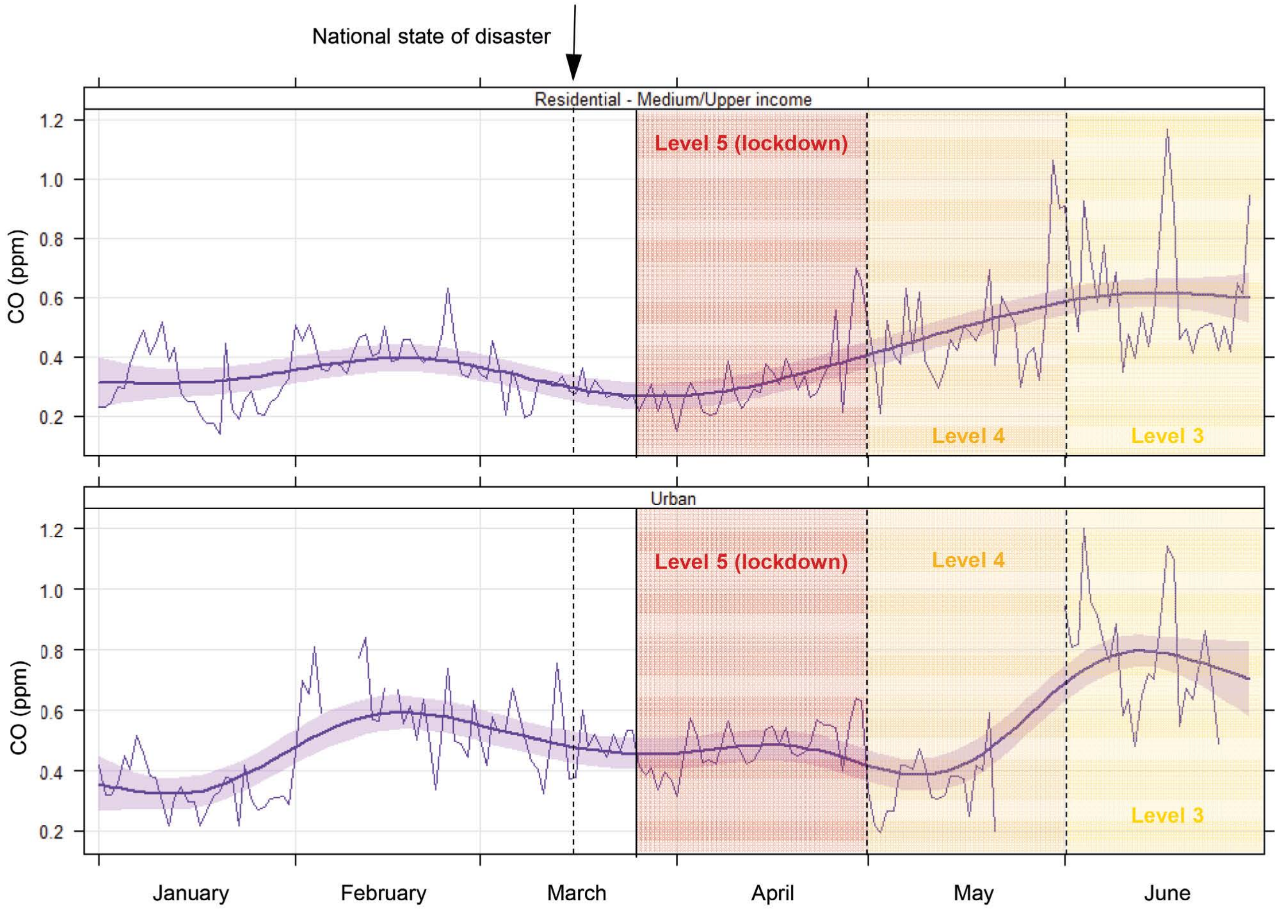
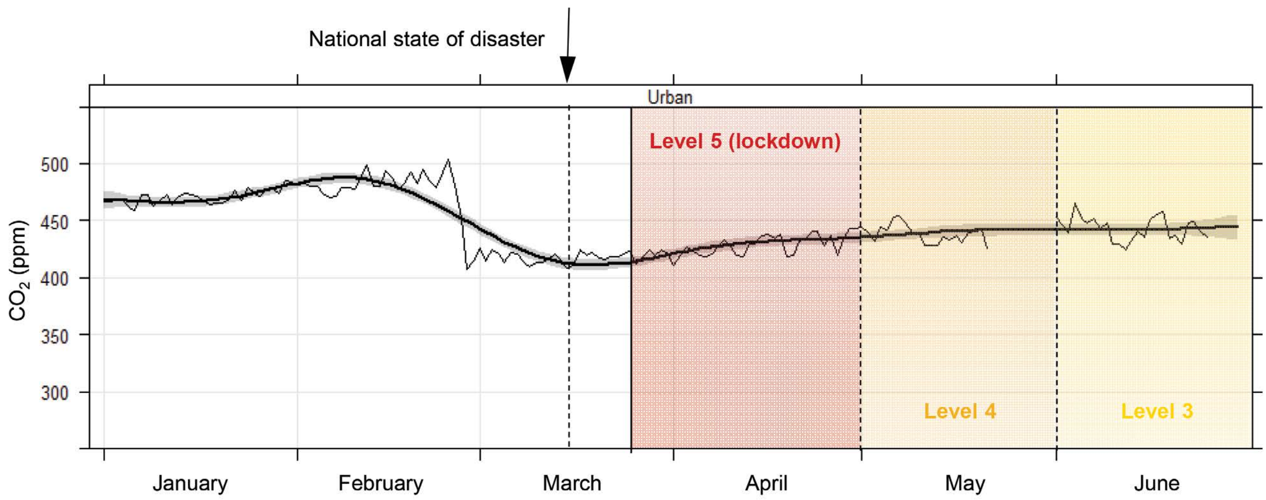


Figure 16: Time plot of CO_2 ambient concentration in Cape Town from January 1st to June 30th 2020 (one urban AQM)



3.5 Conclusions and recommendations

Despite a limited understanding of the complex phenomena that link COVID-19 and air quality, recent studies point out that lower pollution levels would help to minimize the negative health effects of this disease, both by helping both to contain the spread of SARS-CoV-2 as well as to avoid synergetic negative outcomes of the pathogen. All evidence suggests that developing countries and marginalized communities are much more vulnerable to the pandemic as indeed they are to air pollution. Available data inform us that postponing or easing emission abatement strategies, both for air quality and climate pollutants, would be counterproductive. In fact, the evidence supports a call for more decided action towards rapid reduction of air pollution. The early response to the COVID-19 pandemic has shown us the potential of non-technical restrictive measures to alleviate pollution issues. Nonetheless, preliminary findings highlight that optimal control strategies should be tailored for each area, both to avoid air quality trade-offs (Huang et al., 2020) as well as to take into consideration specific socio-economic issues and local conditions. For instance, stay-at-home policies imply increased household emissions and longer periods at home. While such policies may work in many parts of the world, in areas such as Africa where indoor air pollution is a major concern the potential health benefits from such strategies may vanish (Mbandi, 2020), making self-quarantine impractical. This is particularly relevant for informal settlements (Corburn et al., 2020) whose dwellers already suffer the highest burden of disease, due not only to poor air quality but also to communicable diseases like malaria, cholera, Ebola, and dengue fever (Mbandi, 2020).

Corburn et al., (2020) propose prioritizing relocation or de-densification measures as a way to effectively deal with the pandemic in slums. They also highlight the importance of avoiding top-down directives forced upon residents of informal settlements and the need for effective participatory and multi-level governance mechanisms to coordinate the COVID-19 response in low-income areas. That study also maintains that we should build upon our experience with and lessons drawn from earlier pandemics such as HIV, and epidemics such as Ebola, both to establish long-term plans and alliances as well as to exploit the 'silver lining' potential for innovation brought about by COVID-19 (Mbandi, 2020).

More importantly, the COVID crisis underscores the need to urgently tackle chronic sanitary deficiencies, improve waste management systems and address the lack of infrastructures that are also connected to poor air quality. This message is fully consistent with the conclusions and recommendations offered in the rest of this report. It reinforces the need to implement air quality and climate change plans as part of an overarching strategy to improve general living conditions and move towards more sustainable development in Africa.

Postscript: The Way Forward

The present UN-Habitat publication marks the beginning of a journey towards improved air quality in African cities. This journey should be undertaken as part of a broader effort to arrive at cities that are healthy, safe, inclusive and equitable, per the complementary frameworks of the Sustainable Development Goals and the New Urban Agenda.

The complexity of issues at play requires a broad perspective; achieving these goals will necessitate long-term collaborations, at different levels. In addition to the local and national governments themselves, this will involve collaborating at the global level with key sister UN organizations such as UN Environment, the World Health Organisation and UN-Habitat, plus other development and financial institutions, as well as strategic partners in the region. Such combined environmental, health and urban development expertise could provide the technical know-how required, as well as help to raise the awareness, capacity and political will needed to provide an effective, coherent response to air pollution in Africa.

The present report has reviewed air pollution issues and responses in five African cities. We hope that it provides useful insights into the status, importance and potential for improved air quality in urban areas in Africa. At the same time large cities like Accra, Dakar, Nairobi and Cape Town, and megacities like Cairo, are not the whole story. Small and medium-sized cities in Africa are also growing at a fast pace and are likely to develop – and in some cases have already begun to develop – similar air quality issues. The burgeoning urban populations in those contexts are likely to increase the strain on already insufficient infrastructure, resulting in sprawling, unplanned and informal settlements, with attendant challenges in terms of urban air quality. This report highlights that persistent poverty and air pollution are closely intertwined and the causes of social inequity and environmental deterioration must be dealt with simultaneously.

Behind air pollution, in other words, a large spectrum of issues is at play. One starting point for addressing those issues involves strengthening urban planning, to better prepare cities to manage an exploding urban population's needs in terms of mobility, energy, water, sanitation, housing and food. The current COVID-19 pandemic underscores the need to urgently tackle sanitary conditions, improve waste management systems, and address the lack of infrastructures that are also connected to poor air quality – priorities that are fully consistent with the New Urban Agenda and calls from other UN initiatives.

This complex mixture of issues must be decidedly addressed by urban managers and decision-makers at all levels, acknowledging the health risks and long-term costs of air pollution for the future generations of African urban dwellers. At its core, therefore, improving air quality means addressing sprawling, dysfunctional cities, and planning for growth for a new generation of urban commuters and consumers, particularly taking into account the needs of the urban poor. The various dimensions of sustainability are thus inextricably interlinked. A rational approach to addressing these overwhelming challenges is needed, and an inclusive, long-range planning that fully integrates air quality is required for a continent facing a potential new era of increasing urban fragility.

Appendices

Appendix A. Methodology and Sources

In each of the five city-level case studies found in Appendix B, we made an effort to provide a consistent view and comparison that can illustrate relative stages of process towards a comprehensive air quality management strategy. The most up-to-date information available has been gathered for this report, a desk review prepared and ground-checked in collaboration with local authorities, experts and colleagues in each country. The data scarcity and heterogeneity of local information sources makes comparability difficult. To present a synthetic and harmonized view of the status of the five cities analysed, we tried to combine: (i) fully comparable, globally available data with (ii) any other local or national specific data and references that may be relevant to the topic at hand. The data and discussion for each city case study is presented according to the following structure:

Introduction and background

This section presents a basic description of economic activity and infrastructures, general location, key relevant geophysical features and other city-specific information, including climatic factors; this provides a minimum background for each city. All the information in this section is collected from globally available databases conveniently documented, making it traceable and perfectly comparable. Sources are as follows:

- Current population (both sexes), recent trends (population growth rate since 2000) and mid-term projections (total population by 2030 for consistency) according to the World Population Prospects 2018 (UN, 2018) (Population of Urban Agglomerations with 300,000 Inhabitants or More in 2018, by Country, 1950-2035 database).
- A gridded population map for a 120x120 km geographical domain for each city (Figure 1) elaborated from the US NASA Socioeconomic Data and Applications Center (SEDAC) (Columbia University, 2018) (GPWv4 gridded dataset of Population Density Adjusted to Match 2015 Revision UN World Population Prospects). The maps shows the road network according to the information published by SEDAC from Global Roads Open Access Data Set, Version 1 (gROADSv1) (Columbia University & University of Georgia, 2013). Roads are consistently classified according to their functional class (Highway, Primary, Secondary, Tertiary, Local/Urban, Trail, Private or unspecified). The map also shows administrative boundaries, taken from the GADM database version 3.4 (GADM, 2018). A similar map showing man-made Impervious Surface (GMIS) elaborated from (HBASE) Dataset (Wang et al., 2017) is also included.
- Charts of monthly average temperature (ºC) (Menne et al., 2018) and accumulated precipitation (mm) (Thomas et al., 1997) as an average, with the corresponding confidence interval, for a 50 year period (1961-2010) for a representative weather station in each city. This information is elaborated from the integrated database of climate summaries from land surface stations across the globe compiled in the Global Historical Climatology Network (GHCN) by National Centers for Environmental Information of NOAA (National Oceanic and Atmospheric Administration).

The city description is complemented with selected national figures and indicators that are useful to understand the development stage and socio-economic scope and other constraints relevant for air quality management, including:

- Income group, GDP per capita (current international USD), Poverty headcount ratio (proportion of population pushed below USD 5.50 a day), Access to electricity (% of population), and Access to clean fuels and technologies for cooking (% of population), according to the World Development Indicators (WB, 2019a).
- Current population (both sexes), recent trends (population growth rate since 2000) and mid-term projections (expected population interval by 2030 given low and high fertility scenarios) according to the World Population Prospects 2019 (UN, 2019b). Although air quality plans usually have a shorter temporal horizon, a ten-year projection is deemed adequate to analyze and design comprehensive air quality strategies in coordination with climate policies.
- National total (kt) and per capita (t per capita) CO_2 emissions and CO_2 combustion emissions breakdown by sectors (power and heat production, transport, industry and construction, buildings and others) (WB, 2019a). Biomass burning is not accounted for since non-fossil fuel combustion is considered carbon neutral. Although this information is not directly related to air quality, it provides an overview of the relevance of the main activity sectors for each country. Although greenhouse gases are not the main focus of this report, this information provides a basic idea of the emission structure of each country in the absence of air quality-relevant pollutant inventories.

- Life expectancy at birth, current and expected by 2030 according to the World Population Prospects 2019 (UN, 2019b).
- Mortality attributable to joint effects of household and ambient air pollution from the Global Health Observatory data repository (WHO, 2016). Evidence from epidemiological studies have shown that exposure to air pollution is linked, among other diseases, to those taken into account in this estimate: Acute respiratory infections (estimated for all ages); Cerebrovascular diseases in adults (estimated above 25 years); Ischemic heart diseases in adults (estimated above 25 years); Chronic obstructive pulmonary disease in adults (estimated above 25 years); and Lung cancer in adults (estimated above 25 years). Burden of disease (attributable mortality in this case) is calculated from estimated exposure to PM and combined effects of risk factors, as described in Ezzati et al (2003).

Emissions and air quality

This section summarizes the most relevant information available to understand current air quality issues, including relevant sources, ambient concentration levels and health impacts of air pollution. Data scarcity and lack of comparability have been consistently reported as two of the main limitations of air quality studies in Africa. In order to provide a detailed, yet consistent synthesis of the current status of each city, the discussion is split into two separate subsections.

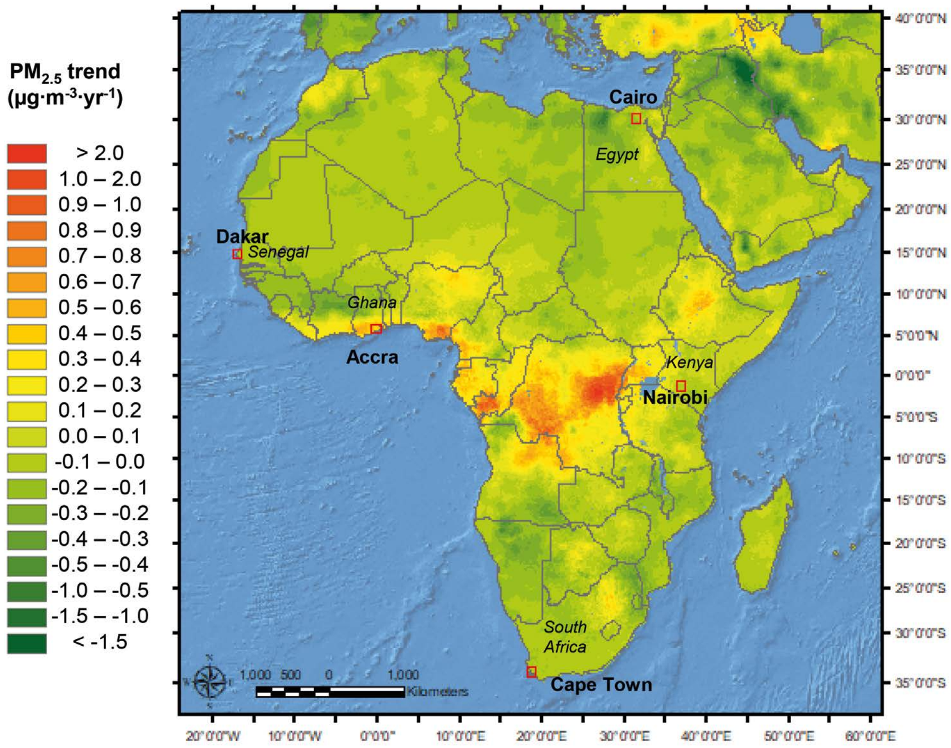
"Air pollution at a glance" provides a review of non-local-specific data. This information comes from global or regional estimates intended to provide a general overview of air pollution in large regions. Consequently, it cannot depict local specific features or support high-resolution analyses. However, this information is consistent and available for all the case studies and serves us well to define a relatively objective context and a comparable framework.

Current air quality and recent trends, as well as emissions are shown and discussed for each region in this sub-section. As previously discussed, it is widely recognized that fine particulate matter ($PM_{2.5}$) is the single most relevant pollutant from the public health perspective. Consequently, the analysis relies on available information on PM emissions and ambient concentration to depict the general situation and trends air quality-wise:

- Emission maps of the major species within $PM_{2.5}$: organic carbon (OC) and black carbon (BC) annual emissions (tons) (year 2015) elaborated from the most updated and comprehensive regional inventory available for the Africa (Keita et al., 2018)[19]. Primary (directly emitted) anthropogenic particles are largely made of OC and BC (Bond et al., 2004) and therefore, they constitute a good proxy of combustion-related emissions. This emission inventory was compiled within the "Dynamics-aerosol-chemistry-cloud interactions in West Africa" (DACCIWA) FP7 program, coordinated by the Karlsruhe Institute of Technology in Germany, and available at on the Emissions of atmospheric Compounds and Compilation of Ancillary Data (ECCAD) website. The DACCIWA inventory provides emission fields at 0.125° x 0.125° spatial resolution (broadly 10 km horizontal resolution) for the entire African Continent from 1990 to 2015. It extends and improves the only previous regional inventory available (Liousse et al., 2014) by establishing an African database on fuel consumption and new emission factor measurements, including biofuel and fossil fuel emissions as well as open waste burning emissions. In this report, all-sector aggregated emission maps are included along with the apportionment of OC and BC emissions to the main anthropogenic sources (Energy, Industries, Residential, Transportation, Waste, Other sectors) in the five target cities.
- Map of current $PM_{2.5}$ levels (annual average [$\mu g \cdot m^{-3}$] corresponding to 2016 (last year available) taken from NASA Socioeconomic Data and Applications Center (SEDAC) and of $PM_{2.5}$ trends (annual average trend [$\mu g \cdot m^{-3} \cdot yr^{-1}$] over the period 2000-2016) (van Donkelaar et al., 2018) (a general view at the Continental scale is shown in Figure 15). This data set combines aerosol optical depth (AOD) retrievals from multiple satellite instruments including NASA's Moderate Resolution Imaging Spectroradiometer (MODIS), Multi-angle Imaging SpectroRadiometer (MISR), and the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS). The GEOS-Chem chemical transport model (Bey et al., 2001) is used to relate this total column measure of aerosol to near-surface $PM_{2.5}$ concentration (van Donkelaar et al., 2016). Ground-level fine particulate matter concentration is provided at 0.01 degrees horizontal resolution (broadly 1 km) although it should be noted that this information is better suited for large-scale analyses. Previous studies highlight the influence of natural sources, mainly Saharan dust (Naidja et al., 2018), on ambient $PM_{2.5}$ concentration in Africa. All concentration maps in this document exclude dust and sea salt for a better understanding of the impacts of anthropogenic sources. However, there is higher uncertainty in the $PM_{2.5}$ values in regions (especially northern

19 This source and the following discussion also apply to Figure 5 in the main body of the report.

Figure 17: Change of anthropogenic $PM_{2.5}$ ambient concentration in Africa (µg/m³ per year) in the 2000-2016 period



Africa) with high contributions from mineral dust, mostly a result of sparse ground-based monitoring and challenging conditions for measurement retrieval and simulation. Hence, there are higher degrees of uncertainty in these regions compared to other parts of the world, even after excluding the natural sources. Of note, these concentrations are likely to significantly differ from local measurements where available. Despite these limitations, it is interesting to provide a consistent view of air quality in all the five cities, not affected by methodological differences on local measurements that seriously hinder comparability.

The second sub-section, "A closer look" discusses finer resolution, city-specific information and references. We review the information available for each city to understand local pollution processes and to support informed measures and strategies as a necessary complement to global or continental information sources previously presented. This discussion is also relevant to identify information gaps and to set up priorities. The information compiled is based on a search of relevant public sources (e.g., official reports from local authorities), literature review of technical reports, studies and scientific journal papers as well as direct communication from city contacts. While this information is essential to depict the current status of each city, the reader should refrain from comparing the figures discussed since they are not necessarily consistent and comparing them may be misleading. To this end, we intentionally failed to produce charts or synthesis graphs that may lead to inaccurate or biased interpretations. Officially reported data by the local monitoring networks should be, in principle, comparable. However, large data gaps, insufficient information about location types or lack of access to observations prevent from analysing this information. The main topics discussed in this sub-section are:

- Air quality measurements from permanent monitoring networks or ad hoc experimental monitoring campaigns
- Emission inventories
- Source apportionment studies
- Air quality modelling activities
- Health impact assessments
- Cost-benefit analyses.

Tackling the issues

This section provides an overarching view of the response given to the air quality issues portrayed in the previous point. The main interest is to discuss the lessons learned from recent actions as well as ongoing initiatives that may be relevant for future planning or inspiring for other urban areas with similar status. The information is taken mostly from official reports and websites in collaboration with local government representatives and experts. The discussion covers, where available:

- Regulations
- Plans and Measures
- Scientific projects

- Stakeholders involvement, alliances and international cooperation
- Other initiatives (communication, public awareness, etc.).

This section builds on the research carried out by UNEP in response to the 2014 UN Environmental Assembly 1 resolution 7 on Air Quality. UNEP prepared a compilation of policies and programs for Improving Air Quality around the World (UNEP, 2016). To facilitate the vision of the response given for each urban area in the context of national programs and regulations, the initiatives are discussed under a common structure for all five target cites. Relevant initiatives regarding 1) air quality standards, regulations and plans, 2) vehicle emissions, 3) public and non-motorized transport, 4) industrial emissions, 5) open burning of waste, and 6) indoor air pollution are briefly summarized.

To what extent "multi-level governance" supports city-level climate and air quality action in each of these case studies is a particular topic of interest to UN-Habitat. To help gain a perspective on this matter, the discussion within those six topics are arranged as follows. Firstly, we provide a review of actions taken in the past and then offer an overview of ongoing and future plans that inform the strategy and expected evolution of emissions and air quality in each city. In both cases, we first refer to the actions and instruments developed at the national level followed by regional (if any) and local plans and measures.

Conclusions and recommendations

A comprehensive assessment of the air quality status and city-specific recommendations are provided for each case study, taking into account the particularities discussed in the previous subsections.

The conclusions made and advice given consider, as much as possible, recommendations from local administrations and other organizations along with the outcomes and conclusions from other UN thematic reports or reference documents, such as the comprehensive review of air quality in Africa prepared by the World Bank (Schwela, 2012).

The main body of the report includes a concluding chapter in which the main results are compared in a synthetic way, and we identify promising practices from each city. According to that information, we propose general strategies for action that may be considered by any other African city in their journey to tackle air pollution. Finally, we discuss further options to provide guidance for the improvement of air quality in urban areas across the continent under a more systematic analytical framework.

Appendix B. In-depth City Case Studies

Accra, GHANA

A case study exploring the urban-environment-health nexus on a city-wide scale

Highlights

- Indoor air pollution arising from charcoal and wood burning is a health concern in Accra. Transportation including resuspension and emissions from unpaved roads as well as solid waste management and construction are major causes of ambient air pollution as well. Ambient PM concentration levels are considerably increased from natural dust during Harmattan wind episodes.
- Despite a comprehensive legal and institutional framework for air pollution management, air quality has not improved in accordance to the number of regulations released in recent years.
- In 2018, Ghana's Environmental Protection Agency (EPA) launched the Greater Accra Metropolitan Area's Air Quality Management Plan (AQMP), to address short lived climate pollutants and associated health challenges. This comprehensive plan with links to other relevant environmental strategies can provide the framework for consolidating and expanding recent successful sector-specific measures implemented in Accra.
- A weak institutional capacity for environmental management, coupled with the lack of an integrated urban development plan and low public awareness of air pollution-related health effects, are the main barriers hindering the effective implementation of air quality policies.

Introduction and background

Accra is the capital city of Ghana and the country's largest city. Accra represents one municipality within the Greater Accra Metropolitan Area (GAMA), whose lawmakers sit within the Accra Metropolitan Assembly (AMA) (Figure 16). AMA has 2,758,161 inhabitants, while GAMA is home to more than 4 million people. Located on the African Atlantic coast, the Metropolitan area is one of the biggest in the sub region and the Abidjan-Lagos corridor; it is the 13^{th} largest urban agglomeration in Africa.

Accra is experiencing rapid growth, with a 2.1% average growth rate during the 2000-2015 period. It attracts people in search of new opportunities, not only from rural parts of but also from neighbouring countries. Moreover, with the existence of the Tema Port and a network of highways and transnational roads, Accra is also a crossway for merchandise transportation and transnational flows. The population in the city is expected to grow at a 2.2% pace over the next several years, reaching a total population of 3,187,458 inhabitants by 2030.

The city has a tropical climate throughout the year, with a dry season that corresponds to the northern hemisphere winter period, followed by a rainy season. Accra is in the coastal savanna areas in the south of the country, with annual average temperature of 27.0ºC and 800 mm rainfall per year (Figure 17).

As for the national context, Ghana is a lower-middle income nation with a GDP per capita of USD 4,738 in 2018 and a poverty ratio (population under the threshold of USD 5.50 a day) of 56.9%. Total national population reached 30,417,858 inhabitants as of 1

Figure 18: Population density (persons/km^2) -left- and man-made impervious surface (%) –right- in Accra and surroundings

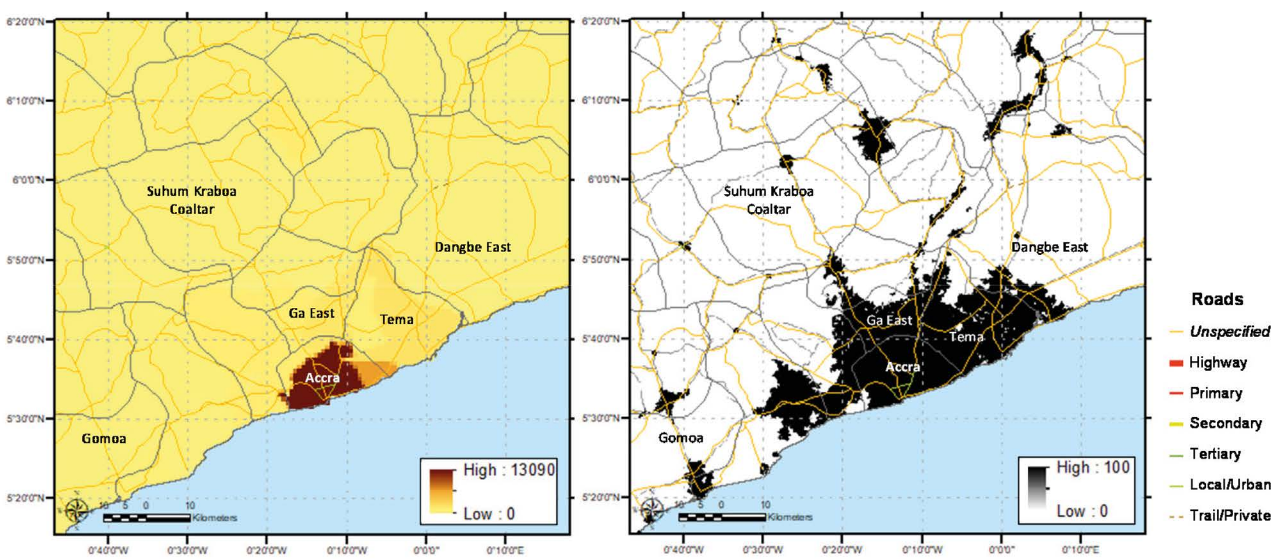
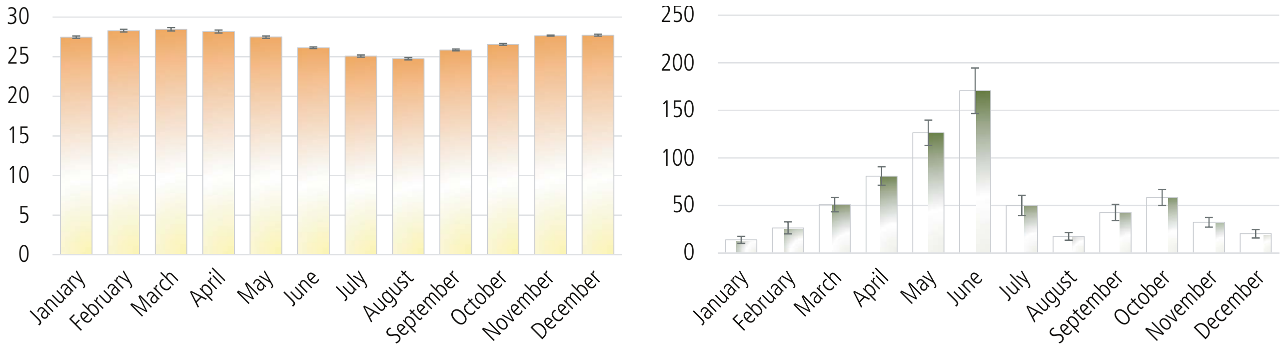


Figure 19: Monthly average temperature (°C) -left- and monthly average accumulated precipitation (mm), according to Accra/Kotoka meteorological station (WMO station 65472; long = 5.605°, lat = -0.167°, altitude = 62.5 m). The 95% confidence intervals are shown



July 2019; this corresponds to an average population density of 127.5 people/km². UN projections estimate that 37.0-38.7 million people will live in Ghana by 2030. Currently 79.0% of total population had access to electricity, while the share of people with access to clean fuels and technologies for cooking is 21.7%. A total of 14,466 kt of CO_2 were released in 2015 (0.53 t per capita), distributed as shown in Figure 18.

Current life expectancy at birth in Ghana is 63.7 years; it is expected to increase to 66.1 years by 2030. At present, the mortality rate attributed to joint effects of household and ambient air pollution is 10.1 (95% confidence interval: 9.1, 11.2) cases by 10,000 population. That implies more than 30,000 premature deaths from air pollution in the country annually, mainly related to lower respiratory infections (43.7%) and ischemic heart disease (24.3%).

Emissions and air quality in Accra today

Air pollution at a glance[20]

Total emissions of the main components of particulate matter in the Accra geographical domain are shown in Figure 20. The highest rates of BC emissions are found in the AMA, which correspond to the highest population density (Figure 21) and the highest traffic intensity in the area. OC emissions are completely dominated by the residential sector (Figure 19); they are mostly related to household combustion of solid fuels such as charcoal, agricultural residues and wood. Consequently, these emissions are more widely spread around the GAMA area.

Figure 20: Breakdown of CO_2 emissions in Ghana (14,466 kt in 2015)

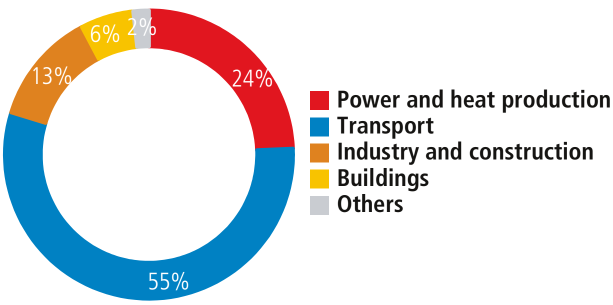
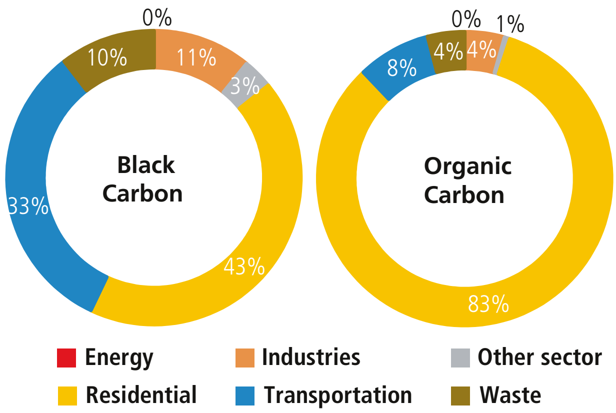
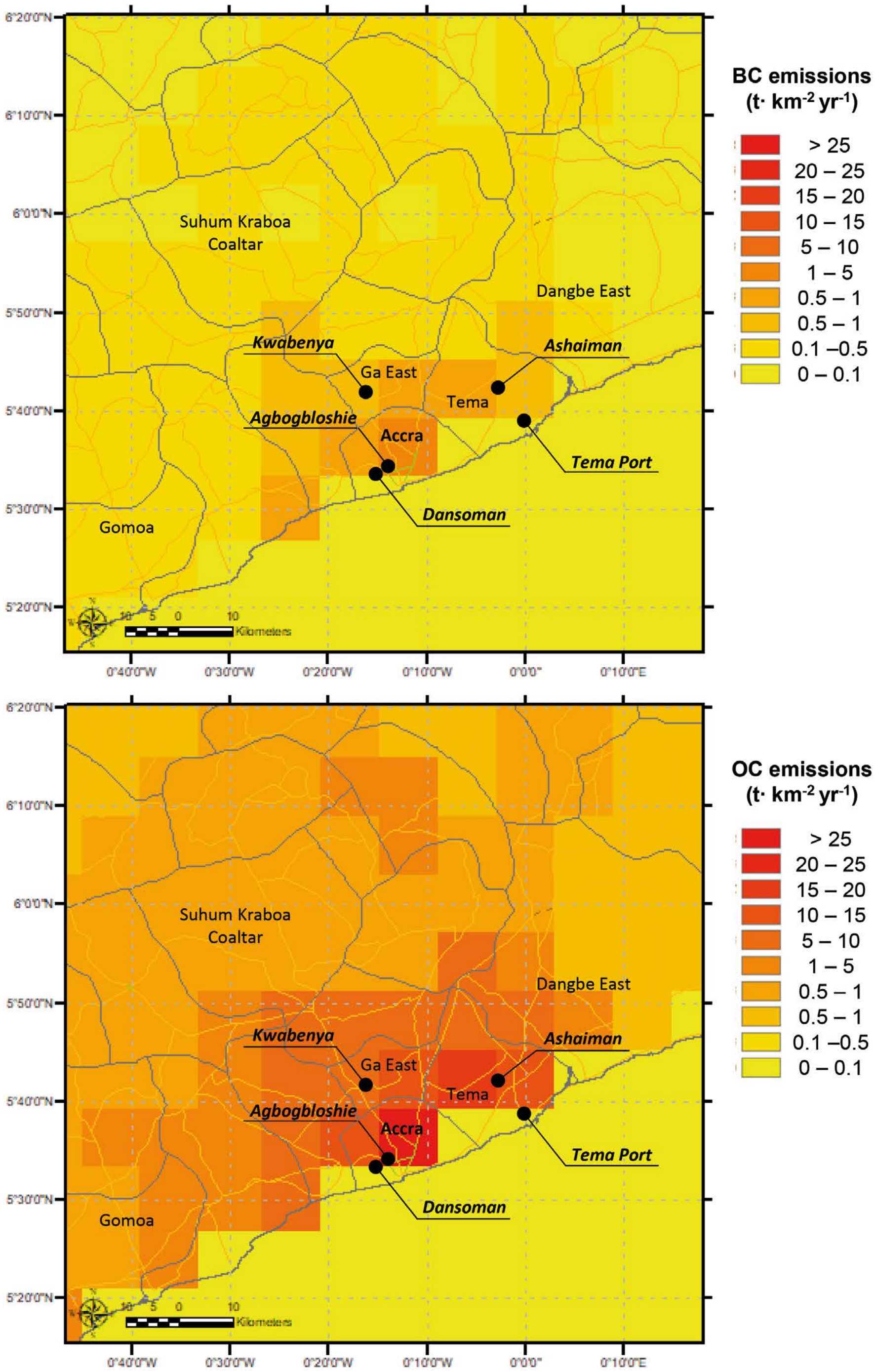


Figure 21: Breakdown of PM emissions in Accra



20 Per the report methodology (see Appendix B), in this and the following city case studies some discrepancies may exist between air quality data reported in the present “At a Glance” section and the following “A Closer Look” section. This is due to the different sources and assessment methods used in the two sections. While sources are consistent for all five cities for the “At a Glance”, data in “A Closer Look” sections are derived from more local sources. For any given city, trying to reconcile any contradictions that exist between these two sets of data and paint a fully coherent picture of air quality in those cities lies outside the scope of the present analysis.

Figure 22: Annual emissions of PM (black carbon –top- and organic carbon –bottom-) in Accra (t/km²)

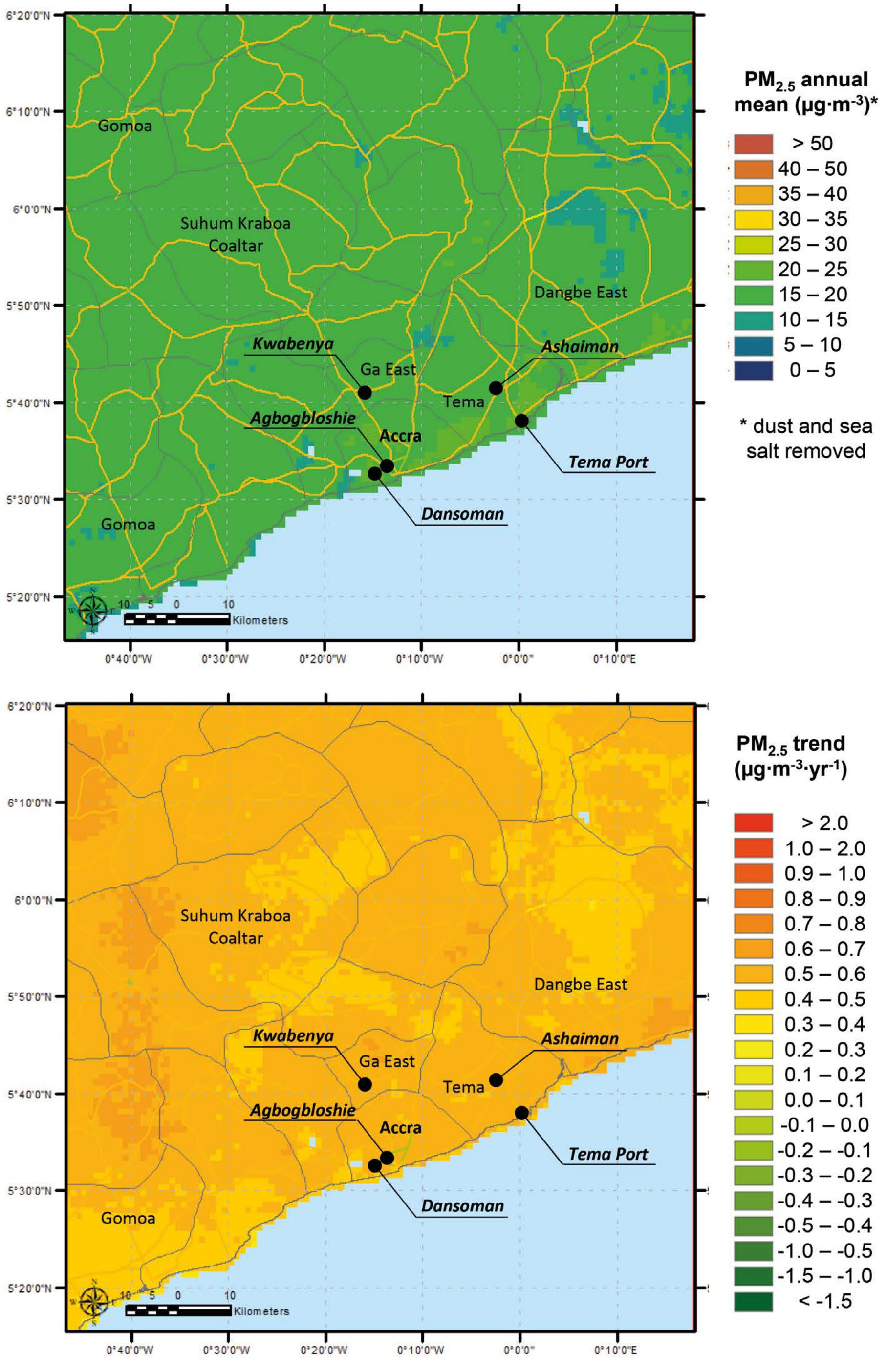


As for air quality; satellite observations show an annual mean of $PM_{2.5}$ of around 20 μg/m³ (sea salt and mineral dust removed) in the city centre. The average concentration change between 2000 and 2016 indicates a generalize worsening of air quality, with annual increases of around 0.5 μg/m³ per year in the city and close to 0.7 μg/m³ per year in some rural areas. Cumulatively, the anthropogenic contribution to ambient $PM_{2.5}$ concentration in the Accra area may have increased around 10 μg/m³ in last 15 years.

A closer look

In July 2004, the United States Environmental Protection Agency (USEPA), the United States Agency for International Development (USAID), and UN Environment (UNEP) selected Accra as one of two African cities to benefit from an Air Quality Monitoring Capacity Building Project. The goal of the project was to develop the infrastructure and the technical capacity needed to formulate a basis of an air quality management strategy for the abatement of air pollution in Accra, and to provide recommendations on next steps in developing a broad-based air quality

Figure 23: Annual mean of $PM_{2.5}$ ambient concentration (excluding natural sources) (µg/m³) –top- and recent concentration trend (µg/m³ per year) –bottom-in Accra



program for Ghana. As a basis for recommendations, initial air quality monitoring took place from April 2005 to April 2006, with ten monitoring sites. It was found that the key pollutants were SO_2, NO_2, O_3, CO, black carbon, PM_{10}, $PM_{2.5}$ and lead (Pb).

After the project ended in 2006, the air quality monitoring system was turned over to Ghana EPA. Over time, they have enlarged the network with six additional roadside monitoring sites (EPA, 2018). Although the network suffers from frequent breakdowns (Schwela, 2012) and data availability is usually below 50%, it has been useful to keep track of PM ambient concentration in the area. According to Appoh (2018), annual average concentration in Accra in the 2006-2017 period ranged from 55-78 µg/m³, and 85-130 µg/m³ for $PM_{2.5}$ and PM_{10} respectively, without a clear trend.

Today, out of the 16 monitoring stations in Accra, 15 remain operational. The Ghanese EPA has released some annual summaries of data collected. According to the last available edition (EPA, 2016), 65% of PM_{10} levels recorded in 2015 exceeded the EPA guideline for that particulate matter (70 µg/m³ for the 24-h mean). This standard was exceeded by 90.2% of measurements from roadside monitoring sites, while industrial sites presented lower levels. $PM_{2.5}$ average levels from the permanent network (with a temporal coverage below 28%) range from 70 to 121 μg/m^3, although a remarkable monthly variability was observed, e.g., in the Dansoman monitoring site, where recorded averages of 21 and 209 μg/m^3 were reported in March and December 2015, respectively. Such high pollution episodes during the dry season have been related to the Harmattan wind, a natural phenomenon that contributes to the load of particulate matter travelling south from the Sahara Desert (Zhou et al., 2013). Estimations of $PM_{2.5}$ concentrations derived from PM_{10} levels (EPA, 2018) for the year 2015 show similar values, with annual averages of 116 and 60 μg/m^3 for roadside and non-roadside monitors, respectively. Accra is the only municipality contributing to Ghana's reporting to the World Health Organization on air quality, being 55 μg/m^3 the last $PM_{2.5}$ urban background data reported (April 2018). Ambient concentrations of SO_2, NO_2, and O_3 are generally lower than EPA Ghana/WHO guidelines (EPA, 2018).

Air quality monitoring capabilities in Accra are being upgraded by USEPA and EPA Ghana under the Africa Megacities Partnership, through a low-cost PM air sensor network. (This network complements Ghana's existing network of monitors, other low-cost sensors by academia, and regulatory-grade monitors planned to be deployed as part of the World Bank's Pollution Management and Environmental Health (PMEH) program.) The AirNow-Ghana system (White et al., 2018) consists of 23 low-cost sensors measuring PM_{10}, $PM_{2.5}$ and PM_1 in ten locations representative of a variety of urban emissions sources (near-road, industrial, and residential). Collected data, starting August 2018, are managed in the cloud by the USEPA AirNow International (AirNow-I) system. Preliminary results show good correlation among the different sensors, with an all-site average $PM_{2.5}$ concentration of around 15 μg/m^3 during the first 3 months of operation (Chan et al., 2018). It is planned to enlarge the network with two regulatory grade, federal equivalence method (FEM) monitors; this will help implementers to calibrate the low-cost PM sensors and assess the accuracy of the sensors by comparing their readings with reference instruments. The results from this initiative will be useful to gain a better understanding of air quality in Accra, but also as a relevant demonstration to characterize sensor performance in environments with high PM concentrations, temperatures, and humidity. Those findings may be relevant for air quality monitoring in other African countries.

Besides permanent monitoring schemes, air quality in Accra has been addressed by a number of limited time-frame studies and ad-hoc campaigns. Zhou et al. (2013) collected PM samples between September 2007 and August 2008 in four neighbourhoods of Accra. They found that the natural contribution, sea salt (up to 13.9 μg/m^3) and mostly mineral dust, were large contributors to ambient PM concentrations. During Harmattan wind episodes, crustal particles accounted for 55 μg/m^3 (37%) of $PM_{2.5}$ mass and 128 μg/m^3 (42%) of PM_{10} mass. This is consistent with the study of Aboh et al. (2009) that found PM crustal elements (dust) fraction to increase more than tenfold during the Harmattan period in Kwabenya, a suburb of Accra that is frequently exposed to dust from the Sahara–Sahel region during the dry season. Outside Harmattan, road traffic was found to be one of the largest contributors to PM, being responsible for approximately 12-33% of PM concentration. Biomass combustion was responsible for between 10.6 and 21.3 μg/m^3 of particulate matter in the study areas, affecting most of the poorest neighbourhoods. Other relevant sources identified were vehicle emissions, tire and brake wear, road dust, and solid waste burning. While total PM_{10} concentration reached values as high as 179 μg/m^3, BC contents were only four μg/m^3 during 2006-2007 period analysed, highlighting the huge influence of natural PM.

More recently, Bandowe et al. (2019) looked into the composition of the dust in 25 streets in Kumasi, the second largest metropolis in Ghana around 200 km away from Accra, in February 2013 (dry season, Harmattan period). They found that street dust was a mixture of PM originally emitted by all sources along with secondary particles that impact PM ambient concentration levels through the resuspension process. They conclude that the population living close to busy streets where exposed to significant amounts toxic pollutants (polycyclic aromatic compounds), particularly in low-income neighborhoods, something relevant for the whole GAMA area. BC contribution to total carbon in street dust averaged 5% (mainly originating from residential biomass burning), which is lower than the 20% found in atmospheric $PM_{2.5}$ in Ashaiman (GAMA) (Ofosu et al., 2012). This location is probably more affected by industrial emissions (accountable for eleven % of ambient PM) due to its proximity to Tema and the Tema Harbour. Large industries such as the Tema Oil Refinery emit considerable amounts of PM and other pollutants (NO_X, SO_2). This produces considerable impacts on the air quality in its surroundings (up to 39 μg/m^3, 20 μg m^3 and 45 μg/m^3 as 24-h for $PM_{2.5}$, NO_2 and SO_2 respectively) (Amoatey et al., 2019), although negative health effects concentrate in the Tema Metropolis (Amoatey et al., 2018).

Arku et al. (2015) focused on the personal exposure of school children in Accra to $PM_{2.5}$. They reported an average exposure of 56 μg/m^3, more than double the average exposure levels in the US or Europe. Moreover, they found important variations between study sites, from less than ten μg/m^3 to more than 150 μg/m^3. This study identified residential emissions (wood and charcoal burning for cooking) and dust emissions from unpaved roads as the most influential sources of exposure. These sources were found particularly relevant in low-income neighbourhoods. They also found that girls generally suffered from higher exposure than did boys. Exposure to emissions from household cooking and garbage burning has been found to impact even the unborn. According to Amegah et al. (2012), these pollution sources significantly reduce birth weight in Accra.

The outcomes of these scientific studies are similar to those of the Urban Health and Short-Lived Climate Pollutants (SLCP) Reduction Project. This project which identified the energy, transportation, industrial and solid waste management sectors as the largest polluting sectors in 2018. Industrialization adds to air pollution from the burning of waste and fossil fuels. The energy sector in this study refers to the use of firewood and charcoal for cooking, which is consistent with the emissions breakdown illustrated in Figure 20. Besides being one of the most significant source of air pollution, this practice also contributes to deforestation.

Tackling the issues

According to some authors Appoh & Terry (2018), air quality management in Ghana can be considered as advanced and the recent evolution of the country can be considered as an instructive case study of air quality management planning in a sub-Saharan Africa context. During recent decades, the country has developed an organizational structure and regulatory framework and, together with partners, launched a series of initiatives, many of them targeting Accra. These can be summarized as follows:

Air quality standards, regulations and plans

The main legislations are the Environment Protection Agency Act (1994), Act 490, and the Environment Impact Assessment Regulation 1999, LI 1652. In 1988, the Government of Ghana initiated a major effort to put environmental issues (including air quality) on the priority agenda with the national Environmental Action Plan as the main environmental protection instrument. The main bodies coordinating the legislations and policies, regarding (air) pollution and environmental issues, are the Environment Protection Agency (EPA), created in 1994, and the Ministry of Environment, Science and Technology (MESTI). Local authorities (districts and towns, who also regulate), NGOs, the business and industry, and the scientific community are also involved in air quality management according to their responsibilities.

National Ambient Air Quality Guidelines were developed in 2000 (24-hour PM_{10} mean ≤ 70 μg/m^3) and are being converted into standards. Ghana EPA expected the full implementation of AQ standards by June 2019 (EPA, 2018), although they are not enforced so far.

The need for a comprehensive National Air Quality Policy has been identified as a national need by the National Environmental Policy (2014) but is still pending. Recently, the national government (Republic of Ghana, 2019) launched the Health and Pollution Action Plan (HPAP), facilitated by the United Nations Industrial Development Organization (UNIDO) in collaboration with the World Health Organization (WHO-Ghana), with funding from the European Union (EU) and USAID; results are still pending. The Urban Health Initiative (UHI) of the Climate and Clean Air Coalition (CCAC), another recent example of international collaboration, built health sector capacities to address air quality issues. More specifically, that initiative sought to demonstrate the full range of health benefits that can be achieved by implementing SLCP reduction strategies at the city level (also see below).

As a Party to the United Nations Framework Convention on Climate Change (UNFCCC), Ghana (which is also pursuing a national development agenda to become a middle-income economy) submitted its Intended Nationally Determined Contribution (INDC) in 2015 (Republic of Ghana, 2015). Some actions in the INDC related to energy, transport, AFOLU (Agriculture, Forestry and Other Land-Use), waste and industry are expected to have air quality and thus, health co-benefits, e.g., in the transport sector (WHO, 2011). Ghana was one of the founding countries of the Climate and Clean Air Coalition (CCAC), launched in 2012. Ghana began to implement CCAC projects that in some cases link air pollution and climate change mitigation actions with strong implications on health (WHO, 2012) by acting on short-lived climate pollutants. They include the control of BC emissions from wildfires associated with agricultural production and landfill gas capture and processing.

Many of the national strategies and regulations affect Accra, but the single most important instrument to tackle Accra's air pollution issues is the recently launched Greater Accra Metropolitan Area's Air Quality Management Plan (EPA, 2018) (AQMP). The main goal of the Plan is for GAMA to comply with national ambient air quality standards by 2025. It intends to achieve this goal even under the rapid economic growth foreseen for GAMA during this period. The Plan also calls for research and technology to help to inform decisions and improve the understanding and involvement of stakeholders and the general public. To secure these goals, the Plan includes five goals and 24 actions with specific indicators, time frames, responsibilities and collaborations needed that intend to comply with the national ambient air quality standards. The Plan addresses all the relevant sources, mainly road traffic, and contemplates the involvement of stakeholders and population under a cooperative governance framework. More importantly, it identifies the capacity gaps that should be addressed for a successful implementation.

This strategy may provide the basis to articulate a wide number of ongoing initiatives and projects related to air quality and climate change in Accra. It may also establish the necessary links to other key action areas such as waste management and sanitation that are being given coherence by the Integrated Urban Environmental Sanitation Master Plan (IUESMP), a USD 3-million cross-cutting project funded by the World Bank, as well as the Greater Accra Sustainable sanitation and livelihoods improvement project (ADF, 2017). These projects seek to provide a holistic approach to sanitation in the national capital, a challenge that is also related to air quality. Consultative forums are held in Accra for key stakeholders under the GAMA operational area. They include both traditional rulers as well as officials within the Greater Accra Region. These fora help to increase the visibility of the initiatives, allowing stakeholders including the primary victims of air pollution to understand the causes and consequences of air pollution, and promoting new behaviours.

These initiatives are underpinned by the improved monitoring capabilities developed under the collaborative initiatives between Ghana EPA, the US EPA and the World Bank. The information generated by the low-cost PM sensors in Accra will be disseminated using the US EPA's AirNow International data management system, contributing to raise public awareness of the impacts of pollution on health, that may be partly attributed to the very little quantitative data available (Appoh & Terry, 2018).

Vehicle emissions

Rapid urbanization brings about growing needs in transportation, which generally means more cars in use. A 2007 study estimated that 270,000 vehicle trips were made in or out the Accra Central area, transporting around 1.6 million passengers in a typical weekday (Morrison and Raunch, 2007). The numbers of private vehicles in the country and especially in the capital city have grown rapidly since then (Fiagborlo, 2017). The current level of private vehicle ownership in the Accra Metropolitan area reaches 90 vehicles per 1,000 people, substantially higher than many other African metropolises (WB, 2017). Available statistics point out that vehicle fleet in Ghana increased more than 300% in the 2000-2016 period (EPA, 2017). As a consequence, like many other urban areas in Africa, traffic is becoming the main source of air pollution in Accra (Naidja et al., 2018), as well as the largest emitter of greenhouse gases, accounting for some 55% of total CO_2 in Ghana (Figure 19).

The country's roadmap to vehicular emissions and fuel economy standards (2014–2020) outlines plans for cleaner fuels, stringent emissions standards for imported vehicles, ways to ensure proper maintenance of in-use vehicles, and transportation planning and demand management. Ghana has successfully reduced sulfur levels in diesel fuel from 3,000 parts per million (ppm) in fuel to 50 ppm, and issued new fuel standards, which took effect September 1, 2017. Unleaded gasoline has been restricted since 2004, partly as a consequence of Ghana having become a party to the Partnership for Clean Fuel and Vehicles Lead Phase Out Program several years earlier. Rising fuel quality standards have been reported to have conferred health benefits, e.g., reductions in levels of lead in the blood of high-risk groups in Ghana (Schwela et al., 2012).

The conversion of previous emissions guidance into standards, Euro 1 both for petrol and diesel vehicles, was intended for 2016. Imported cars that are more than ten years old attract additional charges (up to 50% overage penalty for cars aged 20 years or more), but they can still be imported into the country. Import duty taxes scheme depends on vehicle characteristics. On the one hand, import duties discourage the purchase of large cars, but they may promote (up to a point) the import of cheaper, older cars. Pre-importation inspection is required.

In 2012 the MESTI started to develop an Air Quality and Emission Policy, in partnership with the CCAC. Strategies to implement the policy were identified through workshops organized by the Ministry and based on technical studies. Various stakeholders were engaged including the business and private sector, while the Driver and Vehicle Licensing Authority (DVLA) collaborated with the Ministry to integrate emission testing into road worthiness certification for vehicles. As a result, a new motor vehicle emissions testing programme has been launched in 2018 by the DVLA and Ghana's EPA (with support from UNEP and the Swedish International Development Cooperation Agency), in line with the EPA Act of 1994.

Public and non-motorized transport

Despite the rapid increase of private mobility noted above, more than 80% of the trips in the Greater Accra Region are made by public transport, using mini vans and taxis. These are in most cases older vehicles, imported into the country second-hand. Moreover, public service vehicles are often in poor condition, leading to higher emissions of air pollutants. Private microbus and minibus have proliferated for intra-city commuting in Accra due to deficiencies (low reliability and frequency, over-crowded vehicles among others) in the public transportation system (Birago et al., 2017). Previous studies estimated that 95% of total passenger transportation in the city is provided by the informal sector (a mix of buses, minibuses – 'trotro' – and taxis) (IBIS Transport Consultants Ltd., 2005). Such circumstances, not uncommon in African cities (Kumar and Barrett, 2008), contribute to increased traffic congestion and resulting high emission levels. Around ten per cent of major roads operate at unacceptable levels of service at some point during the day. Areas along major public transit routes are thus likely to register a significant impact of emissions, often disproportionately impacting the poorest population. Furthermore, unpaved roads contribute air pollution through fugitive dust (IBIS Transport Consultants Ltd., 2005).

Despite some local initiatives in cities like Accra (EPA, 2017), there are no national-scale plans to improve and promote public transport. Policies and responsibilities to prioritize non-motorized transport (NMT) are scattered across a range of different agencies and ministries, a fact that has hindered progress on this matter (UNEP, 2019). The Share the Road Programme, in partnership with the Institute for Transportation and Development Policy (ITDP) Africa, is developing a national strategy to harmonize commitments and to safeguard the needs of pedestrians and cyclists. The development of safe infrastructures primarily aims at reducing traffic-related casualties, but it is also expected to bring considerable benefits from the air quality perspective.

Public transport is one of the key focuses of Accra urban interventions that is likely to improve air quality. This is particularly relevant in a scenario of strong increase in vehicle miles travelled, which could increase black carbon emissions from transport sources by up to nine-fold (EPA, 2018). A Bus Rapid Transit System (BRT) project is underway in the capital city, funded by DANIDA (Danish International Development Agency). The BRT system is likely to improve mass transit and reduce traffic congestion, stress and pollution. In December 2016, the first phase was unveiled: the Ayalolo Bus Network, with the support of the UNEP DTU Partnership, through the Low Carbon Development (LCD) plan (EPA, 2017). This plan emphasizes access to green climate finance, and therefore sets up an enabling framework to pave the way for future climate financing. The Ghanaian Government is currently developing a proposal for an expanded BRT system for the city of Accra, for submittal to the Green Climate Fund.

Industrial emissions

Industry in Ghana represents 29% of national GDP (UNEP, 2016). The most important activities are mining, lumbering, light manufacturing, aluminum smelting, food processing, cement, small commercial ship building, petroleum among others (soap production, chemical storage facilities, construction, etc.). All installations that could impact the environment are regulated under national point source emission guidelines, and a scheme to identify non-compliant undertakings/companies is currently in place. However, a significant proportion of the industrial sector is informal and thus not regulated, controlled or monitored. Despite its current shortcomings and limitations, an initiative to improve industrial environmental sustainability in Ghana, the EPA's 'Akoben' programme, is deemed beneficial ; it can be seen as a first step to move from an audit scheme to the development of a legislative framework that permits enforcement (Bawua & Owusu, 2018). Such a consolidated regulation and control scheme would also prevent biases on environmental policies and instruments for large companies in some industrial sectors, such as mining (Ayelazuno & Mawuko-Yevugah, 2019). However, the regulation must also adequately address artisanal and small-scale operations, which are common and important for the local economy (Hilson and Hilson, 2015). The Partnership for Action on Green Economy (PAGE) is a seven-year programme intended to create enabling conditions for national inclusive green economies. The promotion of national institutional capability in resource efficiency and cleaner production is needed to minimize industrial pollution in the context of an increasingly less competitive sector and a lack of support for the manufacturers to invest in cleaner technologies.

Open burning of waste

Around 13,000 t of unsegregated waste are generated every day in Ghana (Samwine et al., 2017), out of which 20-30% remains uncollected. Poor waste management practices result in people openly burning all forms of waste and, in some instances, creating illegal dumpsites. Open burning is regulated since 1991 under the waste management regulation. Since then, national plans have been launched to facilitate gradual reversal of the deficits in sanitary services through effective implementation by Municipal, Metropolitan, District Assemblies (MMDAs) and other stakeholders. One such was the National Urban Policy Framework and Action Plan (2012), which sought to promote adequate disposal and collection of domestic waste. Despite these initiatives, the national government points out that the proportion of solid waste properly disposed of has declined from 79% in 2014 to 70% in 2016. Consequently, improving municipal solid waste management has been identified as a top priority in the national Health and Pollution Action Plan (HPAP) (Republic of Ghana, 2019).

The Local Governance Act (Act 936 of 2016) gives local governments operational jurisdiction over municipal wastes and open burning. Since 2017, six dumpsites have been closed within the Accra region on the instructions of the Ministry of Sanitation and Water Resources and the Accra Metropolitan Assembly. There is no information available as to new destinations and no new sanitary landfills were reported to be opened since 2017, therefore there is a possibility that the problem has just been shifted "further out". The closure and rehabilitation project of the Abloragyei Dumpsite (Ga East Municipality) included a consultation process and constitutes an example of stakeholders' involvement (MSWR,

2018) to address the waste issue. The aftercare management plan of this project includes monitoring of air quality that will provide useful information regarding the benefits of regulations in the waste management sector in Accra.

Open burning of e-waste has become a pressing priority in the agenda of many African countries, including and particularly Ghana, one of the top five importers of e-waste in the world (Sovacool, 2019). According to the Blacksmith Institute (2013), around 215,000 tons of second-hand consumer electronics are imported into the country annually, primarily from Western Europe. Burning e-waste to extract materials for recycling exposes workers and nearby communities to toxic fumes and chemicals, with negative health effects (Feldt et al., 2013; Amankwaa et al., 2017).

The 2016 Hazardous and Electronic Waste Control and Management Act (Act 917) prohibits the import, transboundary movement, and sale of hazardous waste unless there is written authorization from the sectoral minister of the country of origin. The Act designates Ghana's EPA as responsible for monitoring and managing all kind of waste; it establishes a fund to, inter alia, manage and ensure the environmentally sound disposal of e-waste in Ghana.

The E-Waste Programme, sponsored by the German Federal Ministry and others intends to improve the political macro-conditions and create the appropriate legal and administrative basis for the proper collection and recycling of e-waste at national level. The UN-led Ghana-Wide Multi Stakeholder "Waste" Resource Platform seeks to foster innovative recovery businesses. E-waste Management in Ghana (E-MAGIN Ghana) is a project funded by the European Union to facilitate the application of Act 917 and the Hazardous and Electronic Waste Control and Management Regulations (LI 2250) by strengthening enterprises that support good management practices and raise awareness.

The e-waste issue is particularly relevant in Accra. This city is home to one of the largest e-waste dumps in Africa, Agbogbloshie, occupying 31.3 ha of land along the banks of the Odaw River and Korle Lagoon, situated northwest of Accra's central business district (Blacksmith Institute, 2013). There is an informal local e-waste economy to recover metals including gold, silver, copper, aluminium, and iron used in electronics. In some cases, e-waste is burnt in open-air pits, causing harmful and toxic gas emissions (Feldt et al., 2013; Amankwaa et al., 2017). In addition to the projects noted above, a relevant local initiative is the Agbogbloshie Scrap Yard project, implemented by Pure Earth (formerly known as the Blacksmith Institute), that has tested a pilot e-scrap facility in that location. The goal is to protect livelihoods while minimizing the adverse health and environment risks of scavenging and exposure to toxic substances. Workers were trained to use the appropriate machines to disassemble the materials and directly extract the metals, plastics, and other sellable items in an efficient and profitable way, avoiding burning copper wires. The scrap yard plan is run by a local cooperative and is recovering 450 pounds of copper and 40 pounds of aluminum per month (Pure Earth, 2015). The project demonstrated that a modest investment (around USD 200,000) can produce considerable environmental benefits. The Greater Accra Scrap Dealers Association (GASDA) is trying to scale-up the project and to promote Agbogbloshie as a recycling knowledge center.

Indoor air quality

Regrettably, indoor air quality is not regulated, although the Government of Ghana and its Ministry of Health consider indoor air quality a critical health problem in view of the high burden of disease attributed (more than 60% of air quality-related total mortality according to WHO, 2018). In addition, household air pollution has been identified as the most impactful of the modifiable risk factors in Ghana (Stanaway et al. 2018). According to Zhou et al. (2014), cooking-related emissions account for 74–87% indoor $PM_{2.5}$ concentration in rural areas in Ghana. There are some initiatives to install new improved clean stoves and to promote the use of LPG, and subsidized LPG cylinders that have demonstrated a high potential to reduce personal exposure to $PM_{2.5}$ (Piedrahita et al., 2017). Charcoal is still commonly used for cooking, despite the availability of cleaner alternatives such as electricity, LPG or ethanol. In addition to its negative impact on indoor air quality, burning charcoal also contributes to deforestation, which also yields negative impacts, including on air quality. One of the main barriers to phase out this fuel is that charcoal production is often a source of complementary income to agricultural activities for rural dwellers. There are also logistic issues (distribution and delivery) as well as cultural reasons and distrust of modern fuels. Other than what is noted above there is very little quantitative data in Ghana regarding indoor air pollution levels, and very little public awareness of its impacts on health (Appoh & Terry, 2018). Certain initiatives to reduce emissions from the residential, commercial and institutional sector such as a mandatory scheme to improve electric appliances efficiency ("Ghana Electrical Appliance labelling and Standards Programme") may yield indirect benefits for indoor air quality.

Conclusions and recommendations

Officials in Ghana and particularly Accra are taking action to develop and implement a multi-level comprehensive air quality management scheme that builds on demonstrative pilot projects and international alliances. The main conclusions drawn and recommendations that can be made within the six key guidance framework areas of Air Quality Management Planning (AQMP) are as follows:

1. Air quality standards and monitoring

Although National Ambient Air Quality Guidelines (only for $PM_{10)}$ are in operation since 2000, they have not yet been converted into standards. Ghana EPA has put off the date of implementation several times in the last decade.

> **Recommendation:** Convert National Ambient Air Quality Guidelines into air quality standards to improve air quality in Accra and elsewhere.
>
> **Recommendation:** Encourage other cities to start monitoring air quality.
>
> **Recommendation:** Establish standards for $PM_{2.5}$. Standards for other substances, such as NO_2, SO_2 or O_3, should be added in further stages in line with strengthened air quality monitoring capabilities in the country.

The development of the air quality monitoring network in Accra offers an encouraging example of capacity building supported by international collaboration. Ongoing activities should soon demonstrate the potential of low-cost sensors to complement more reliable but also more expensive reference methods. (Lessons from these pilot experiences will be highly beneficial not only for Accra but virtually all other urban areas in the continent.) Information from such supplemental sources may be particularly helpful to provide a more nuanced and localised understanding of the strong spatial concentration gradients reported for the city in the scientific literature. Accra has a good understanding of the challenges that a comprehensive air quality monitoring strategy poses, in terms of investment, maintenance and calibration, staff requirements, security issues and management.

> **Recommendation:** Encourage the Accra administration to allocate funds to increase the reliability of the network and to guarantee its sustainability.
>
> **Recommendation:** Seek additional, complementary support from international agencies to strengthen the monitoring network.
>
> **Recommendation:** Involve local partners such as universities in the maintenance and improvement of Accra's monitoring capabilities.

2. Emission inventories and modelling

As a Party to the United Nations Framework Convention on Climate Change (UNFCCC), Ghana has produced a national GHG emission inventory. Besides that, there are no local inventories of GHGs or air pollutants that could hlep inform the priorities of the air quality agenda and feed air quality models that could be used to assess the potential outcome of interventions or future emission scenarios. The compilation and periodical update of a comprehensive emission inventory is a difficult task, but there are many references in the scientific literature and specific studies that constitute a useful starting point.

> **Recommendation:** Compile a local inventory. Initial efforts should focus on household cooking, open waste burning (both domestic and e-waste) and traffic, including PM emission and resuspension from roads, especially unpaved ones.
>
> **Recommendation:** Build on current capabilities of local universities and research centres to address this task, in cooperation with Ghana's EPA and GAMA administration.

3. Health and other impacts

There is a breadth of studies and reports highlighting the negative health impacts of air pollution specifically in Accra. These include the recent estimate made by the Greater Accra Metropolitan Areas Air Quality Management Plan that suggests that successful implementation of this plan would reduce premature deaths due to air pollution by 430 per annum due to a 20 per cent air quality improvement by 2030. It has been demonstrated that PM emissions from wood and charcoal burning for cooking are responsible for the largest burden of disease, especially in low-income neighborhoods. Road traffic is also a very relevant source whose emissions are increasing very rapidly as the local population increases. The impacts of inadequate waste management have also been found responsible for substantial health effects in the vicinity of dumpsites. Lastly, industrial emissions amplify the negative effects of air pollution in the Tema area. PM pollution in Accra is seriously aggravated during Harmattan wind episodes during the dry season.

> **Recommendation:** Keep delving into the relationships of air pollution to health, especially regarding the most vulnerable populations.
>
> **Recommendation:** Use current evidence to build the policy case for action, as well as to engage stakeholders in an effective strategy for emission abatement in the abovementioned priority sectors.

4. Communication

A lack of effective communication hinder action on needed policies. Well-communicated information is particularly important to raise awareness on the dangers of air pollution and possible solutions. This is particularly relevant for Ghana, where the level of awareness on air quality and on the negative impacts of air pollution is very low. The consolidation of the air quality monitoring network and the implementation of the AirNow-Ghana system may play a vital role in that direction. Accra is the target of a wide number of initiatives in cooperation with UN, the World Bank and other partners (Urban Health and SLCP Reduction Project and BreatheLife campaign, among others) that may use international funds to foster communication and education among the Accra population. Community-based actions and campaigns could further help raise awareness on the impact of human activities such as household cooking on air pollution.

Recommendation: Involve Ghana's EPA and GAMA administration in the coordination of communication and awareness projects, so as to maximize their impact.

Recommendation: Disseminate the results from ongoing air quality monitoring activities that use low-cost sensors.

Recommendation: Set up and approve air quality standards, and then report on episodes where those standards are exceeded, as one way to raise awareness among the population regarding the detrimental effects of air pollution on their health.

5. Clean Air Action Plans

The Greater Accra Metropolitan Areas Air Quality Management Plan (AQMP), recently launched by Ghana's EPA, is a major milestone that should lead to major improvements in air quality. In addition, there are a series of plans and initiatives with promising emission abatement potential and health benefits that may inspire further action.

Recommendation: Strengthen the EPA's Akoben programme for industrial environmental sustainability in Accra, to allow the enforcement of a progressively stricter regulation supported by enhanced monitoring capabilities.

Recommendation: Catalyse the transition from charcoal and wood to LPG and ethanol in the residential sector by means of demonstration projects. Such efforts can pave the way for strengthening the regulatory framework for commercializing and distributing cleaner fuels.

Recommendation: Implement effective economic instruments to consolidate new business models and to strengthen enterprises that support good waste management practices. Raise awareness about the regulatory framework that is already in place. Expand and replicate initiatives such as the one working with the Greater Accra Scrap Dealers Association (GASDA) in Agbogbloshie to other informal industrial sectors.

Recommendation: Reinforce public transport projects such as the Bus Rapid Transit System in Accra as a necessary step towards reduced congestion and more sustainable and equitable urban mobility.

Recommendation: Enforce emission standards for imported vehicles.

Recommendation: Develop the infrastructure and resources needed for an effective vehicle inspection program that can effectively enforce current emission standards. A centralized inspection database and the improved coordination of testing facilities will provide for more effective management and quality assurance.

6. Governance

Ghana's sustained economic growth since the early 2000s is underpinned by its reputation for relatively robust democratic institutions in the African context. The necessary enabling environment including institutional, legal and regulatory structures is now largely in place, with an adequate regulatory framework for most of the key sectors. Ghana has passed numerous environmental acts and is involved in a wide variety of cooperation projects and campaigns. However, despite the development of instruments and the proliferation of initiatives, air quality in Accra does not exhibit a positive trend. The main challenge facing the effort to control air quality, as well as other environmental issues, is the weak institutional capacity for environmental management. Furthermore, unplanned and uncontrolled urbanization, the lack of planning, the unavailability of the air quality data and poor implementation of environmental laws, bylaws and municipal regulations, constitute major obstacles in addressing air pollution. Accra has been experiencing rapid urbanization and is expected to grow at an even faster pace in the near future. This circumstance poses considerable challenges but also offers a great opportunity to prevent even more serious air quality and health issues in the Accra urban agglomeration.

Recommendation: Strengthen the administration to improve its monitoring capabilities and, more importantly, its ability to enforce the already available legal instruments.

Recommendation: Enhance the social, economic and cultural conditions as the underlying, most peremptory need to increase the chances of effective enforcement of plans and regulations.

Recommendation: Make effective links of the new AQMP with other plans that have direct implications for air quality such as the Integrated Urban Environmental Sanitation Master Plan (IUESMP), or broader instruments like the UNESCO Man & the Biosphere (MAB) Programme.

Recommendation: Develop effective governance mechanisms to engage all stakeholders in implementing the AQMP measures: national authorities and agencies, local authorities, the traditional actors from civil society and communities, as well as the private sector.

Recommendation: Develop comprehensive urban plans for new urban developments that fully incorporate environmental and social considerations.

Cairo, EGYPT

A case study on nationally-driven efforts to reduce air pollution in Egypt's megacity

Highlights

- Cairo has been struggling with elevated levels of air pollution. The transport, industry, heavy infrastructure and energy sectors emit particulate matter that adds to wind-blown desert dust and emissions from open burning of rice straw to create what is known as the black cloud phenomenon.
- Various ministries have stepped up action to reduce air pollution. As a result, Greater Cairo has managed to reduce pollution levels despite the intense population growth. This is demonstrated by reports that periodically synthesize data generated by a network of 88 air quality monitoring stations around the country.
- Over the years, the Greater Cairo Metropolitan Area has attracted international support in addressing air quality. It has taken relevant action at both the local and national scales, making significant investments in transport and energy infrastructure, and adopting natural gas as a source of energy in the industrial, residential and transport sectors.
- Many existing environmental policies are sector-specific; an integrated response is lacking. A more robust engagement with stakeholders and the public will be necessary for future sustainability and further air quality improvement.

Introduction and background

Cairo (Al Qahirah) is the capital of the Arab Republic of Egypt. It is the largest urban agglomeration in the country and one of the biggest the entire world, with 18,820,072 inhabitants. Besides being the central point of the region's political and cultural life, international media, business and organizations concentrate in the city along with heavy industries and the largest solid waste disposal sites of the country around the city. Cairo has grown at a 2.2% annual rate in the 2000-2015 period, a pace that is expected to slightly decline in the future, with a 2.0% annual rate of growth projected for the 2015-2030 period. Even if the rate of growth thus slows, the population of Cairo may well grow beyond 25 million people by 2030 (with growth projected more precisely to 25,516,696). The Greater Cairo Metropolitan Area (GCMA) includes Giza (Al Jizah) and Qalyoubiya (Al Qalyoubieh) governorates to the west and north, respectively, in addition to the city proper; this forms a fan shaped agglomeration bounded by the Nile delta to the north that stretches over 100 km in the east-west direction (Figure 22).

The city of Cairo is principally located on the east bank of the river Nile, with an average elevation of 74 m above sea level. Cairo has a hot and extremely dry desert climate. The annual average temperature is 21.7 ºC, with considerable temperature contrast during day and night hours and throughout the year. Maximum temperatures over 40 ºC are common in summer. The average total annual rainfall is 24 mm, with virtually no rain during the summer months (Figure 23). Wind storms from the south are common in March to May, transporting dust from the Sahara. In addition, typical valley thermal inversions are common in autumn, causing stagnant conditions and high pollution levels. These unfavourable meteorological conditions usually result in high-concentration episodes (Zakey et al., 2008).

Figure 24: Population density (persons/km^2) -left- and man-made impervious surface (%) –right- in Cairo and surroundings

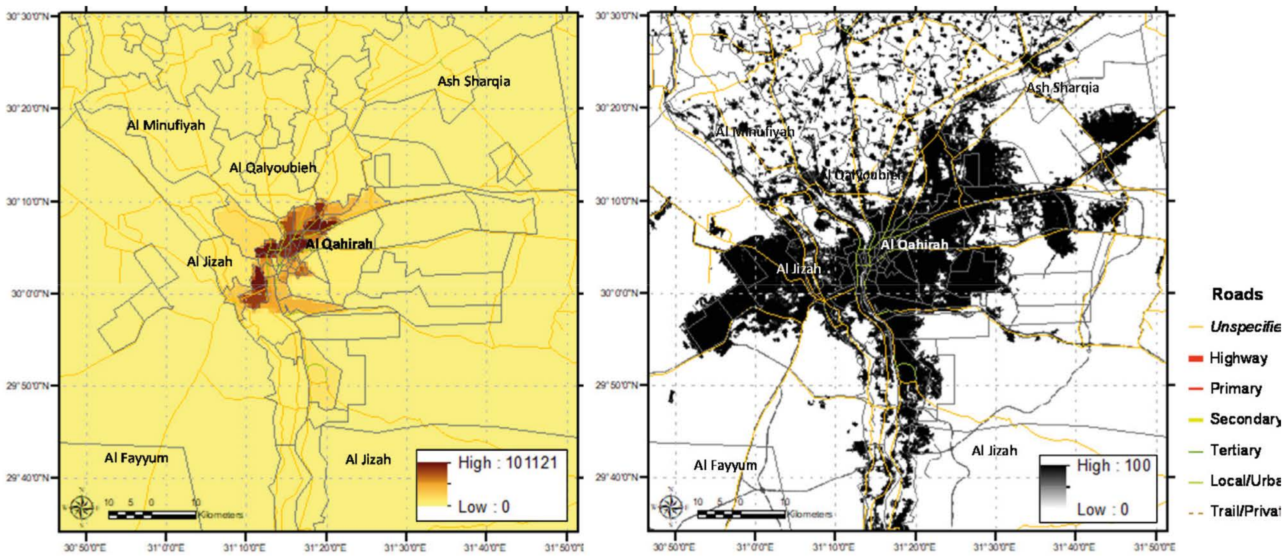
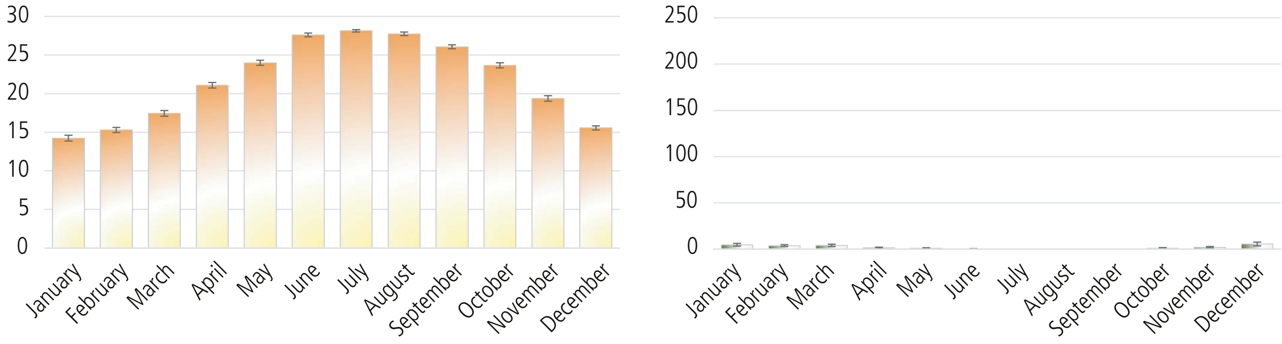


Figure 25: Monthly average temperature (°C) -left- and monthly average accumulated precipitation (mm), according to Cairo Intl Airport (WMO station 62366; long = 31.414° E, lat= 30.111° N, altitude = 75 m). The 95% confidence intervals are shown



As for the national context, the Arab Republic of Egypt is a lower-middle income nation with a GDP per capita of USD 12,390 in 2018, and a poverty ratio (population under the threshold of US$ 5.50 a day) of 61.9%. Total national population reached 100,388,076 inhabitants as of 1 July 2019 (average population density of 100.2 people/km^2). UN projections estimate that 118.2-123.5 million people will live in Egypt by 2030. Virtually the entire country population has access to electricity, while the share of people with access to clean fuels and technologies for cooking is 97.6%. A total of 201,894 kt of CO_2 were released in 2014 (2.23 t per capita), distributed as shown in Figure 24.

Current life expectancy at birth in Egypt is 71.7 years and it is expected to grow to up to 73.3 years by 2030. At present, the mortality rate attributed to joint effects of household and ambient air pollution is 10.9 cases by 10,000 population (9.6, 13.5 confidence interval). That implies nearly 110,000 premature deaths in the country annually, mainly associated with lower ischemic heart disease (58.8%) and stroke (18.5%).

Emissions and air quality in Cairo today

Air pollution at a glance[21]

Total emissions of the main components of particulate matter in the Cairo geographical domain are shown in Figure 25. OC emissions are dominated by the waste treatment sector and are related to open air burning of agricultural residue and domestic waste. Emissions from diesel vehicles contribute a higher share of total BC although the waste treatment sector still dominates. Both PM species present high emission intensities in the central area of Cairo, as shown in Figure 26.

As for air quality; satellite observations (Figure 27) show an annual mean of $PM_{2.5}$ (sea salt and mineral dust removed) around 10-15 µg/m^3 in most of the Cairo area. It should be noted that discounting the large amount of Saharan dust in this particular domain may increase the uncertainty of the estimates. As a

Figure 26: Breakdown of CO_2 emissions in Egypt (201,894 kt in 2014)

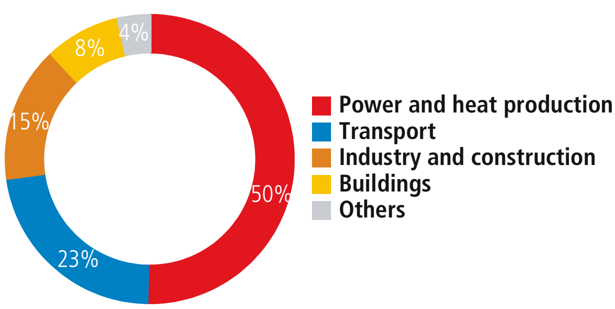
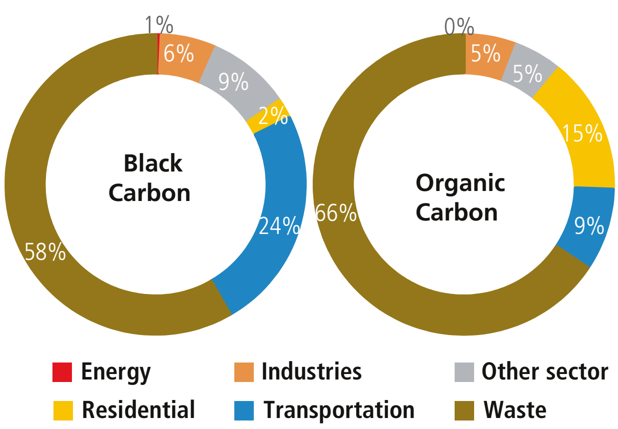
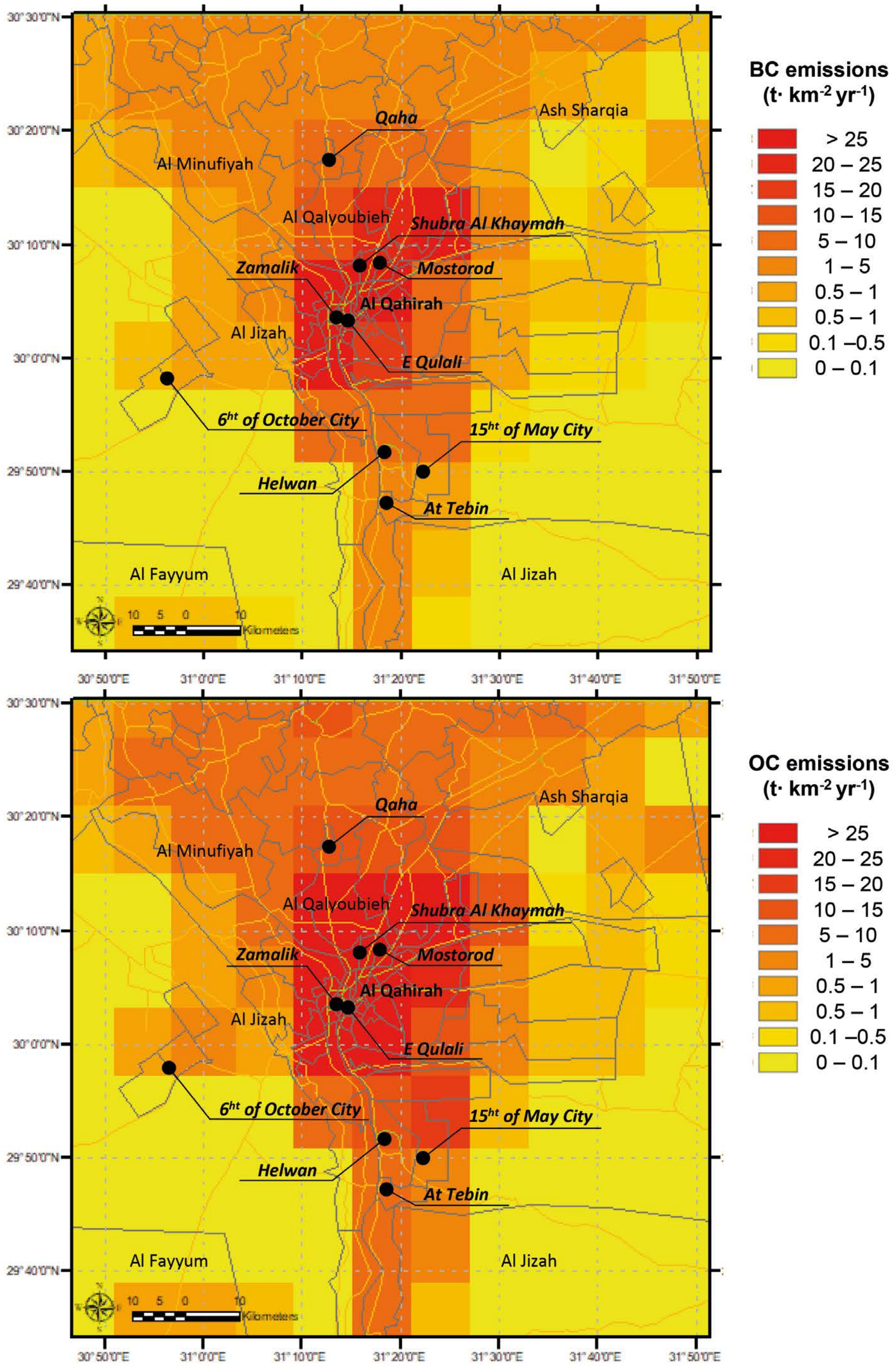


Figure 27: Breakdown of PM emissions (combustion processes) in Cairo



21 For methodological note, see Footnote No. 1, above.

Figure 28: Annual emissions of PM (black carbon –top- and organic carbon –bottom-) in Cairo (t/km²)

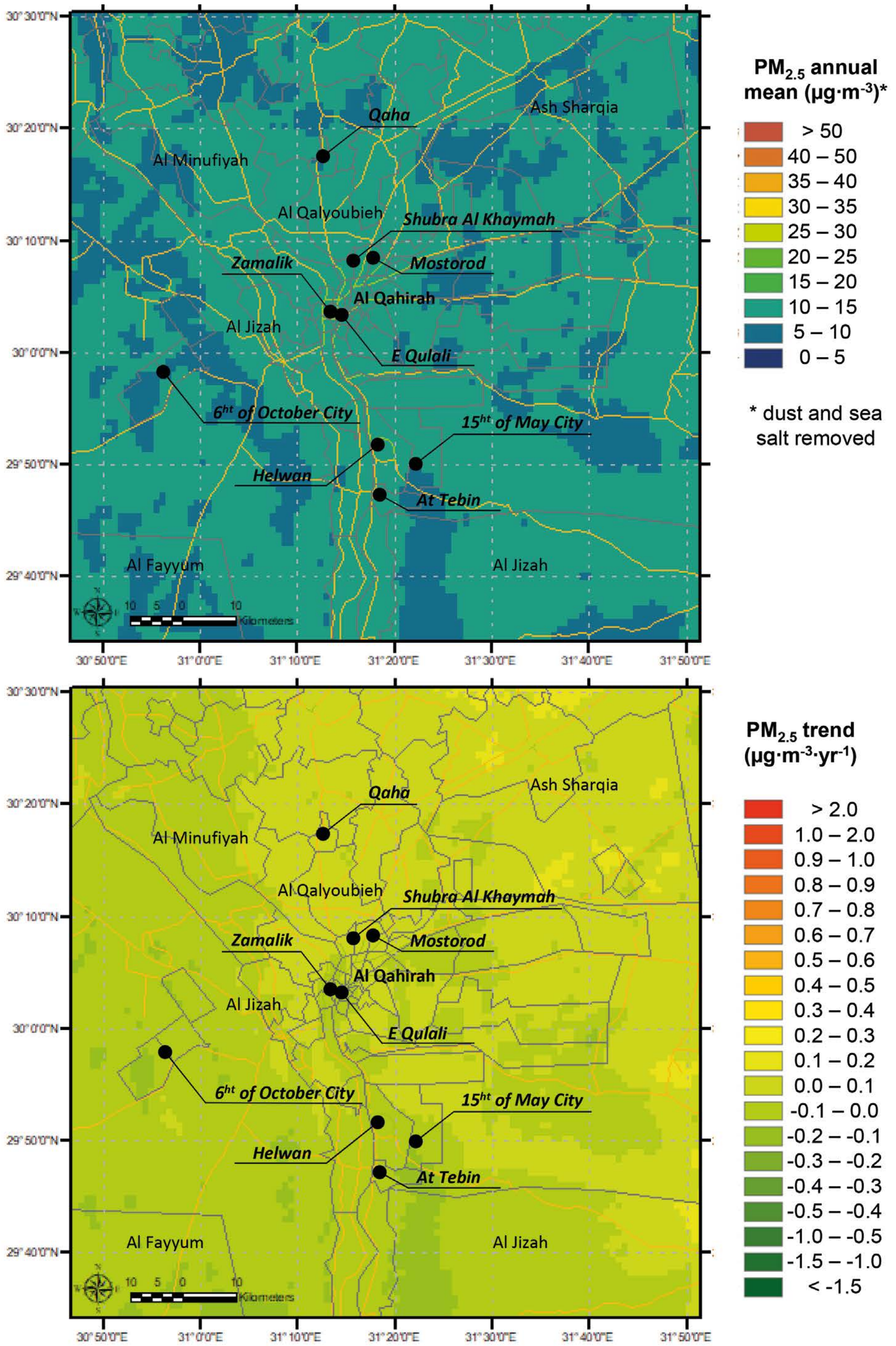


consequence, no clear air quality trends are detected in the region between 2000 and 2016 according to these data. $PM_{2.5}$ levels have remained constant as an average in the Cairo geographic domain, with accumulated changes ranging from -3 μg/m³ to 2 μg/m³ over the last 15 years. According to this global source of information air quality in the city centre would have experienced a very slight improvement in recent years.

A closer look

As in many megacities in the world, air pollution has been a chronic problem in Greater Cairo. The first air quality measurements (SO_2 and smoke) were carried out by the Ministry of Health (MoH) in 1973 (Nasralla, 2001). In 1999, the Egyptian Environmental Affairs Agency (EEAA) within the Ministry of State for Environmental Affairs (MSEA)

Figure 29: Annual mean of $PM_{2.5}$ ambient concentration (excluding natural sources) (µg/m³) –top- and recent concentration trend (µg/m³ per year) –bottom-in Cairo



initiated a more systematic air quality monitoring strategy under the Environmental Information and Monitoring Programme, deploying an initial 42 monitoring stations across the country. Currently, the EEAA maintains the National Air Quality Network of Egypt through collaboration with the Centre for Environmental Hazard Mitigation (CEHM) of Cairo University and the Institute of Graduate Studies and Research (IGSR DANIDA) of University of Alexandria. This network has expanded to include 88 air quality monitoring stations, of which 42 are real-time continuous air monitoring stations (including 24 in the GCMA), and 46 are sampling stations (including 25 in the GCMA). This information is used to elaborate annual and monthly reports that are made available by EEAA,owever, they are not updated systematically and are only in Arabic, limiting international review. The December 2016 report, last one available as of January 2020, for example, provides average monthly PM_{10} concentrations from 48 stations: 38 located in urban (non-industrial) and 10 in industrial areas. It further concludes that reported PM_{10} levels met Egyptian air quality standards 72% of the time. During that period, $PM_{2.5}$ levels in Cairo averaged 60-99 µg/m³ (EEAA, 2018). At present, the PM_{10} is reported to be at an annual mean of 179 µg/m³. However, caution is needed to draw conclusions from Cairo's air quality monitoring network since insufficient quality assurance and quality control (QA/QC) procedures have been reported in the past (Nasralla, 2001).

According to observations from the network, routinely monitored pollutants (such as PM_{10} and $PM_{2.5}$) have seen a significant drop between 1999-2009, except for O_3 (WB, 2013). According to EEAA, Pb levels dropped at a 12% rate per annum during that period. The annual concentration reductions of PM_{10} and $PM_{2.5}$ were estimated in 5% and 2%, respectively, similar to the trends for other major pollutants such as CO, SO_2 or NO_2. On the other hand, O_3 concentrations in the city rose significantly during that period. This trend has been observed in other urban areas where reduced NO_X emissions reductions from traffic lead to higher O_3 concentration levels due to non-linear photochemical processes (Saiz-Lopez et al., 2017).

Despite the declining trend, the PM_{10} concentration in the GCMA is still high and generally above the Egyptian standard. In addition, it should be considered that the rapid population growth (by more than 3 million from 1999 to 2010) has led to a net increase in population exposure to air pollution.

Wheida et al. (2018) assessed long-term exposure to $PM_{2.5}$, NO_2, and O_3 in Greater Cairo. As a basis for their analysis, they examined ambient concentration data during the 2010-2015 period, drawn from 18 representative monitoring stations from the entire air quality network. They found an average PM_{10} of 155 (±35) μg/m^3, although large concentration gradients were found across the megacity. Similarly, average $PM_{2.5}$ concentrations varied from 50 to more than 100 μg/m^3. Both PM levels were affected by massive wind-blown desert dust since the city is within the Sahara region. With the exception of a few traffic hot spots, NO_2 concentrations were found to be below 40 μg/m^3, defined as an air quality standard in Egypt in accordance to the WHO guidelines (WHO, 2006). Some authors (Ndour et al., 2008) suggest that high natural dust loads in urban atmospheres may enhance the photocatalytic uptake of NO_2. Despite the increase of tropospheric O_3, further recent analyses confirm that current air quality issues in Cairo primarily concern PM (Mostafa and Zakey, 2018).

According to WB (2013), approximately 35–55% and 25-35% of the total concentration of PM_{10} is attributable to airborne geological material during the summer and winter, respectively. This is consistent with the findings of Boman et al. (2013) that also found a significant influence of marine aerosols. In an earlier study, Favez et al. (2008) sampled PM at two urban sites in Cairo from January 2003 to May 2006. They observed maximum dust concentrations in spring and winter due to the higher frequency of dust storms, but noted high dust contribution throughout the year (around 50 μg/m^3) as well as a significant contribution of sea salt from the Mediterranean Sea. In addition, they reported that natural dust interacting with NO_X and SO_2 emissions adds secondary compounds to the aerosol in a so-called "dust anthropization" process. Similarly, Hassanien and Abdel-Latif (2008) reported significant amounts of toxic polycyclic aromatic hydrocarbons (PAH), such as benzo (a) pyrene, in road dust samples collected across Cairo.

In addition to changes in air quality due to natural phenomena, Cairo residents also face an episodic deterioration in air quality through the so-called Black Cloud phenomenon every October and November (WB, 2013). Burning of rice straw in the governorates around Cairo in the Upper and Middle Nile Delta takes place during these months, coinciding with typical autumn thermal inversions; this gives rise to very high PM pollution episodes popularly known as the 'Black Cloud' (Marey et al., 2010; Zakey et al., 2008). During these events, the aerosols originated from the burning of agricultural residue account for 12% of BC and up to 50% of OC (soluble fraction) (Favez et al., 2008). On the other hand Mahmoud et al. (2008), studying BC levels in the city during autumn 2004 and spring 2005, observed large temporal variations even over diurnal scales, with peaks up to 25 μg/m^3. They concluded that traffic was the majority source of BC in Cairo during the daytime, even in autumn when biomass burning takes place in the Nile Delta.

There are several studies that have focused on Pb. According to Boman et al. (2013), the concentration of this metal was 95 ± 200 ng/m^3, well below the Egyptian legal limit of 500 ng/m^3. Similarly, Safar and Labib (2010) documented how Pb concentration in two industrial areas (Shubra Al Khaymahand and At Tebin) had dramatically decreased after closing the lead smelter activities. Before that, Pb ambient concentration levels were as high as 1.8 μg/m^3 (2001-2002) (Zakey et al., 2008).

An emission inventory was developed for the year 2010 (WB, 2013), following the EMEP/EEA methodology (EEA, 2009) used in European countries for their national emission inventories. The results showed that PM_{10} emissions were dominated by industrial activities, including construction and demolition (53%); those activities also accounted for 25% of total $PM_{2.5}$ emissions. During that study period, road transport (with a large share from heavy-duty vehicles) was responsible for 79% and 24% of NO_X and $PM_{2.5}$ emissions, respectively. The local inventory has not been updated since 2010, but current regional estimates of continental scale inventories (Figure 26) suggest that the waste sector has gained importance as a source of PM.

The World Bank (WB 2013) used that 2010 emissions inventory to carry out a PM source apportionment study (also in 2010). The study was based on the

Chemical Mass Balance (CMB) approach (Watson et al., 1984), and used observations from five locations (Qaha, a rural agricultural site upwind Greater Cairo); Shubra Al Khaymah, an industrial area (mostly lead smelters); E Qulali square and Zamalik (traffic and urban background locations in the city centre, see Figure 26); and Helwan (a residential-industrial area). In comparison with the findings of a similar study carried out ten years earlier, they found that PM_{10} and $PM_{2.5}$ had declined by a factor of 1.8 and 2.4 respectively. The major contributors to PM_{10} concentrations were soil dust, traffic, and open burning; $PM_{2.5}$ were mostly related to mobile sources, although burning of agricultural waste becomes the dominant source for both PM_{10} and $PM_{2.5}$ in autumn. The study demonstrates that the influence of mineral dust is increasingly important since its contribution remains constant while anthropogenic sources have declined.

Tackling the issues

During the last decades, Cairo has faced virtually all of the underlying drivers that contribute to air quality degradation in megacities: a rapidly growing population and urban expansion, uncontrolled rural-to-urban migration, inadequate land use planning, as well as the unsustainable growth of the industrial zones and other heavy infrastructure sectors in and around the city. However, most ministries of the Egyptian government have established an environmental unit or department to deal with air pollution in their respective sectors. As a result, considerable progress has been made in tackling air quality issues in the GCMA, as the trends discussed in the previous section demonstrate. Some of the actions that explain that progress are discussed below.

Air quality standards, regulations and plans

The legal framework for air quality management is given by Egypt's Environment Protection Law No. 4 (1994) amended by Premiership Decree No. 1741 (2005) and by Law No. 9 (2009). This regulation establishes the National Air Quality Standards for the Country. They include a maximum annual average concentration of 90 μg/m^3 and 70 μg/m^3 of total suspended particles (TSP) and PM_{10} respectively. Safar and Labib (2010) suggested that the natural contribution to PM_{10} background will prevent Cairo from ever attaining this standard as currently defined. Of note, this consideration is taken into account in the air quality standards of European countries (EC, 2008) that exclude exceedances that are proved to be caused by natural sources, such as desert dust outbreaks.

Although Egypt monitors $PM_{2.5}$ ambient concentration, no regulation is in place for this important pollutant. The Egyptian government considers a standard of 60 μg/m^3 for black carbon, for the annual concentration mean. While this is an acceptable proxy for anthropogenic aerosols, the WHO recommends regulating total $PM_{2.5}$, given its effects on human health (Burnett et al., 2018). In addition, this fraction of PM is less affected by natural contributions than PM_{10}. Standards for NO_2, SO_2 and O_3 are relatively stringent for the region, comparable to the European ones. The same applies for Pb, with a maximum annual mean of 0.5 μg/m^3 for urban areas (1.5 μg/m^3 as a 6-month average for industrial zones). Egyptian law also sets a standard for black carbon (BC) (60 μg/m^3).

Egypt lacks a comprehensive plan or strategy for the promotion of clean air; likewise, Cairo-specific plans or strategies do not exist. Nonetheless, certain international and national initiatives have proven relevant to improve air quality in the city. The Environmental Information and Monitoring Project (EIMP, funded by DANIDA), and the Cairo Air Improvement Project (CAIP, funded by USAID) were two flagship programmes led by EEAA in the early 2000s that played a fundamental role in helping officials address air quality issues in Cairo. Furthermore, a long-term collaboration with the World Bank has been instrumental to pilot the air quality improvement process in Egypt. In lieu of a coordinated, cross-sectoral effort, up to nine ministries (WB, 2013) have been actively developing legal and institutional mechanisms, as well as programmes and projects with international development cooperation partners, to improve air quality. Among others, these include the following:

- The National Environmental Action Plan of Egypt 2002/17 (NEAP) (EEAA, 2001 –incomplete draft-), developed in cooperation with the United Nations Development Programme (UNEP), was conceived as a participatory, consultative, gender-anchored, holistic planning modality to create an enabling environment. The plan articulated the strategic framework and action plans for six priority topics, including air. Within that topic, it was mentioned that a National Strategy for Air Quality Management would be developed, but to the best of our knowledge this instrument has not been officially approved (however, see the following discussion).
- In 2004, the EEAA formulated a national air quality strategy (NAQS) framework in collaboration with USAID; this sought to alleviate socioeconomic burdens suffered in urban areas in Egypt caused by poor air quality. The framework covered four policy areas: i) reduce industrial impact through land-use planning, cleaner production, and pollution control and abatement; ii) reduce emissions fossil fuels; iii) improve waste management systems to reduce solid waste burning and increase the recovery and reuse of waste; and iv) minimize the impact of agricultural burning practices. The framework developed was

useful for the development of sectoral plans but the NAQS per se was not implemented, reportedly due to lack of coordination among ministries and the proper institutional structure.

- In 2007, the Supreme Energy Council (SEC), a multi-ministerial body, reformulated Egypt's energy policy to enhance natural gas utilization, adjust energy prices and remove subsidies, and promote renewable sources and energy savings, including in the transport sector. Egypt has advanced on a Unified Electricity Law to involve the private sector in the expansion of renewable power plants.
- The Ministry of Planning and Economic Development launched a Sustainable Development Strategy (SDS) called "Egypt Vision 2030" (MPED, 2016). This Strategy provides a roadmap towards economic development dealing with the three dimensions of sustainability (economic, social, and environmental), in line with the UN Sustainable Development Goals. Related to the latter, it includes key performance indicators (KPI) directly linked to improve air quality in the country. Specifically, it aims at reducing fine airborne dust by 50% by 2030. It also promotes enlarging the national air quality monitoring network to up to 120 stations, and monitoring site-specific emissions at up to 500 industrial sites. The SDS's urban development targets should act to foster better air quality in cities across the country, including in Cairo.

Other sectorial strategies and measures that have or are expected to affect air quality in Cairo are as follows.

Vehicle emissions

Road transport has experienced a remarkable increase in Egypt in the last decades, with an average annual growth of 4.6% and 4.9% of passenger and freight transport respectively (Korkor, 2014). Abou-Ali and Thomas (2011) estimated that, in 2010, the motor fleet in GCMA (broadly 1/3 of that of the country) consisted of 1.4 million private passenger cars, 120,000 taxis, 234,000 trucks, and approximately 200,000 motorbikes. Of these vehicles, around 25% were more than 25 years old. According to El-Dorghamy (2014), the total number of licensed vehicles in Egypt grew to 7.04 million in 2013, about half of them in GCMA. At the same time, only eleven per cent of households in Greater Cairo metropolitan region own a car (El-Dorghamy, 2014), and about two-thirds of total vehicle miles travelled in the city involve public transport (mostly taxis and minibuses) (WB, 2013). Virtually, the totality of passenger and light-duty vehicles use gasoline or compressed natural gas (GNC), while heavy duty vehicles run on diesel fuel. The vast majority of buses and trucks lacks catalytic converters or diesel particle filters (Abou-Ali and Thomas, 2011).

The Egyptian Government has taken specific actions to reduce emissions from the existing car fleet and change the relative costs of various transportation modes to encourage less polluting modes by developing new policies around pollution control, economic instruments, and governance mechanisms (Thomas, 2016). The traffic law (no. 121 of 2008) enacted by the Ministry of Interior prohibited vehicles older than 20 years (including taxis, buses and microbuses) from renewing their license to operate; this provision accelerated the vehicle replacement rate and improved air quality (El-Dorghamy, 2014). The Government also implemented a replacement scheme for taxis, which offered subsidies (EGP 10,000) to scrap old vehicles. This program was structured as a Public Private Partnership (PPP) involving the Ministry of Finance, the Ministry of Interior, three participating commercial banks, five car companies, an insurance company and an advertising company, among other stakeholders (El-Dorghamy, 2014).

Another relevant measure to promote compressed natural gas (CNG), liquefied petroleum gas (LPG) and biodiesel involved the enforcement around 1995 of a vehicle inspection programme (Korkor, 2014). In part as a result of the tests required for mass transport vehicle licensing (taxicabs, microbuses, trailer trucks and buses) regulated by Egyptian Law 2008/121, the bus fleet has been progressively modernized (Thomas, 2016). The government has plans to extend incentives to encourage the replacement and conversion of passenger cars.

Since 2008, private vehicles can also be inspected (such vehicle emission testing is currently confined to Al Jizah and Al Qalyoubieh Governorates). Vehicles not complying with emission standards have to follow a procedure of mandatory repair, technical inspection and re-test. Although vehicle testing may increase public awareness (Korkor, 2014), it has been argued that their actual implementation is very limited. In addition, emission standards are not particularly stringent in Egypt, being comparable to Euro 2 and Euro 3 norms (WB, 2013).

Subsidies for transportation fuels in Egypt have long been amongst highest in the world (GIZ, 2014), consuming around 7% of Egypt's GDP – an expenditure that is sadly larger than that devoted to health, education and infrastructures combined (El-Dorghamy, 2014). These instruments have been criticized for encouraging overconsumption and increasing social inequity (WB, 2013). Consequently, they have been subjected to gradual reductions since 2014. In July 2019, Egypt announced the fifth and final stage of a fuel subsidies cut. According to Thomas (2016), this plus a corresponding increase of gasoline prices during the same period resulted in at least a short-term impact in car sales, which were initially reduced by 35%.

In addition to the incentives to switch to natural gas, Egypt has sought to improve fuel characteristics. Although Egypt is one of the few countries in Africa where leaded gasoline is still nominally allowed (Boman et al., 2013), in reality only lead-free gasoline is available (WB, 2013). As of 2013, a maximum sulphur content of 500 ppm and 4000 ppm was permitted for gasoline and diesel fuels respectively, with reductions planned for the future (down to 10 ppm) (WB, 2013). These sulphur levels (still above Euro 3 standards; EN 590:1999; 350 ppm and 150 ppm for diesel and gasoline respectively) are incompatible with newer engine and gas treatment system requirements. They thus discourage the penetration of newer vehicle emission control technologies and, thus, Egyptians enjoying the health benefits that that result from current, more stringent standards (e.g., Euro 6).

To further modernize its fleet and reduce emissions, Egypt has applied various economic instruments at its disposal such as import duties, taxes and controls. The commercial ban on imports for passenger cars was lifted in 1993 and replaced with import duties. Later, in 1998, several regulations were issued to limit the maximum age of imported second-hand vehicles to three years (UNEP, 2016), and to introduce variable taxes depending on vehicle characteristics such as engine size). Then, a December 2007 effort to reduce motorcycle emissions resulted in the prohibition of two-stroke engine motorcycle importation and local production. This was particularly relevant from an air quality perspective due to the proliferation of tok (motorized tricycles imported from India) on local streets. These vehicles had been massively imported with no emission standards or approval tests whatsoever (WB, 2013), in part to compensate for the shortcomings of the public transport system in Cairo.

Public and non-motorized transport

Cairo suffers from severe traffic congestion. In particular, Cairo's downtown suffers high auto-dependency and near-permanent congestion. According to El Aziz (2018), average speed is as low as 11 km/h in morning and evening peak periods (8:00-10:00 am and 5:00-7:00 pm, respectively). One 2011 study concluded that, considering personal time, vehicle operating cost, air quality, public health and negative impact on business operations, the cost of inaction regarding congestion could reach EGP 7.5 billion per year in the foreseeable future (Abou-Ali and Thomas, 2011).

To try to address the growth in population and mobility demand, the city has developed and continues to develop its network of major transportation infrastructure such as bridges, ring roads, radial motorways and underground carriageways (Korkor, 2014). At the same time, the Egyptian Environmental Affairs Agency (EEAA) has promoted a number of projects to foster alternative transport models, including under the framework of the Greater Cairo Urban Transport Master Plan (WB, 1982). The most relevant initiative is the development of a four-line metro system totalling 70 km, with an associated investment of EGP 75 billon (Korkor, 2014). This infrastructure eventually will connect eight new satellite towns, to encourage the deconcentration of Cairo's population and to develop new economic growth poles (WB, 2013). A Bus Rapid Transit (BRT) System is also planned to connect inner Cairo to western satellite towns (specifically 6th of October) (Figure 27). Besides transforming public transport service, the BRT project aims at improving conditions for pedestrians and cyclists (ITDP, 2018).

In addition to large infrastructures and other 'hard' measures, the governorate of Cairo has made a number of 'soft' interventions in downtown Cairo (original designed in 1869) to accommodate rapidly increasing traffic (Awatta, 2015). These include measures such as parking limitations, regulation of traffic control devices, creation of pedestrian paths and removal of street vendors. With congestion still severe, analysts have proposed additional measures. El Aziz (2018) assessed a range of both short- and long-term measures to address traffic and pollution issues. Measures with high feasibility and impact included minimizing street parking, encouraging walking, and further restricting traffic (e.g., through low emission zones). Thomas (2016) suggested that revenues from 'soft' measures such as congestion charge schemes or fuel taxes could be devoted to the development of public transport. More recently, Ibrahiem (2018) concluded that further energy conservative policies (e.g., imposing additional fuel taxes and emissions standards) would not deteriorate economic growth in Egypt.

Industrial emissions

Industrial activity is responsible for 24% of Egypt's GDP (UNEP, 2016), and is well represented in the Capital city. There are more than 12,500 industrial facilities in Greater Cairo (WB, 2013) including several large-scale industries producing iron and steel, aluminium, coke, cement, and fertilizer. Also of note is the Cairo oil refinery in Mostorod (Figure 25), with 2 million tons annual capacity. Medium and small industrial activities, such as foundries, secondary smelters, pottery workshops, brick kilns, mechanical workshops, lime crushers, charcoal producers, etc. are scattered in informal settlements within and close to GCMA. Small industrial enterprises have been reported to use heavy oil (mazut), coal, wood, and rubber and even waste materials as fuel, with subsequent deleterious effects on air quality (EEAA, 2001).

Rather than setting up a formal monitoring and regulation system, the Government has approached the industrial sector in Egypt through incentives and large subsides to favour natural gas consumption through the Second Egypt Pollution Abatement Project (EPAP II). While a questionable shift from a long-term climate perspective, in the short-term this change brought about substantial benefits regarding PM_{10} airborne concentration levels in Cairo (WB, 2013). Additionally, the Cairo Air Improvement Project (CAIP), undertaken in cooperation with USAID (1997–2004), targeted the specific issue of lead, mainly related to factories smelting lead scrap. Small and medium enterprises that processed Pb were relocated outside of the GCMA limits, away from densely populated areas. Besides these initiatives, the government has piloted the use of compressed natural gas in brick factories; this initiative was later expanded to other industries in the GCMA area.

In terms of reducing emissions from industrial production, the current MSEA industrial strategy in Egypt (EEAA, 2004) seeks to move away from end-of-pipe methods such as the dust control technologies used by the cement industry (Nasralla, 2001) to a more proactive, holistic and cleaner industrial production. Among other performance indicators, the current strategy proposes targets for CO, PM_{10}, NO_X and SO_X emissions per unit product. However, the strategy does not establish a formal framework for monitoring and reporting, and it depends at least partly on industrial self-monitoring and sporadic inspection visits. The strategy does, however, consider the development and subsequent application of National Environmental Standards by the Ministry of Industry, something that would represent an advance over the current voluntary "eco-label" scheme.

As for the energy sector, Greater Cairo includes seven thermal power stations with an installed capacity of 4,585 MW (WB, 2013), most of them fuelled by natural gas. As a whole, 87.6% of the installed electricity generating capacity in the country (26.91 million KW in 2010) is generated from fossil fuels (natural gas and fuel oil), 10.4% is generated from hydropower and the rest (2.0 %) is generated from other renewable sources (UNEP, 2016). This is clearly reflected in the CO_2 emission structure in the country (Figure 24). Egypt foresees a six to seven per cent increase in electricity demand within the next decade. The government targeted meeting 20% of total energy generated from renewable energy sources by 2020, including eight per cent from hydro and twelve per cent from wind energy; this would reduce emissions of GHGs by an estimated 17 million tons of CO_2, with with substantial co-benefits for air quality (WB, 2013). Infrastructures such as the 1,650 MW Benban Solar Park, one of the largest photovoltaic power stations in the world, located some 650 km south of Cairo, are a decided step forward in the decarbonisation of the Egyptian electricity mix. This project is being developed as a part of the Egyptian government's Sustainable Energy Strategy 2035 that aims to produce 42% of electricity from renewable sources by 2035 (IRENA, 2018).

Open burning of waste

Cairo generates 9.5 million tons per year of municipal solid waste, which represents 47% of the country's waste. It is estimated that 40% of total municipal solid waste generated in Egypt is left uncollected (MoLD/EEAA/KfW, 2011). According to the World Bank (WB, 2013), about 83% of municipal solid waste (MSW) ends up in streets or on illegal dumping sites, where open burning is a common practice. Efforts had been made to establish new sanitary landfills with composting plants, and to rehabilitate or close poorly managed existing dumpsites and landfills in Cairo. However, an appropriate legal framework to address the technical and financial aspects of MSW management in a comprehensive way does not exist. Such a framework would need to help manage agricultural waste and rice straw burning that causes the 'black cloud' phenomenon previously described. Preventing open burning of agricultural waste near Cairo has been identified as a priority to avoid these high pollution episodes, first identified in 1997 (Nasralla, 2001). According to one study (WB, 2013), the eradication of open burning practices would be the single most beneficial policy to reduce ambient PM_{10} concentration levels in the GCMA.

Farmers burn agricultural waste in part because they are unable to transfer straw from their fields to recycling centres. More fundamentally, no framework exists to make improved rice straw and agricultural waste management economically sustainable at both the local and the national levels (WB, 2013). Egypt has invested in composting, animal feeds, biogasification (anaerobic digestion), production of fertilizers and pelletizing of agricultural residues in cooperation with the private sector, with promising results in several governorates to the north (Ash Sharqia, Ad Dakhiliyah, Gharbiya, and Qalyoubiya). In addition, cement factories are being encouraged to use rice straw. WB (2013) reported that this agricultural waste can be disposed in cement kilns (replacing up to 30% of the conventional fuel), an alternative that has been already tested in a pilot project under EPAP II.

The Government has prohibited waste burning (Article 37 of the Environmental Protection Law No. 4 in 1991, amended by Law No. 9 in 2009), with fines of up to EGP 5,000. The efficacy of this measure is unclear. However, analysts estimate that the increase of inspection campaigns, the reduction of areas dedicated to rice cultivation and the investments made to valorise rice straw have decreased PM_{10} and SO_2 emissions by some 20% (WB, 2013).

Efforts have also been made to deal with non-agricultural waste. Presidential Decree (86/2010) was issued to regulate the closure and rehabilitation of existing dump sites and landfills in Greater Cairo. The MSW management strategy for Greater Cairo seeks to improve MSW collection; it is also establishing five new sanitary landfills with composting plants, and 20 transfer stations. The composting plant at 15th of May City reportedly constitutes a successful model that could be replicated elsewhere (MoLD/EEAA/KfW, 2011).

Indoor air quality

Unlike the generalized situation in sub-Saharan African countries, virtually 100% of the population in Cairo has access to electricity and relies on relatively clean fuels and technologies for cooking (natural gas). Due in part to those circumstances, Egypt has been reported as experiencing the lowest indoor/outdoor air pollution ratios in the MENA Region (Croitoru and Sarraf, 2010).

At the same time, almost 50% of the energy generated for Cairo is used by residents, so the national government is promoting some initiatives to increase energy efficiency in households. One such initiative is the introduction of energy efficiency standards and corresponding labelling for refrigerators, air conditioners and washing machines, etc. The National Efficient Lighting Initiative (NELI) includes a public awareness programme that seeks to accelerate the penetration of low-consumption lamps.

Some studies indicate that 40 to 90 per cent of outdoor pollutant concentrations in Egypt are also found indoors; this represents a health concern (EEAA, 2001) since people spend a considerable fraction of their time indoors, especially women and children. Therefore, it is expected that the various measures and initiatives reported in this chapter designed to improve ambient air quality will also have a positive impact on indoor air quality.

Conclusions and recommendations

This case study presents efforts to deal with air pollution in the Cairo Megacity over the past two decades. It shows how decision makers were able to improve urban air quality despite multiple constraints including rapid population increases and urban expansion. The main conclusions drawn and recommendations offered within the six key guidance framework areas of Air Quality Management Planning (AQMP) are as follows:

1. Air quality standards and monitoring

Egypt has set comprehensive ambient air quality standards, as stringent as European standards for some pollutants. The evidence available suggests that current air quality issues in Cairo are primarily related to particulate matter, to a large extend affected by wind-blown dust from the Sahara Desert. This non-controllable source poses a huge challenge to meet current PM_{10} national standards (24-h limit of 70 μg/m^3).

Recommendation: Consider a scheme to exclude natural contributions when assessing compliance with PM_{10} standards. This approach may better measure progress.

Recommendation: Consider a specific standard for $PM_{2.5}$ as a replacement or complement to the current black carbon standard. This may be more appropriate from a public health perspective.

The case study illustrates the value of international cooperation to generate reliable information and capacities for planning. In the 1990s and 2000s, with international support national and city-level officials actively considered options and designed specific actions to tackle air pollution. As a result, GCMA today has a permanent air quality network that it uses to routinely monitoring the most relevant pollutants. This infrastructure provides the necessary basis to understand air quality trends and to assess the impact of recent plans and measures. While the ambient air quality monitoring strategy is generally fit for purpose, Egypt lacks a comprehensive scheme to monitor both industrial and vehicle emissions.

Recommendation: Revise and update the design of the network (number and location of monitoring points for each pollutant) in accordance with the development of GCMA, and implement a comprehensive auditing and QA/QC programme.

Recommendation: Expand the vehicle inspection schemes and industrial emission monitoring systems that are already in place.

2. Emission inventories and modelling

Cairo is the only city in this study that has completed an urban emission inventory. Although the inventory was compiled for 2010, it included emission projections up to 2020 that were used to study future air quality scenarios. Those simulations were based on air quality models that did not consider chemical processes.

Recommendation: Compile a new urban emission inventory, building on the information and methodological framework (EMEP/EEA methodology) of the 2010 inventory, to assess the effect of recent policies and to produce updated emission projections.

Recommendation: Perform new air quality simulations in the Cairo region with mesoscale photochemical models. These simulations should yield insights into the reasons for the increase of urban O_3 levels, and better represent particulate matter dynamics by considering secondary aerosol (both organic and inorganic).

3. Health and other impacts

Despite a favourable trend, PM_{10} and $PM_{2.5}$ concentrations remain high, and more people are now being exposed to the effects of this pollution because of rapid growth in Greater Cairo. Wheida et al. (2018) propose that 4,550 premature deaths would be avoided every year in the GCMA alone if the existing national PM_{10} standard was met. The economic case for emission abatement was given by UNEP (2004). That study revealed that the cost of air pollution in Cairo was in the range of USD 1-2 billion per year, which represents 3 to 6% of the GDP. The interconnections between air pollution and social issues, in the context of a 61.9% poverty ratio in the country, have not yet been fully described.

Recommendation: Perform further local health impact analyses to gain a better understanding of the potential benefits of new air quality policies and interventions, including specific impacts on low-income communities and environmental justice considerations. Vigorously implement the most beneficial and cost-effective measures.

4. Communication

Some of the many plans launched in recent years (EEAA, 2004) have identified potentialbarriers to successful implementation related to communication, including limited corporate, governmental and public awareness and poor transparency. Egypt developed the framework of a National Strategy for Environmental Communication (NSEC) (EEAA/DANIDA, 2005) to improve internal communications and to promote public knowledge and awareness of environmental issues. NSEC made a diagnosis of communication gaps and proposed a framework to overcome them. Regarding air pollution, a specific website for the visualization and retrieval of air quality data by the general public (one such proposal) is not currently available.

Recommendation: Ensure the implementation of the NSEC as an important first step to increase awareness and support the implementation of current and future strategies.

Recommendation: Develop a dedicated web platform to make air quality monitoring data recorded by the national network publicly available, and to disseminate specific studies and reports.

Recommendation: Increase transparency in general and update reports regularly.

Recommendation: Carry out specific campaigns to sensitize the population and institutions about the benefit of improving air quality and responsible energy consumption as a means to accomplish certain environmental targets.

5. Clean Air Action Plans

The reduction of air pollution in Cairo has been supported by the massive introduction of natural gas in the domestic, industrial, power generation and transport sector through economic instruments driven by the national government. While this served to cut down dangerous PM emissions, the effectiveness of such a strategy to meet climate change targets or NO_2 issues is limited. Another pillar of recent achievements has been the implementation of large infrastructure projects that support public transportation, such as the metro system, even while the roadway network is also expanded. The successes of many of the plans and measures discussed in this chapter are rooted in effective public-private partnerships and the involvement of relevant stakeholders.

More than a decade has passed since the conclusion of the CAIP and EIP programmes. It is time to engage in a new phase of programmes with international organizations to tackle the sources of air pollution in Cairo through innovative interventions in the area of policies and legislation, planning and finance, capacity building and awareness raising. Remaining challenges are substantial and are expected to grow in the context of demographic projections and increasing demand for infrastructure and services.

Recommendation: Develop an air quality strategy for the Greater Cairo Metropolitan Area that builds on national initiatives while also targeting specific air quality issues and emerging challenges, based on the particular constraints and features of the megacity.

Recommendation: Accelerate the transition to non-fossil energy sources, as well as the uptake of non-technological demand-side measures, as an integrated strategy to tackle air quality and climate change issues.

Recommendation: Pay attention in the short-term to soft, non-technical measures to reduce dependency on motorized transport as a necessary complement to increases in the capacity of transportation infrastructures; move towards more sustainable solutions in the mid- to long-term.

Recommendation: Enforce more ambitious vehicle emission standards and stringent fuel properties (including sulphur content) that have contributed to air quality improvements in other cities. This measure should be accompanied by the development of the necessary infrastructure and mechanisms for effective enforcement.

Recommendation: Promote cross-sectoral collaborations. Replicate successful public-private partnership schemes such as the pilot projects to use rice straw as fuel in some industrial sectors.

6. Governance

Successful experiences at controlling air pollution in megacities across the world are sustained by the political will at the highest level (WB, 2013). Egypt has succeeded at improving air quality by addressing the options that yield more substantial benefits in term of emission abatements (mainly particulate matter) through nationally-driven plans. However, many of the direct or indirect environmental policies are mainly sector-specific and independent of one another, and even at times contradictory. The promotion of rice cultivation around Cairo, with subsequent increased burning of biomass, has been identified as an example of uncoordinated policy. Large infrastructure investments and other measures to control air pollution were made in the absence of 'softer' complementary measures, a clear institutional framework, coherent, cross-sectoral planning and robust analytical capacity (to undertake cost/benefit analysis, prospective, strategic environmental studies and so on). Another shortcoming has been the scarce public participation in the formulation, implementation and monitoring of sectoral policies. This limited coordination and lack of a clear institutional framework may compromise the sustainability of this implementation model and fail to meet the increasingly challenging environmental needs of the Cairo megapolis in the future.

Recommendation: Revise the regulatory framework and coordination mechanisms so as to break sectoral/ministerial silos and provide the necessary conditions to enable public participation.

Recommendation: Strengthen the role of local Governorates and cities in a multi-scale, multi-level governance system. This engagement should help to facilitate the design and implementation of effective transversal plans and strategies, including to address air quality. Develop a robust, coherent GCMA air quality plan.

Cape Town, SOUTH AFRICA

A case study on multi-level governance for air quality action in an inequity context

Highlights

- The City of Cape Town has a second-generation Air Quality Action Plan in place, to guide its efforts to meet South Africa's national air quality standards.
- The case study shows the interplay between the national-level air quality policy framework and local government monitoring and compliance action. While the provisions that enable multi-level governance can foster cooperation towards cleaner air, they entail additional complexities.
- Air quality in Cape Town is generally acceptable, except for PM and O_3. Despite a profuse regulatory framework and a breadth of strategies, plans, guidelines and working groups, recorded concentration levels for these pollutants show no clear improvement, especially in low-income areas.
- Air pollution is closely related to poverty; it is a particularly serious problem in the largest informal settlements of the city. Meeting the national air quality standards will bring substantial health benefits, especially for the poorest, most vulnerable communities.
- Climate change has the potential to worsen these inequities. Some efforts have been made to harmonize the air quality and climate change agendas, however further action should be undertaken.

Introduction and background

Cape Town is a city with 4,100,334 inhabitants, located in the south-west corner of South Africa (Figure 28). While the city has a smaller amount of industrial activity than a couple of other major cities in the country, it is a major economic hub. The city's urban population grew at a 2.6% annual rate in the 2000-2015 period and the city holds nearly two thirds of Western Cape Province's total population. The city is expected to grow more slowly in the near future, i.e., at a 1.9% annual rate for the 2015-2030 period, reaching 5,467,695 inhabitants by 2030.

The city has a warm Mediterranean climate with mild winters and dry, warm summers, with an average temperature of 24.2 ºC and a 611.8 mm total annual rainfall. As shown in Figure 29, the most precipitation falls during winter months, from May to October.

Cape Town is flanked by Devil's Peak and Lion's Head, enclosing the city in the so-called City Bowl. This topographic configuration favours temperature inversions during the winter months; this gives rise to pollution episodes, including the brown haze phenomenon (Wicking-Baird et al., 1997). On the other hand, the city's coastal location and "Cape Doctor" summer wind (strong wind from the south-east associated to the South Atlantic High pressure system) help to disperse air pollution.

As for the national context, South Africa is one of the largest economies in the continent. It is considered to be an upper-middle income nation with a GDP per capita of USD 13,730 in 2018, yet with a relatively high poverty ratio (population under the threshold of USD 5.50 a day) of 57.1%. The total national population reached 58,558,267 inhabitants as of 1 July 2019;

Figure 30: Population density (persons/km²) -left- and man-made impervious surface (%) –right- in Cape Town and surroundings

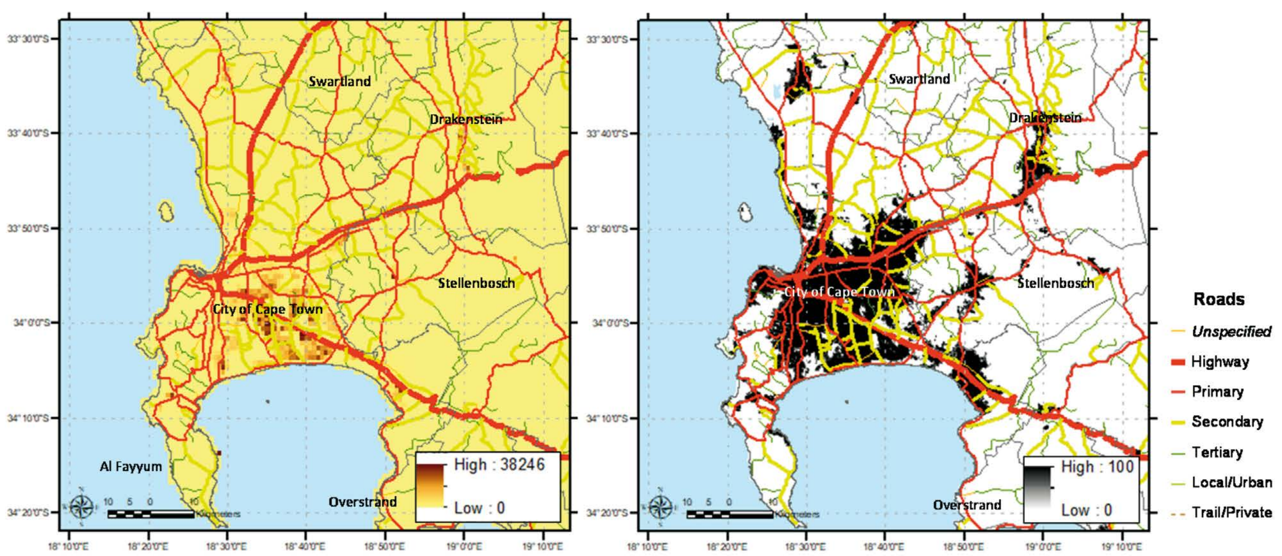
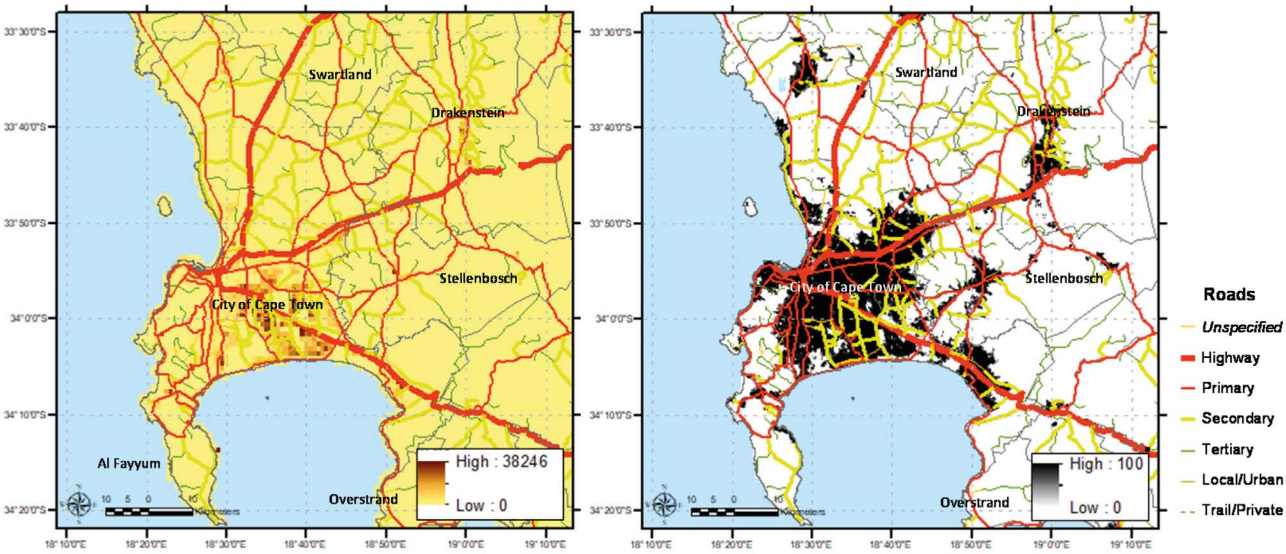


Figure 30: Population density (persons/km^2) -left- and man-made impervious surface (%) –right- in Cape Town and surroundings



this corresponds to an average population density of 48.0 people/km^2. UN projections estimate that 64.3-67.6 million people will live in South Africa by 2030. Currently 84.8% of the total population has access to electricity; this same proportion of the population uses relatively clean fuels and technologies for cooking. A total of 489,772 kt of CO_2 were released in 2014 (8.98 t per capita), distributed as shown in Figure 30.

Current life expectancy at birth in South Africa is 63.6 years; this health indicator is expected to grow to 66.0 years by 2030. At present, the rate of premature deaths attributed to the joint effects of household and ambient air pollution is 8.7 cases per 10,000 population (95% confidence interval, 7.3, 10.3). That implies over 50,000 premature deaths in the country annually, mainly related to lower respiratory infections (32.9%), followed by ischemic heart disease (28.0%).

Figure 31: Monthly average temperature (°C) -left- and monthly average accumulated precipitation (mm), according to Cairo Intl Airport (WMO station 62366; long = 31.414° E, lat= 30.111° N, altitude = 75 m). The 95% confidence intervals are shown

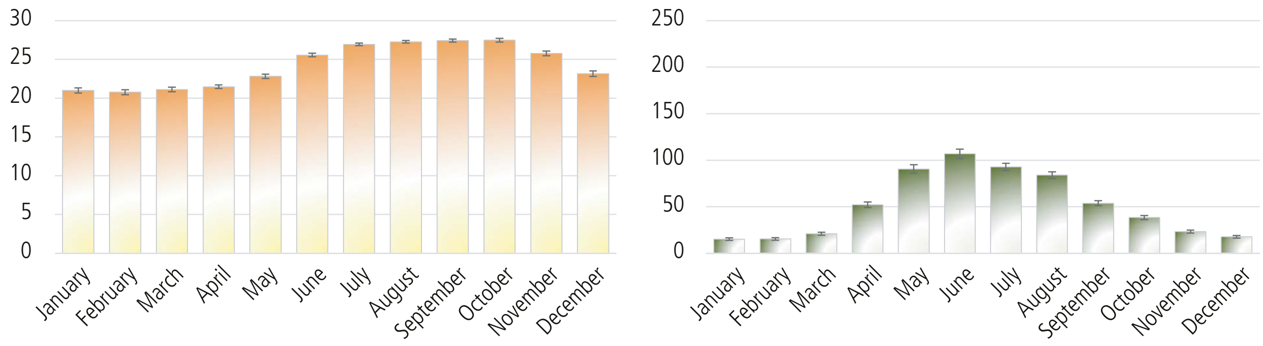
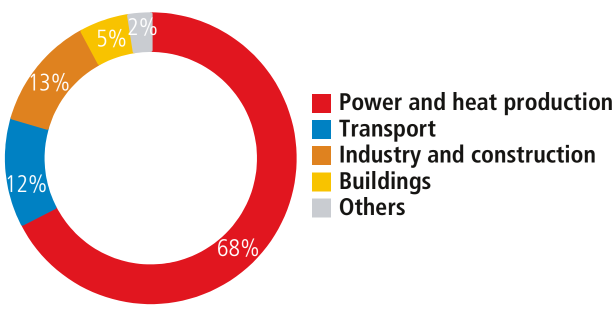


Figure 32: Breakdown of CO_2 emissions in South Africa (489,772 kt in 2014)

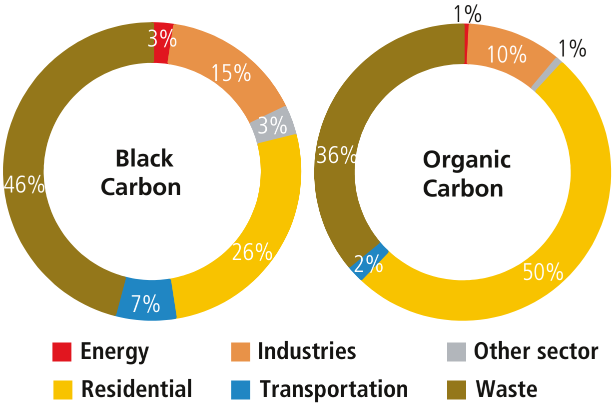


Emissions and air quality in Cape Town today

Air pollution at a glance[22]

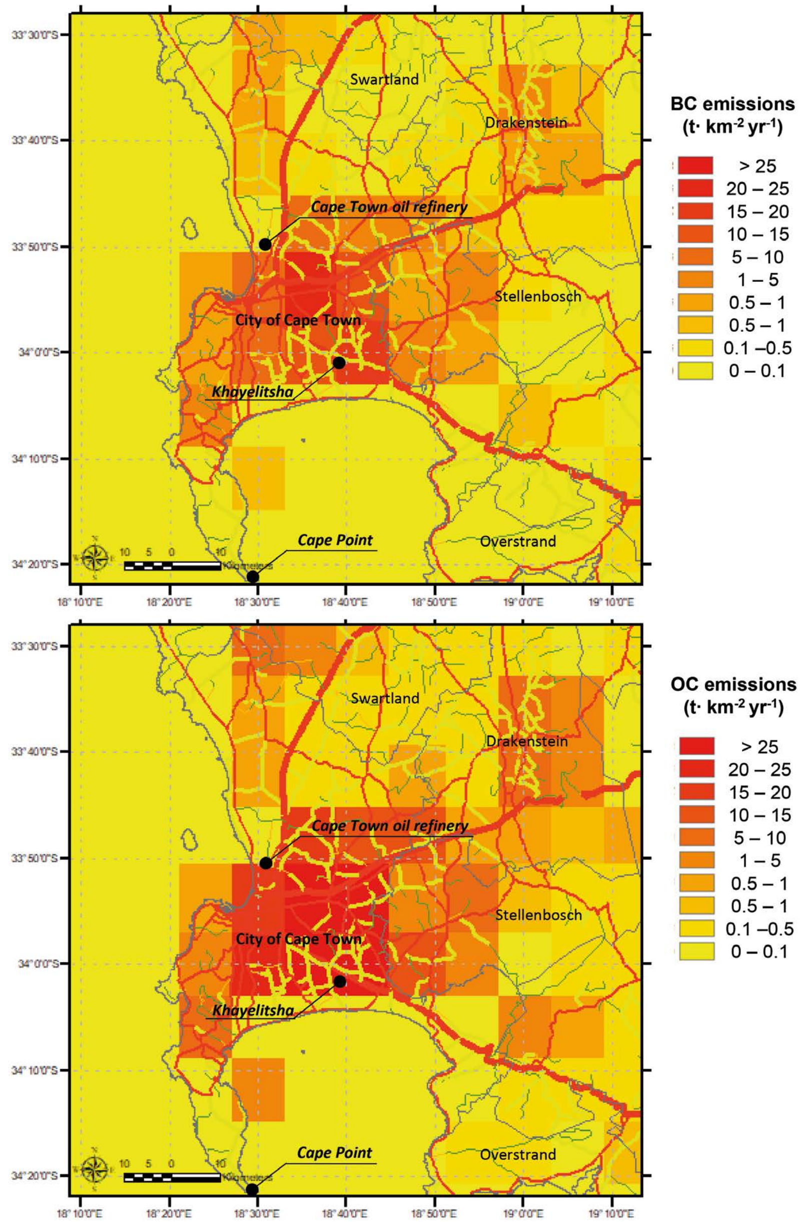
Total emissions of the main components of particulate matter in the Cape Town geographical domain are shown in Figure 31. The residential and waste sectors are mostly responsible for both BC and OC emissions, although there is also a significant contribution from industry in the case of both pollutants. The highest emission rates of both PM fractions are found in the city centre, as shown in Figure 32.

Figure 33: Breakdown of PM emissions in Cape Town



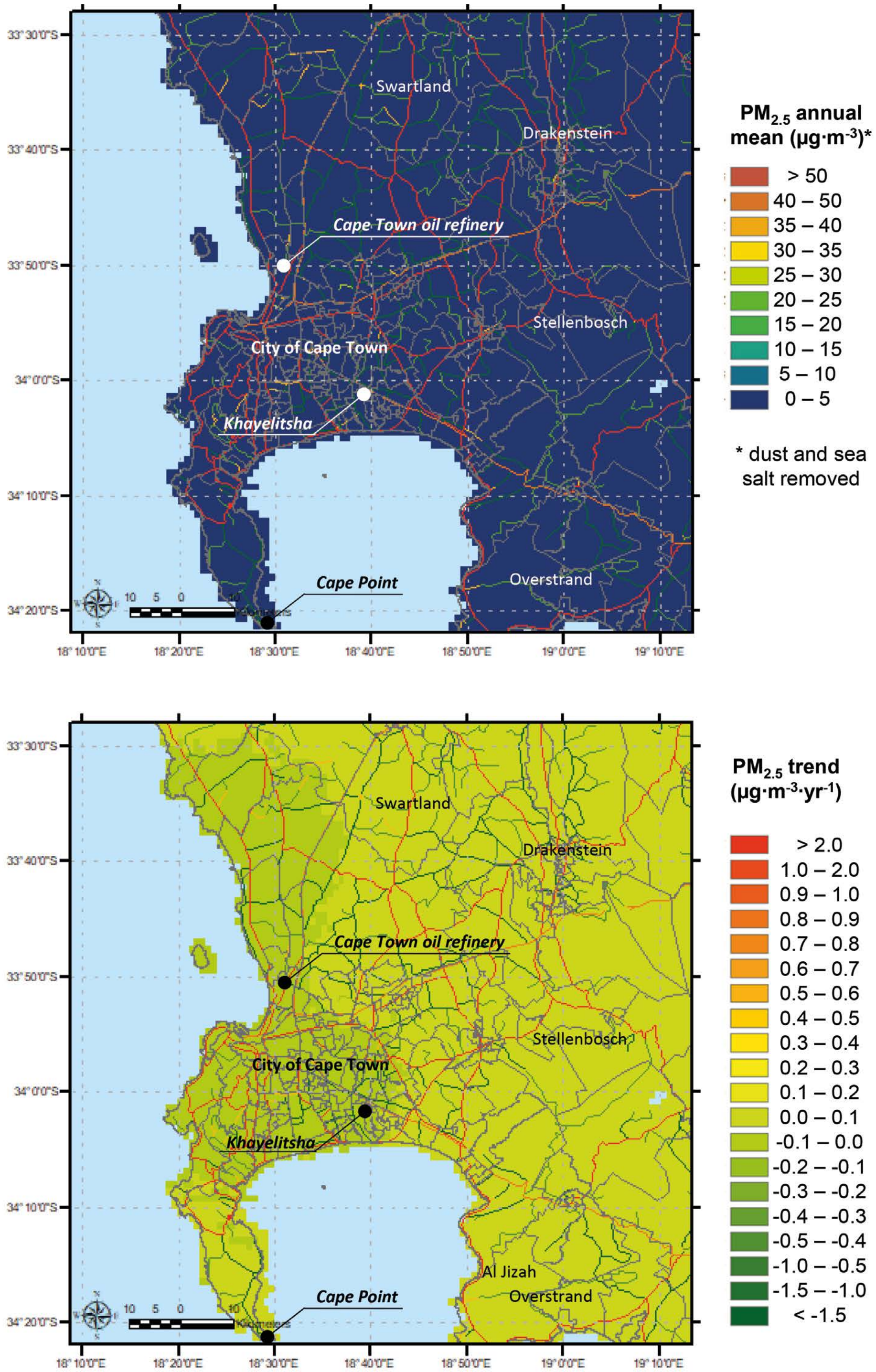
As for air quality; satellite observations (Figure 33). Annual mean of $PM_{2.5}$ ambient concentration (excluding natural sources) (µg/m^3) –top- and recent concentration trend (µg/m^3 per year) –bottom-in Cape Town) show an annual mean of $PM_{2.5}$ (with sea salt and mineral dust removed) close to 5 µg/m^3 in the Cape Town area and 2-3 µg/m^3 in surrounding areas. The average concentration change between 2000 and 2016 in the region according to these observations is not clear, ranging from -0.025 µg/m^3 yr-1 to 0.045 µg/m^3 yr-1; however, see discussion below. Satellite observations suggest that, while air quality worsened in the eastern part of the Cape Town domain (an increment close to 1 µg/m^3 in the 2000-2016 period), $PM_{2.5}$ annual average concentration levels in the city have improved around 0.3 µg/m^3 per year over the last 15 years.

Figure 34: Annual emissions of PM (black carbon –top- and organic carbon –bottom-) in Cape Town (t/km²)



22 For methodology note, see Footnote 1.

Figure 35: Annual mean of $PM_{2.5}$ ambient concentration (excluding natural sources) (μg/m³) –top- and recent concentration trend (μg/m³ per year) –bottom-in Cape Town



A closer look

The City of Cape Town (CCT) installed 14 monitoring stations between 1992 and 2013. The Department of Environmental Affairs and Development Planning (DEA&DP), a branch of the Western Cape Government, set up another three monitoring stations between 2008 and 2014. The network monitors conditions at different type of locations, ranging from general urban background measurements to locations where industrial and traffic emissions require the monitoring of SO_2, NO_2, CO, O_3, PM_{10}, $PM_{2.5}$, H_2S, C_6H_6 and CO_2 along with basic meteorological parameters. All measurements are based on reference analytical techniques in accordance with the US EPA standardized methods (DEA&DP, 2019a). All the information is submitted to the South African Air Quality Information System (SAAQIS) where nearly real-time air quality information can be visualized and downloaded (https://saaqis.environment.gov.za). To facilitate the interpretation of air quality data, SAAQIS produces an aggregated air quality index

(1 to 10) associated to different categories: good, moderate, unhealthy, very unhealthy and hazardous. In addition to this website, the DEA&DP produces an annual report summarizing relevant activities related to air quality monitoring, planning and enforcement (DEA&DP, 2019a).

Historically, SO_2 and PM_{10} have been the air pollutants of concern in South Africa (UNEP, 2016). Exceedances of O_3 have also been reported (DEA&DP, 2019a). Recent data show a general decrease of SO_2 ambient concentration levels, while there is not a clear trend regarding PM_{10}. Currently air quality in the Western Cape Province is generally good, below the South African National Ambient Air Quality Standards (SANS). While NO_2 is expected to increase due to increasing number of vehicles and congestion (DEA, 2012), ambient concentration levels in CCT remain low, with annual means in the range of 12-26 μg/m^3. Regarding O_3, the eight-hour mean SANS for ozone was exceeded on 19 occasions in 2018 at Khayelitsha, with values up to 175 μg/m^3; eight-hour mean levels of this secondary non-linear pollutant in the city centre are lower, between 66 and 97 μg/m^3. Khayelitsha is the largest informal settlement situated south-east of Cape Town (Figure 33), where high PM levels have been usually reported due to residential wood burning, waste burning and dust from unpaved roads, among other sources (DEA&DP, 2016). Despite PM_{10} exceedances in Khayelitsha, the levels have shown a slight decline over the last decade (DEA&DP, 2016), which is consistent with the regional trends derived from satellite observations (Figure 34). Measured annual mean PM_{10} concentration in Cape Town oscillated between 14 and 32 μg/m^3 in 2018. A few, exceptionally high values (up to 387 μg/m^3 in 1 hour) have been linked to wildfires in the surroundings of the city (DEA&DP, 2019a), a phenomenon that exhibits a marked increasing incidence (DEA, 2012). Windblown dust has also been found to be responsible for daily PM_{10} levels up to 82 μg/m^3.

Of note, no PM data from Khayelitsha station were available for the year 2018 due to insufficient measurements. Such information gaps are common throughout the country. Currently, less than 40% of the 94 monitors included in the national network meet the minimum 70% data recovery rate for PM measurements (DEA, 2019). Actually, despite the lack of reporting from certain stations like Khayelitsha, Cape Town is one of only two municipalities in the country with data of sufficient quality per this standard to be included in national statistics. Data below this threshold is available from the network; however, such data should be used with caution. Such deteriorations in data quality relate to ageing infrastructure and insufficient funding (DEA&DP, 2019a); these circumstances seriously jeopardize the quality and ultimate sustainability of the air quality monitoring network in Cape Town. For this reason, the DEA is considering letting provinces take over the running of monitoring network as a way to secure needed budgets and improve network performance (DEA, 2019). Also, to partially address these monitoring deficiencies, the DEA&DP has purchased a portable air sampling laboratory, to be mounted on a drone to fly over six priority areas, including Khayelitsha (DEA&DP, 2019).

In addition to the data recorded by the air quality monitoring network, there are a number of studies that delve into the status and nature of air quality issues in the city, including the following.

Wicking-Baird et al., (1997) developed an emission inventory to support the application of the US EPA Chemical Mass Balance (CMB) model (Watson et al., 1990). Based on monitoring for a one-year period beginning in July 1995, they concluded that visibility issues in the city during brown haze episodes were mainly related to road traffic, responsible for 65% of total $PM_{2.5}$ mass. Other important sources of pollutants were combustion (14%), boilers (six %) and natural PM sources (five %). This situation has not changed significantly according to more recent studies that identified traffic, domestic burning of fuels, industry and waste burning as the major pollution sources in Cape Town (Mbow-Diokhane, 2019; Keen and Altieri, 2016). Measurements of relevant anthropogenic VOCS concentrations in Cape Town suggest that urban background concentrations of these pollutants are dominated by traffic or industrial sources in different areas of the city (Kuyper et al., 2020).

Other studies show that urban air pollution presents important spatial gradients related to a heterogeneous distribution of emission and local scale dispersion processes, coupled with urban development patterns. Based on secondary data sources, Mumm et al. (2017) concluded that low socioeconomic districts generally experienced higher levels of air pollution. Similarly, Hersey et al. (2015) identified low-income townships and informal settlements as the worst polluted areas in South Africa, exceeding even the heavily industrialized areas of the country (Venter et al., 2012). Specifically in Cape Town, Keen and Altieri (2016) claimed that the largest health benefits of improving air quality in the city would be found in the Khayelitsha area (Figure 33). According to that study, meeting the SANS for PM_{10} annual mean would avoid 857 premature deaths per year in the city, with benefits particularly accruing in Khayelitsha. Health effects, however, are not limited to PM. For instance, Everson et al. (2020) suggest that negative health effects related to NO_2 and benzene occur in Cape Town, even though their concentrations are below current air quality standards.

Hersey et al. (2015) identified biomass burning (veld fires) and domestic burning in informal settlements as significant sources of PM_{10}. Using large-scale models based on global inventories, these authors found that dust enhancement was particularly high in May-July; contributions from the nearby Namib Desert may make up to 25% of total PM_{10}. Sea salt represented around 20% of total PM_{10} in Cape Town. Higher-resolution modelling exercises confirm that high PM_{10} episodes in Cape Town are related to air masses travelling over major dust source regions such as the Kalahari or Namib Deserts (Molepo et al., 2019). Recent warmer and dryer weather conditions have been connected to the marked increasing trend of biomass burning pollution due to wildfires (DEA, 2012a). The growing influence of windblown dust on PM_{10} levels in Cape Town has been also linked to increasingly severe droughts in the Western Cape (DEA&DP, 2019a). According to DEA&DP (2019a), climate change is influencing these trends. In addition to negative air quality ramifications, climate change has been identified as a major health threat in South Africa, especially for vulnerable groups (Chersich et al., 2018). Unfortunately, greenhouse gas emissions in the country have raised by 20% in the 2000-2010 period (DEA, 2016) as a result of the coal dependency in one of the most carbon-intensive economies in the world (Klausbruckner et al., 2016). This is clearly reflected in the CO_2 emission breakdown shown in Figure 30.

Jenner and Abiodun (2013) concluded that the highest SO_2 concentrations observed in Cape Town are associated with stagnant conditions that accumulate both local emissions as well as sulphur released by industrial activities in the Mpumalanga Highveld, more than 1000 km away to the northeast. This pattern has also been related to elevated O_3 episodes (Nzotungicimpaye et al., 2014), as well as NO_x and HNO_3 pollution (Abiodun et al., 2014). Mining activities and shale gas exploitations in other parts of the country (Saldanha Bay and Central Karoo) also represent long-range sources of pollution. In addition to such long-range sources, closer-to-home industrial emissions are believed to seriously affect the surrounding population due to poor land use planning (DEA, 2012) and persistent social inequities inherited from the apartheid era (Dugard and Alcaro, 2013). The oil refinery in Cape Town represents one such closer-to-home industrial pollution hotspot (DEA&DP, 2019a). Kuyper et al. (2020) claim that VOCs observed in Cape Point (Figure 32) were emitted in the CCT metropolitan area, suggesting that the city also exports pollution to other parts of the country.

The small number of measurements made in industrial areas of persistent organic pollutants (POPs), suggests that POPs also represent an air pollution concern. Mercury air pollution is largely unknown in South Africa but it has been identified as a potential health threat as well (DEA, 2012). Previous studies have estimated that nearly 80% of Hg emissions in South Africa may be originated from coal-fired power stations (Masekoameng et al., 2010). Nonetheless, both ambient concentration and deposition of Hg species are strongly dependent on meteorological processes (Brunke et al., 2016).

Tackling the issues

Air quality has drawn the attention of policy-makers in South Africa for nearly two decades, making the country a reference point regarding air quality management in sub-Saharan Africa (Schwela, D., 2012). In addition to the national framework (see below), the Provincial Government's 2016 Air Quality Management Plan (DEA&DP, 2016) is the current regional strategy that aims at improving air quality. The main instruments and actions taken in Cape Town in recent years are discussed in the following sections.

Air quality standards, regulations and plans

Overall air quality policy in South Africa is set and managed by the national government. An early, whole-of-society milestone was the establishment, in 1969, of the National Association for Clean Air (NACA), a non-profit organization that brings to bear on the issue the perspectives of a large array of government representatives, academicians and other stakeholders (Mbow-Diokhane, 2019). As for the governmental legal framework, the most important environmental regulatory instrument is the National Environmental Management Act (NEMA) 107 of 1998. (Klausbruckner et al., 2016). The first comprehensive air pollution law is the 2004 National Environmental Management: Air Quality Act 39 of 2004 (AQA), which replaced the Atmospheric Pollution Prevention Act 45 of 1965. National Ambient Air Quality Standards within the AQA, were promulgated in 2009 and further strengthened in 2012 and 2015. Current standards address SO_2, NO_2, PM_{10}, O_3, C_6H_6, Pb, CO and $PM_{2.5}$. In some cases, these standards are as stringent as those applied in other industrialized countries, including Europe (EC, 2008). For instance, the South African National Ambient Air Quality Standards (SANS) set an annual limit value of 20 µg/m^3 and a 24-h maximum concentration of 60 µg/m^3 for $PM_{2.5}$ (DEA, 2012b); these levels are consistent with EU standards even if they are not as stringent as the WHO-recommended values of 10 and 25 µg/m^3, respectively. South Africa argues that its national standards reflect its status as an emerging economy, even while it plans to reduce the $PM_{2.5}$ annual limit to 15 µg/m^3 from January 2030.

Besides SANS, the most important provision derived from the 2004 AQA is the 2007 National Framework for Air Quality management (updated in 2012; Republic of South Africa, 2013). This Framework enables co-operative governance at different administrative levels. According to it, twelve municipalities within the Western Cape Province have promulgated air quality by-laws, including the 2010 City of Cape Town Air Quality Management By-law (Province of West Cape, 2010), updated in 2016 (Province of West Cape, 2016).

The multi-level governance scheme applies to planning as well. DEA developed a National Framework for Air Quality Management in the Republic of South Africa (DEA, 2018) along with a manual for air quality management planning (DEA, 2012c) to support the development of regional or local air quality management plans (AQMP). Regional AQMP are already implemented in most of the regions of the country along with some municipalities, including Cape Town. The first AQMP for the City of Cape Town, launched in 2005, proposed the ambitious target of becoming the city with the best air quality in Africa. The rationale was to reduce deleterious health effects related to air pollution, especially during Brown Haze episodes (CCT, 2005). This plan set up eleven key objectives along with the policy principles for the implementation of the strategy, although it lacked a concrete action plan. The next strategy to specifically target local air quality was the 2010 Air Quality Management Plan in the Western Cape (DEA&DP, 2010), developed in cooperation with the Danish International Donor Agency (DANIDA). A special emphasis was made to engage relevant stakeholders in development of this plan, in sectors such as industry, transport and agriculture. Nonetheless, DEA&DP notes that air quality plans in the region may have focused more on the legislative and administrative spheres, while measures to address the root causes of air pollution were not well developed.

The current Western Cape AQMP (DEA&DP, 2016) updates the strategy for emission reduction in the Western Cape Province and strengthens the links with the response to climate change. While prior to 2016 the City had been active in both spheres (CCT, 2007; CCT, 2011; DEA&DP, 2014), the resulting policies had been largely disconnected and a need for better alignment was clear. This new integrated strategy provides a wide vision of the problem and sets goals and responsibilities. But again the current AQMP has not well defined the specific means to achieve significant emission reductions to improve air quality in Cape Town.

Complementary, more specific plans to address the most pressing local air quality issues have also been formulated, including a strategy to address air pollution in dense low-income settlements (DEA, 2016). Another plan, the provincial SMART-air Programme, aims to gather information, strengthen enabling conditions and enhance communications. This programme (implemented from 2019 onwards) aims to recognize the best emission reduction practices in industry, commerce and communities while raising awareness on air quality and climate change (DEA&DP, 2019a).

Besides specific plans, a series of policies with direct implications for air quality have been promulgated. At the national level, the country development vision is pictured in the South Africa's National Development Plan (NDP) (National Planning Commission, 2013). This strategy aims at achieving social cohesion and development, with the reduction of poverty and inequality by 2030 as a primary target. The interventions called for in the energy, habitation and transport sectors in particular should considerably contribute to improve air quality in Cape Town and other cities. Analogously, the development agenda for the Western Cape Province is drafted in the OneCape 2040 plan (Western Cape Government, 2012). Climate policies (Town Energy and Climate Change Strategy (CCT, 2007), Cape Town's Action Plan for Energy and Climate Change (CCT, 2011) and the Western Cape Climate Change Response Strategy (DEA&DP, 2014)) identify to varying degrees links and co-benefits with air quality. The effective implementation of the AQMP is identified as a priority focus by the current Province Health Plan (DEA&DP, 2019b). The Environmental Strategy for the City of Cape Town (CCT, 2017) also includes long-term health objectives related to air pollution. The local Resilience Strategy recently adopted (City of Cape Town / 100 Resilient Cities, 2019) recognizes the need of a better air quality, and identifies links to other 22 local plans, nine provincial plans and four national plans.

Vehicle emissions

Cape Town has been described as the most congested city in South Africa, with increases in travel time up to 71% in the peak hours relative to free-flowing traffic conditions (TDA, 2017a). According to the City of Cape Town's Transport and Urban Development Authority (TDA), the congestion problem is exacerbated by social disparities. Despite a significant improvement of the economy, a large fraction of the population still lacks decent employment and housing. The poor continue to live in the sprawling city outskirts, with corresponding mobility needs (TDA, 2005).

Car ownership in South Africa is the highest in the southern Africa region, although it remains relatively low in comparison with OECD countries (110 vehicles per 1000 people). Nonetheless, there are one million registered vehicles in Cape Town, and 80% of peak hour traffic is made up of private cars. The growing use of private cars has increased the consumption of fuel, mostly diesel, at a 5.6% annual rate (ICCT, 2017, DEA, 2012a). In addition to increasing CO_2 and PM emissions, the rapidly increasing number of (mostly diesel-burning) vehicles on top of the ageing existing fleet has been associated with exceedances of NO_2 and O_3 ambient concentration levels (DEA, 2012a).

Unlike other African countries, South Africa has a strong domestic vehicle manufacturing industry, and imports of second-hand cars are strictly banned (Mbandi et al., 2019). Imported new vehicles sold in the country are Euro 5 or Euro 6 (ICCT, 2017). The vehicles manufactured in the country are Euro 3 for diesel and mostly Euro 4 for gasoline. Euro 2 (light-duty vehicles) and Euro II (heavy-duty vehicles) emission standards are enforced in South Africa since 2006. It has been argued that the country is ready to shift to more stringent standards (even Euro 6/V), since high quality fuels are already available. Although the sulphur content limit for diesel is 500 ppm (Schwela, D., 2012), actual sulphur content of the diesel sold in South Africa (53% of total automotive fuels) ranges from 50-500 ppm (ICCT, 2017). Moreover, the country has committed to commercialize 10-ppm fuels under the Department of Energy Clean Fuels 2 (CF2) program (by 2017 allegedly). Although SO_2 pollution is no longer a pressing concern in South Africa, this would favour the penetration of newer engine technologies that imply lower PM or NO_x emission factors. As for gasoline, leaded fuel was phased out in 2006 (UNEP, 2016).

In addition to air quality-related pollutants, South Africa introduced a CO_2 emissions tax on new passenger cars in 2010 (DEA, 2012a). Currently the CO_2 tax and the fuel efficiency labelling scheme apply to all new vehicles (UNEP, 2016). This measure has raised concerns regarding its impact on the automobile industry's competitiveness and potential issues of fairness since it does not target existing vehicles in the country (DEA, 2012a); however, counterarguments can also be advanced.

Controlling vehicle emissions was one of the key objectives of Cape Town's first AQMP (CCT, 2005). A vehicle inspection scheme and testing procedure was implemented at the provincial level (DEA&DP, 2010). According to the provisions of the corresponding city by-law, Cape Town set up an Air Quality Management Unit with three Diesel Vehicle Emissions Testing Teams for roadside inspection at fixed locations. They conducted more than 700 vehicle tests in 2015, with a failure rate below one per cent (DEA&DP, 2016). A positive downward trend was confirmed by the figures available for the year 2018, where virtually none of the 8,494 vehicles inspected failed the test (DEA&DP, 2019). Currently, the test is limited to dark smoke (Province of West Cape, 2010), a proxy for PM emissions.

Public and non-motorized transport

One of the reasons behind the increasing dependency on private mobility is the low reliability and practical availability of public transport alternatives (Venter et al., 2012). Currently 53% of total mobility on a typical working day in Cape Town relies on private transport, 38% is supported by public transport modes (18% rail, six per cent by contracted bus, two per cent by Bus Rapid Transit, (MyCiTi), and twelve per cent by minibus-taxi; the remaining nine per cent is related to non-motorised transport (NMT) (TDA, 2018). Modal choice is strongly conditioned by socio-economic status. Public transport is the main mobility alternative (71%) for low-income commuters, contrasting with the eleven per cent share for the high-income commuters who massively rely on private transport (88%) (TDA, 2017a). Of note, 82% of total trips are associated with low or low-medium income groups that, as noted above, are forced to commute from the outskirts of the city.

The need for an affordable, reliable and safe public transportation system in Cape Town has been reflected in all air quality strategies developed since the 2005 AQMP (CCT, 2005). However, the main improvements to reduce the vast inequalities and social unsustainability of the transport sector have naturally been associated with sectoral transport plans (DEA, 2012a). They include the roll-out of Bus Rapid Transit (BRT) systems not only in Cape Town but also in other major cities of South Africa, and the national taxi recapitalization programme. The City of Cape Town recently formed an integrated Transport and Urban Development Authority (TDA), to pursue a multi-mode, multi-sector, integrated approach to transport and urban planning. TDA then developed an Integrated Public Transport Network Plan (IPTN) with a 2032 time horizon (TDA, 2014), to deal with a deteriorated public service and the harmonization of transport and land use in Cape Town. The strategic analysis of alternative solutions explicitly took into account air pollution as an evaluation criterion.

The Cape Town's Comprehensive Integrated Transport Plan (CITP) (2018-2023) (TDA, 2018) builds on the main elements of the IPTN, and defines a variety of actions that are expected to confer air quality benefits. Among them, it considers the upgrade of the MyCiti system, the City's flagship public transport project introduced in 2010. There are now 32 km of dedicated road bus lanes, being used by a fleet complying with Euro 4 emission standards, including eleven electric buses added to the fleet in 2017. For the City, this represents an initial step towards meeting its commitment under the C40 network's Clean Bus Declaration to achieve a 100% electric bus fleet by 2025. The CITP also states the need to invest in infrastructures, including new roads for informal settlements, maintenance and congestion relief projects, as well as new facilities to improve public transport (multi-modal connexions and systems management). The Travel Demand Management (TDM) strategy (TDA, 2017a) is an essential component of the CITP that seeks to provide the enabling conditions for a change in individuals' travel behaviour, mainly to switch from single-occupancy vehicles to more sustainable transport modes.

The city has also promoted various non-motorized transport (NMT) projects to encourage clean and healthy mobility, including the 2005 NMT strategy (TDA, 2005). This is a very relevant issue from the public health perspective since the NMT environment in Cape Town is characterized by poor environment quality and unsafe conditions; these circumstances lead to high exposure to road traffic pollutants and a risk of accidents. Inadequate provision of NMT facilities makes this mode inefficient and dangerous (Baufeldt and Vanderschuren, 2017). Approximately 40% of pedestrian fatalities recorded in South Africa can be said to be related to a non-prioritization of NMT (Mokitimi and Vanderschuren, 2017). The city's Road Safety Strategy (TDA, 2013) should help to significantly reduce pedestrian and cyclist casualties (414 and nine, respectively in Cape Town in 2013). Cape Town's Cycling Strategy (TDA, 2017b) seeks to raise cycling mode share to eight per cent by 2030 from the current one per cent by improving safety and security around a proper cycling infrastructure.

Industrial emissions

South Africa has the largest industrialised economy in sub-Saharan Africa, with significant mining and metallurgical activities (Venter et al., 2012). South Africa is the world's largest producer of platinum, gold and chromium. Automobile manufacturing, metalworking, machinery, iron and steel and chemical are other relevant industrial activities in the country, which collectively represent 29% of GDP. Industrial emissions have been consistently reported as one of the leading causes of pollution in the country (DEA, 2012a) and are projected to increase in the coming years (UNEP, 2016). The growth of energy intensive industries was possible due to the low energy prices in South Africa (Klausbruckner et al., 2016). Ninety-one per cent (91%) of electricity is produced from fossil fuels (UNEP, 2016), mainly in coal-fired power plants. These plants help make South Africa the largest CO_2 emitter in Africa, (in absolute terms) with emissions per-capita that are four-fold and 30-fold those of Egypt or Kenya, respectively.

Industrial emissions in South Africa are regulated through the 2004 Air Quality Act (AQA) that provides for the Minimum Emission Standards (MES) for designated (listed) industrial activities including power plants, petroleum refineries, and metallurgical industry among others. MES were introduced in 2010 and amended in 2013 with an increasingly restrictive schedule for progressive enforcement until 2020 (Republic of South Africa, 2013). Emissions from small industrial activities remain unregulated (UNEP, 2016).

The MES for coal-fired electricity plants are under discussion since EKSOM (national energy company) and the SASOL chemical company have applied for a postponement of their implementation (Klausbruckner et al., 2016). These industries question the achievability of the MES through retrofitting and propose to offset emissions by alternative actions with equivalent air quality improvements, an option contemplated by the 2014 Draft Air Quality Offset Policy (DEA, 2014). The FRIDGE (Fund For Research into Industrial Development Growth and Equity) study suggests that electrification may be preferable (from a financial and economic perspective) over retrofitting measures (Scorgie et al., 2004).

In 2010, Provinces and Municipalities became Licensing Authorities for AQA Section 21 Listed Activities. The DEA&DP compiled a catalogue of industrial sources in the Western Cape Province, comprising 2166 sources (DEA&DP, 2010). A total of 47 Atmospheric Emission Licences (AEL), some of them provisional, were issued in Cape Town City between 2010 and 2015 (DEA&DP, 2016).

Since 2013, the DEA&DP and the CCT have conducted regular inspections. In 2017, most of the listed activities in the metropolitan area were audited and seven facilities were issued with notices of non-compliance. This compels industries to implement emission abatement measures and demonstrate compliance with the pollution limits stipulated in their license to avoid fines up to ZAR five million. This scheme seems to be acting as an adequate deterrence since the City has not prosecuted any listed activity since 2010, although other explanations are also possible.

The National Energy Act 2008 (amended in 2012) promotes renewable energy production while supporting economic growth and poverty alleviation (Klausbruckner et al., 2016). The Integrated Energy Plan (Department of Energy, DoE) establishes a 15% final energy demand reduction target for power generation, industry and mining sectors through an incentive scheme (DEA, 2012a). Other relevant initiatives are the Industrial Action Plan (IPAP2) and the Renewable Energy Independent Power Producer Procurement Programme (REIPPP) (UNEP, 2016). To date, REIPPP has mobilized ZAR 65.7 billion for 92 renewal energy projects, of which 43 are already connected to the grid (DTI, 2016).

Open burning of waste

Open burning of waste in South Africa is mostly related to agricultural waste (UNEP, 2016). For instance, 90% of sugarcane crop residues are burnt (DEA, 2012a). Open burning issues in Cape Town, however, are mostly associated with black smoke emissions from used tyres (DEA, 2012a). In South Africa, more than 28 million tyres per year are dumped illegally or burnt to recover steel wires. Tyre burning take place mostly in low-income residential areas, worsening the already deteriorated air quality due to solid fuels used for cooking (DEA&DP, 2010). Fires from informal meat trading also help to pollute informal settlements (DEA&DP, 2016).

Dark smoke emissions from dwellings are prohibited by the AQM by-law in Cape Town (Province of West Cape, 2016). Emissions caused by tyre burning and other material for the recovery of metal are specifically banned (Province of West Cape, 2010), and individuals in violation of these regulations may be fined and even imprisoned. The National Environmental Management: Waste Act (No 59 of 2008 – NEM:WA) promotes the safe reuse, materials and energy recovery and safe disposal of tyres. Concerted implementation of its provisions would reduce toxic emission and harmful exposure resulting from indiscriminate burning of used tyres (DEA, 2012a).

Indoor air quality

Indoor air quality issues have been consistently linked to domestic fuel burning and poor ventilation conditions (UNEP, 2016). The burning of wood and paraffin for cooking and lighting, respectively, is a common practice in low income and informal settlements. According to Arku et al. (2018), 36.1% of households in Cape Town rely on solid fuels for cooking. This figure is lower than the national average (46.1%), due to the lack of access to electricity in rural areas. Reliance on dirty fuels in urban areas is due at least in part to unaffordable electricity prices for poor urban dwellers (DEA, 2012a). Although the use of paraffin declined by 7.2% between 2002 and 2010, the poorest households still use dirty fuels (DEA, 2012a). As informal settlements are usually densely populated, this implies high exposure levels and a major health risk (Altieri and Keen, 2019). A study in an informal settlement in the central Gauteng Province found that indoor PM levels constantly exceeded ambient air standards, by a factor of seven in winter (Language et al., 2016). Although health impacts associated to poor indoor air quality are declining in South Africa since 2005 (see Figure 6 in Chapter 2), the research of Scorgie (2012) concluded that poor indoor air quality was responsible for 68% of the total health costs related to air pollution in the country.

Local outdoor emission sources also contribute to high indoor pollution levels in low-income areas. The Khayelitsha Air Pollution Strategy (KAPS) identified the most cost-effective options for reducing air pollution in this settlement (Muchapondwa, 2010). Consequently, the city has adopted local measures such as the greening of open spaces and parks, the hardening of unpaved surfaces to reduce windblown dust, and improving waste management collection services; their expected benefits should include improved air quality, including indoors. Distant emissions from forest and savannah fires have also a direct impact on both ambient and indoor air quality (UNEP, 2016). In part to improve indoor air quality, the City is subsidizing the retrofitting of houses that were built without ceilings. As of 2019, around 8,000 houses had been retrofitted in Cape Town. On a broader scope, the draft strategy to address air pollution in dense low-income settlements (DEA, 2016) is expected to have a strong impact on indoor air quality. This plan considers the establishment of a National Coordinating Committee (NCC) to procure the actual implementation of interventions and subsidies for clean fuels as well as a continuous monitoring of the efficiency of such measures. Other responses at the national level to reduce indoor air pollution levels are the campaign to promote the Basa njengo Magogo (BnM) stove fire-lighting method (DEA, 2012a), the Low-Smoke Fuel Programme, the Integrated Household Clean Energy Strategy (ICHES), and the National Liquefied Petroleum Gas Strategy (Klausbruckner et al., 2016).

Conclusions and recommendations

South Africa provides an interesting example of multi-level governance for air quality action, whereby the policy and regulatory framework is established at the national level and enforcement, compliance and other measures are implemented by regional and local governments. In addition to the challenges of changes in policy from one administrative to another, Cape Town faces the problem of persistent poverty and social inequity that shapes its physical reality and yields an unbalanced burden of air pollution-related disease. Even in a city of relative prosperity, mobilizing the resources for all planned interventions is an ongoing challenge. Other challenges include a lack of political will, limited consultation and communication, and shortcomings in the planning process (Naiker et al., 2012). Some conclusions and suggestions in the framework of the six key guidance framework areas of Air Quality Management Planning (AQMP) can be summarized as follows:

1. Air quality standards and monitoring

Cape Town has one of the best urban air quality monitoring networks on the African continent. However, the performance of this infrastructure has been severely hampered by a lack of proper maintenance over the past few years. In addition to operational shortcomings, a deficit of $PM_{2.5}$ and PM_{10} monitoring exists, especially in low-income areas. Poor ambient air quality conditions reported for Khayelitsha are likely to be mirrored in other informal settlements where air quality monitoring stations do not exist.

Recommendation: Revise the number and location of air quality monitors for different pollutants in Cape Town's monitoring network to allow a better diagnosis and monitoring of progress related to a number of pollution hotspots and the impact of ongoing initiatives.

Recommendation: Secure the necessary funds to upgrade monitoring equipment and improve the reliability and representativeness of the observations in the future.

South Africa has a comprehensive and rather stringent set of national air quality standards (SANS) that provide complete and generally sufficiently restrictive regulation in that area. The government is considering tightening $PM_{2.5}$ standards in the future.

Recommendation: Improve the enforcement of current SANS, especially in pollution hotspots, usually related to poor neighbourhoods, even while considering the further tightening of standards.

2. Emission inventories and modelling

Although this has been identified as a priority since the 2005 AQMP (CCT, 2005), current official inventories are limited to fuel burning equipment (DEA&DP, 2010) originated in the FRIDGE study (Scorgie et al., 2004). The need to compile a comprehensive emission inventory including all diffuse sectors has been recognized also by the regional government (DEA&DP, 2016). Road traffic and biogenic emissions are particularly relevant from a modelling perspective (Zunckel et al., 2004). Despite some relevant studies, such as the Dynamic Air Pollution Prediction System (DAPPS) (Sowden et al., 2008), modelling activities have been hindered by the lack of reliable emission estimates. Models are key for strategic planning; they can, for example, support cost–benefit-based analysis of policies, including regarding the timing of implementation. The City of Cape Town has acquired some modelling tools and capabilities as a part of the implementation of the Khayelitsha Air Pollution Strategy (KAPS). Nonetheless, more sophisticated modelling systems are needed to deal with emerging air quality issues such as long-range transport or tropospheric ozone (Tshehla and Wright, 2019).

Recommendation: Compile a comprehensive emission inventory for Cape Town. This should build on information generated and gathered in previous projects and monitoring activities, including sectoral inventories such as that for combustion energy sources, data related to industrial licensing activities and the transport demand model developed earlier.

Recommendation: Improve planning capabilities by implementing advanced 3D photochemical models in collaboration with local universities and technological companies. Such collaborations would foster capacity building and contribute to the development and update of a proper emission inventory covering both anthropogenic and natural sources.

3. Health and other impacts

The few studies available confirm the remarkable health benefits that would accrue from improved air quality in low-income areas throughout the Western Cape. These findings underscore the critical need of pro-poor public health interventions, in addition to the compelling urgency to improve general living conditions of the poorest communities that cannot afford electricity. From a wider perspective, the promotion of climate change mitigation and adaptation measures is crucial from a public health perspective, especially when poor air quality intersects with weather risks, communicable diseases and food security issues (Chersich et al., 2018).

Non-motorized transport (NMT) can contribute both to cut down emissions and promote good health. While NMT facilities have had significant impacts on improving the levels of safety of both pedestrians and cyclists, a large margin for improvement still exists.

Recommendation: In future plans, provide for improvements to indoor and outdoor air quality in low-income settlements. Prioritize measures related to the replacement of wood and paraffin as domestic fuels, fires from informal meat trading, refuse burning and dust from unpaved roads. Draw clear links between such measures and climate and pro-equity policies.

Recommendation: Increase awareness of NMT modes to promote healthy mobility. Secure funds for safe pedestrian and cycling infrastructures in the City.

4. Communication

The South African Air Quality Information System (SAAQIS) can be considered as a good example regarding the public dissemination of air pollution information. Of note, Cape Town was the only city among the five in this study that offered sufficient air quality data to support the analysis of the impact of recent restrictions related to COVID-19 on air quality in this report (see Chapter 3). At a different level, the role of the National Association for Clean Air (NACA) is also noteworthy. Among other activities, NACA publishes The Clean Air Journal, a publication that focuses on air quality management and the impacts of air pollution in Africa. This is deemed a very interesting initiative to build technical capacity and to foster collaboration towards better air quality on the continent. However, more and better information about air pollution is still needed. The low level of community awareness and lack of understanding of the benefits associated to emission abatement options have been consistently reported as a fundamental short-coming (DEA&DP, 2010; DEA&DP, 2016).

Most of the many projects recently developed or currently ongoing in South Africa pay attention to education and communication strategies. However, ill-defined measures or insufficient funding have failed to sufficiently sensitize citizens to the impacts of air pollution on their life. The continuation of existing educational campaigns is not guaranteed due to funding challenges. The lack of political will has been also identified as a key factor to explain the lack of progress (Naiker et al., 2012). The recent SMART-air Programme (DEA&DP, 2019a) may considerably help raising awareness among key target groups including, policy makers, industry and the public.

Recommendation: Follow up on and strengthen existing communication and dissemination programmes so as to increase public awareness and political will. Such initiatives strengthen fundamental drivers towards cleaner air.

Recommendation: Increase transparency regarding emission permits and emission inventories to help raise awareness and provide useful inputs for additional studies and analyses.

5. Clean Air Action Plans

Cape Town and the Western Cape Province have launched a considerable number of regulations and plans, including three air quality plans, three climate strategies and many other instruments with evident links to air quality in the last two decades. However, air pollution trends in Cape Town are not keeping up with regulation and planning.

Despite (at least until very recently) fragmented planning, evidenced by the lack of integration of transport and air quality plans (DEA&DP, 2010) and insufficient funds, the reasons for limited progress can be found in the lack of well-formulated measures in the majority of these strategies. While previous AQMP have presented a clear diagnosis and an elaborate conceptual framework and organizational structure, they have failed to specify quantifiable, concrete actions. The Khayelitsha Air Pollution Strategy (KAPS) constitutes a good example of the opposite. Based on the cost-effectiveness analysis of PM_{10} abatement measures (Muchapondwa, 2010), KAPS ranked a number of interventions that could simultaneously improve air quality and provide for sustainable livelihoods for the poorest households, and then fleshed out the most promising measures.

Combustion of coal for power generation has been linked to a wide number of atmospheric issues, from rapidly increasing CO_2 emissions to Hg pollution. Long-range pollution has also been pointed out as a cause for air quality deterioration in Cape Town, with strong implications regarding the limited potential for air quality improvement offered by exclusively local strategies on their own (DEA, 2012).

Recommendation: Consider the measures proposed in KAPS i.e., the priority lines of action for further interventions, as a first step to alleviate air pollution and health issues in Cape Town.

Recommendation: Reinforce the provision of a sustainable, integrated and socially just public transport service. The steps given with the MyCiti bus system aim in the right direction, but bolder action is needed to keep up with the steep rise of mobility and vehicle sales.

Recommendation: Include other relevant pollutants (e.g., NO_X) in vehicle emission tests, and consider tightening current emission standards. The introduction of dedicated inspection fees may help to more sustainably support inspection and maintenance programmes, including the necessary administrative structures and capacity building.

Recommendation: Reduce the dependency of the power generation sector on coal by the promotion of renewable energy sources as a key element to improve air quality both in Cape Town and South Africa as a whole.

6. Governance

Despite significant efforts to develop a comprehensive multi-level regulatory scheme and decentralize the administration in South Africa, cities are struggling to implement effective measures. Some air quality improvements have been made but they still lag behind the strategic goals set by the NEMA more than 15 years ago (Tshehla and Wright, 2019). It has been suggested that previous plans did not address the problems surrounding poverty (Language et al., 2016), the underlying causes of environmental deterioration, and the structural reasons why low-income communities are more vulnerable to air pollution (DEA, 2012a). Consequently, it has been argued that air quality issues can only be overcome through the socio-economic upliftment of low-income groups (Venter et al., 2012). That is to say, the twin goals of poverty alleviation and public health converge (Klausbruckner et al., 2016). Cross-cutting development strategies such as the South Africa's National Development Plan (NDP), the OneCape 2040 and the local resilience strategy (City of Cape Town / 100 Resilient Cities, 2019) focus on improving social and economic conditions; therefore, at the same time they are expected to provide the enabling conditions to improve air quality and environmental justice.

Nonetheless, such visions should be complemented with more effective tools to manage air quality specifically. Entities such as the Local Government Medium-Term Expenditure Commission (LGMTEC) supported by donor agencies are expected to help secure funds for municipal air quality management (DEA&DP, 2016). This is a key issue since the lack of funding and insufficient personnel are one of the main reasons why air quality is not more effectively addressed at the municipal level. Inadequate financial provisions to deal with air pollution may be linked to insufficient political commitment and acceptance by local authorities (DEA&DP, 2010). In addition to economic challenges, the decentralization of the administration may have resulted in at-times too complex management and legislative structures. The lack of understanding of roles and responsibilities between regional and local administrations hinders the implementation of air quality management functions (DEA&DP, 2019). The multi-level coordination with other thematic strategies such as climate policies, mostly driven at the national scale, is of the utmost importance. The current legal framework deters a harmonized roll out of air quality and climate change policies that have evident potential synergies, e.g., the reduction of the coal dependency previously discussed.

Recommendation: Accept the institutional framework for reducing persistent poverty and social inequity as the relevant enabling framework for the development of air quality and climate change strategies.

Recommendation: Consolidate specific financial mechanisms to sustainably procure funds for an efficient and coordinated multi-level air quality governance, with an emphasis on the enforcement of current legislation.

Recommendation: Create a centralized emissions and air quality department or other responsible body in Cape Town; this may facilitate the allocation of responsibilities and an effective allocation of resources. The recent creation of the integrated Transport and Urban Development Authority (TDA) may be considered as an illustrative example of the sort of institutional development that is required.

Recommendation: Develop multi-level coordination mechanisms to guarantee the coherence of air quality and climate change policies in South Africa. Promote international collaboration to exploit synergies and to deal with transboundary pollution issues.

Dakar, SENEGAL

A case study on managing the air quality impacts of transport growth

Highlights

- Despite the current limitations of its air quality monitoring system, Dakar transparently communicates its levels of air pollution to the public and policymakers – an important element of any such system.
- Particulate Matter pollution is the main concern in Dakar. This problem is seriously aggravated by wind-borne Saharan dust during the dry season.
- Road transport appears to be a major contributor to air pollution. The national development strategy known as the Emerging Senegal Plan calls for large-scale engineering projects to address increased travel demand. However, such measures cannot keep up with this increased traffic, and may contribute to corresponding increases in emissions.
- Current sectoral plans and measures intended to curb greenhouse gases offer good co-benefit prospects for air quality. Such measures should be better integrated into national and urban scale clean air strategies.
- Dakar could develop stronger and more comprehensive local policies to strengthen its air quality response. It could implement those in part by engaging the private sector and implementing smaller-scale demonstration projects.
- In recent years, Senegal has improved governance at all administrative levels, and has mobilized international assistance to improve living conditions. Nonetheless, a holistic set of measures including further building public awareness and further engaging a range of stakeholders to tackle air quality is called for.

Introduction and background

Dakar, the capital of Senegal, is home to 2,758,161 inhabitants, nearly a fifth of Senegal's entire population, and hosts about 70% of Senegal's industries (UNEP, 2016). Population has increased at a 2.6% annual rate in the 2000-2015 period due to Dakar's employment opportunities. Most of the population is concentrated in the relatively small Cap Vert peninsula (Figure 34). The rapid urbanization of the Dakar region translates into the unplanned occupation of the space and the proliferation of informal settlements, which represent about 30% of the city area. The population is expected to grow even faster in the near future (3.0% annual rate for the 2015-2030 period) due to further industrial growth, reaching 4,338,834 inhabitants by 2030.

Dakar, the westmost city in continental Africa, is surrounded by the Atlantic Ocean. This feature moderates temperature (annual average of 16.5 ºC), since the city benefits from a cool sea breeze all year round. Nonetheless, very hot and dry winds from the Sahara Desert (Harmattan) are also common. The climate of Dakar is semi-arid, with a marked rainy season, from July to October (Figure 35), where virtually all of the 511.3 mm average annual precipitation accumulates. The change of seasons is controlled by the annual oscillation of the Intertropical Convergence Zone (ITCZ). A quasi-permanent thermal inversion favours air stagnation during the dry season (Sarr et al., 2018), which is also the period with the highest frequency of Saharan dust outbreaks.

As for the national context, Senegal is classified as a Least Developed Country by the United Nations. It has a GDP per capita of USD 3,776 in 2018 and a poverty ratio (population under the threshold of USD 5.50 a day) of 88.1%. Total national population reached 16,296,362 inhabitants as of 1 July 2019; that corresponds to an average population density of 82.8 people/km^2. The UN projects that 21.1-22.0 million people will live in Senegal by 2030. Currently 61.7% of total population has access to electricity, while the share of people with access to clean fuels and technologies for cooking is 31.7%. A total of 8,856 kt of CO_2 were released in 2014 (0.62 t per capita), distributed as shown in Figure 36. Emissions from traffic represent the largest share; these largely come from urban areas.

Current life expectancy at birth in Senegal is 67.5 years; this average is expected to grow to up to 70.1 years by 2030. At present, the mortality rate attributed to the joint effects of household and ambient air pollution is 16.1 cases by 10,000 population (95% confidence interval 13.9, 18.3). That implies around 22,600 premature deaths in the country annually, mainly related to lower respiratory infections (35.5%) and ischemic heart disease (34.9%).

Emissions and air quality in Dakar today

Air pollution at a glance

Total emissions of the main components of particulate matter in the Dakar geographical domain are shown in Figure 37. OC emissions are dominated by the residential sector and are mostly related to household burning of wood and charcoal. Although this source also significantly contributes to black carbon (BC) emissions, most BC emissions originate in open waste burning. While emissions of both PM fractions peak in the city centre, OC emissions related to the household sector have significant emissions in the surroundings as well (Figure 38).

Figure 36: Population density (persons/km²) -left- and man-made impervious surface (%) –right- in Dakar and surroundings

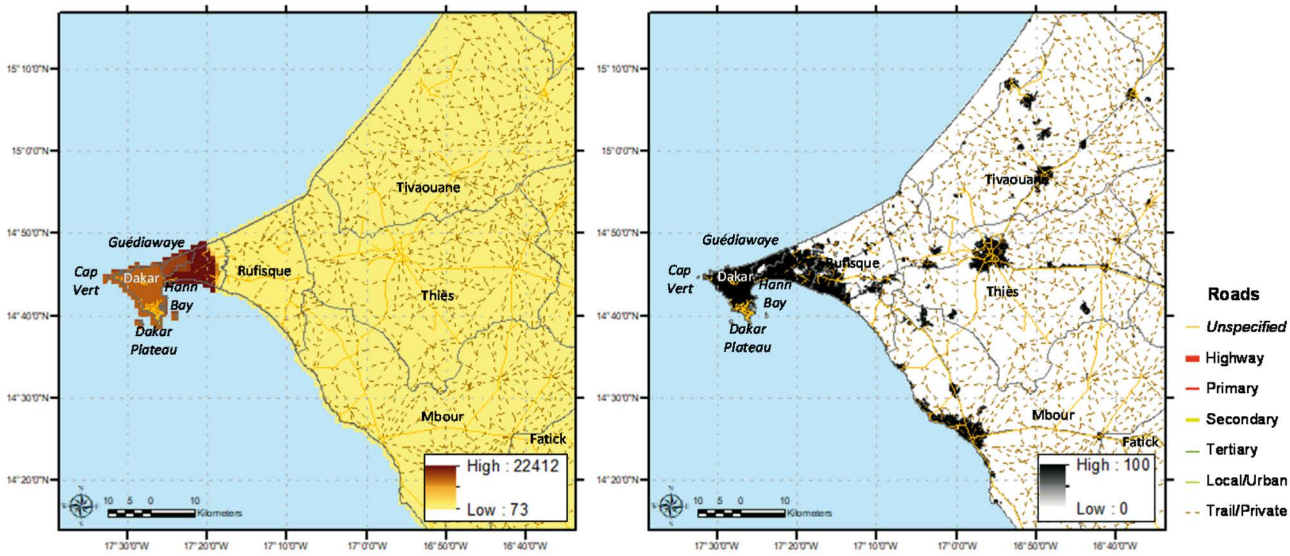


Figure 37: Monthly average temperature (°C) -left- and monthly average accumulated precipitation (mm), according to Dakar/Yoff meteorological station (WMO station 61641; long = 17.490° W, lat = 14.740° N, altitude = 24 m). The 95% confidence intervals are shown

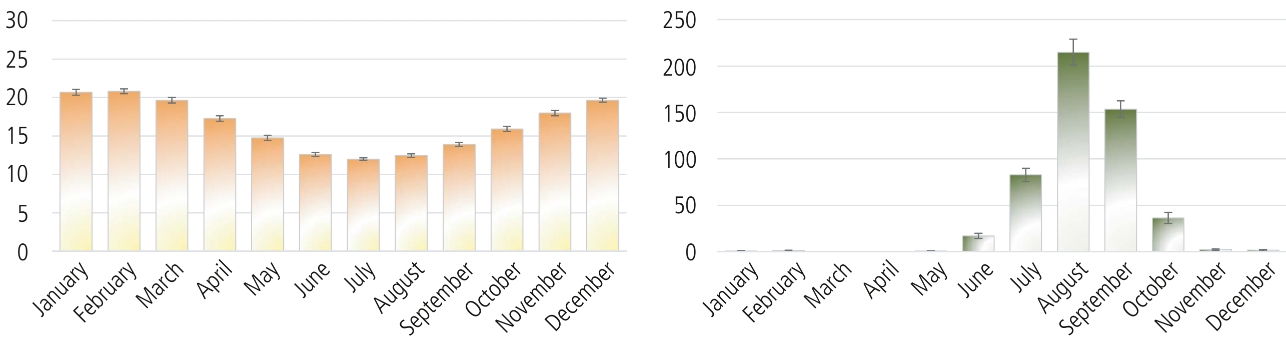


Figure 38: Breakdown of CO_2 emissions in Senegal (8,856 kt in 2014)

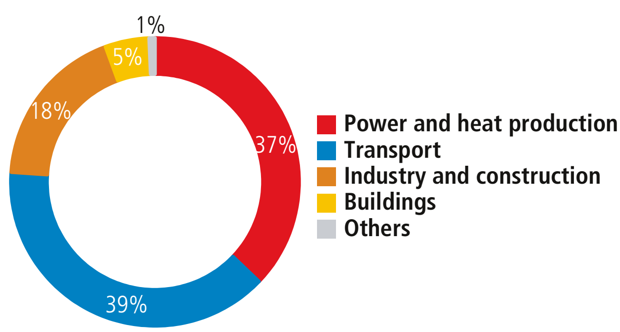
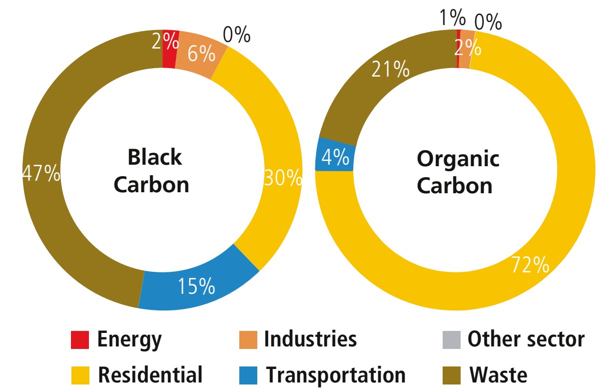
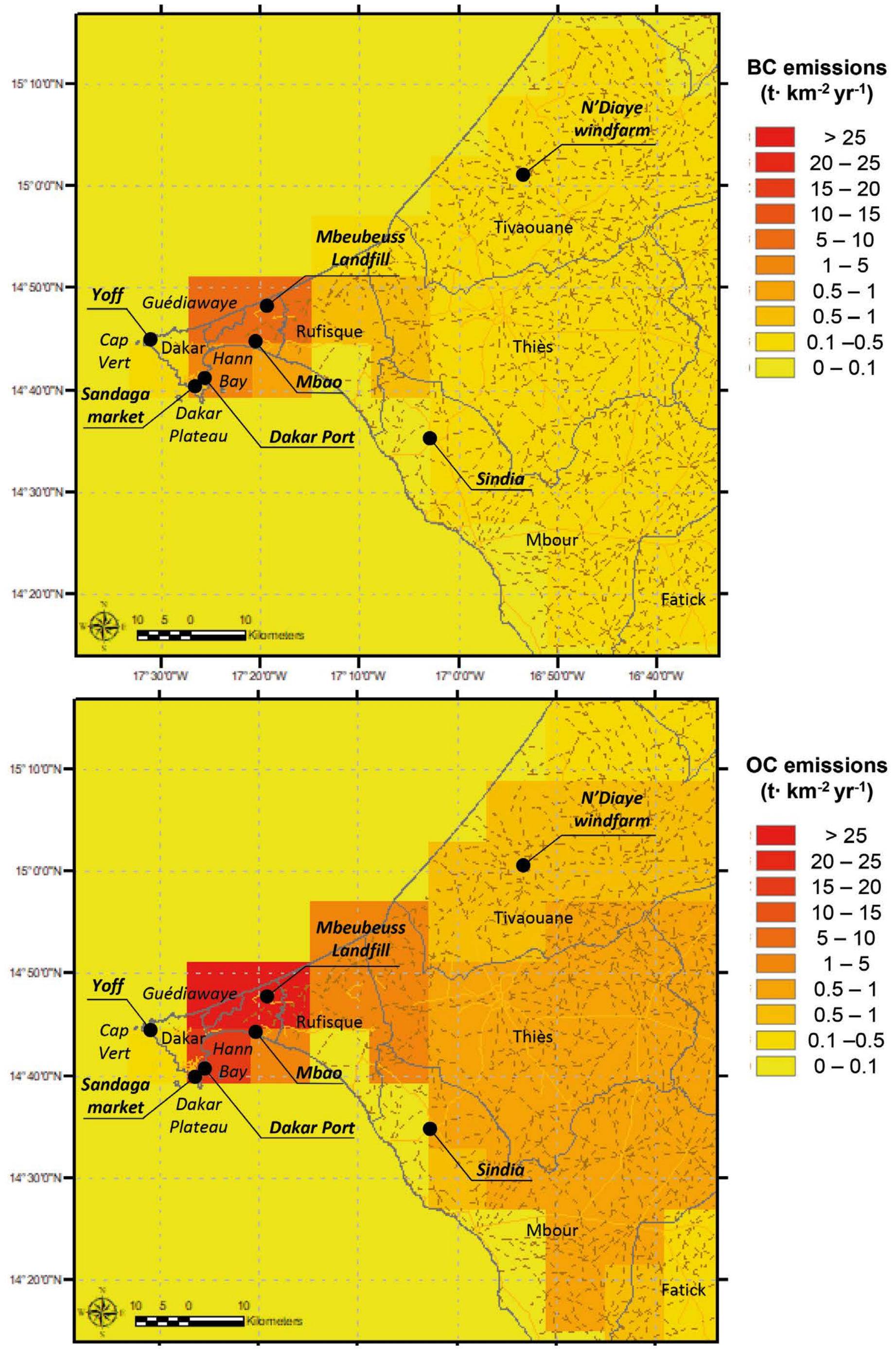


Figure 39: Breakdown of PM emissions in Dakar



As for air quality: satellite observations (Figure 40) show an annual mean of $PM_{2.5}$ (sea salt and mineral dust removed) below 5 µg/m³ in most of the Dakar area. As discussed in the methodological appendix (Appendix A), the allocation of the anthropogenic fraction of total PM is highly uncertain in areas with a strong contribution of sea salt and Saharan dust, which is the case of Dakar. The average concentration change between 2000 and 2016 in the region is very small, with a total variation of 0.5 µg/m³. Satellite observations suggest that the increment was slightly higher in rural areas.

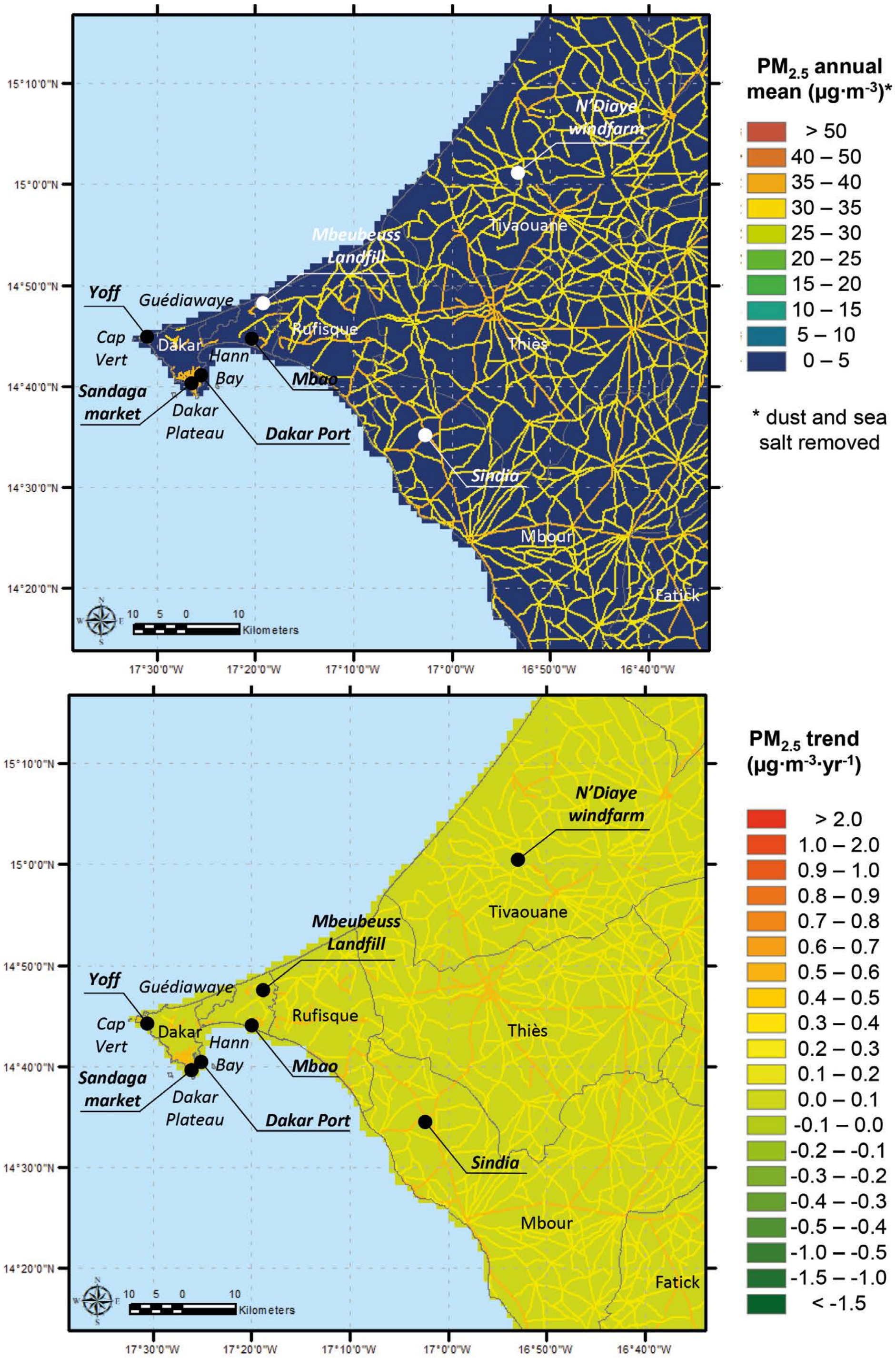
Figure 40: Annual emissions of PM (black carbon –top- and organic carbon –bottom-) in Dakar (t/km^2)



A closer look

Senegal is the only country in west Africa that has set up a continuous air quality monitoring network. Dakar's monitoring capabilities were developed within the framework of the Urban Mobility Improvement Programme (Programme d'Amélioration de la Mobilité Urbaine – PAMU), an ambitious mobility strategy financed by the World Bank in collaboration with other donors, with a total budget of USD 134.4 million for 2001-2007 (WB, 2009). The DEEC and the Conseil Executif des Transports Urbains de Dakar (CETUD) created the Center for Air Quality Management (Centre de Gestion de la Qualité de l'Air; CGQA) in November 2009 under a component of this programme. The CGQA consisted initially of five air quality monitoring stations and a reference laboratory; it was funded by the Nordic Development Fund (NDF). The network became operational in 2010 (Mbow-Diokhane, 2019). The stations are equipped with reference analysers that can measure NO_X, O_3, PM_{10}, $PM_{2.5}$, CO, SO_2 and BTX and track pollution levels at industrial, urban, suburban, peri-urban and regional sites throughout the city. While a sixth monitoring station (Yoff regional background station) was added in November 2017, its use was discontinued due to the massive influence of sea salt aerosol on PM records at that location (CGQA, 2018). Data captured is made publicly

Figure 41: Annual mean of $PM_{2.5}$ ambient concentration (excluding natural sources) (µg/m^3) –top- and recent concentration trend (µg/m^3 per year) –bottom-in Dakar



available by CGQA. Among other statistics, an Air Quality Index (AQI) is computed considering the five major pollutants (NO_2, SO_2, PM_{10}, CO, O_3). AQI values range from 0 to 500 and are helpfully classified into four categories (good, moderate, unhealthy and very unhealthy). Besides the AQI, the CGQA official website (https://www.air-dakar.org/) provides information regarding potential effects and cautionary language for sensitive groups. The data is also used to compile monthly, seasonal and annual reports regarding air quality in Dakar (CGQA, 2018). These reports suggest that PM is the most problematic pollutant, with annual average urban background levels as high as 182 µg/m^3. CGQA states that PM is strongly affected by marine aerosols and windblown dust from the Sahara, partly explaining the strong differences with pollution levels observed shown in Figure 39. Air quality can be classified as good or moderate 52% and 34% of the time, respectively, as an average over an eight-year period; it reaches very unhealthy levels during high pollution episodes (one to five percent of the time). Concentration peaks have been associated with the westward propagation of Harmattan pulses loaded with mineral dust from the desert (Rodríguez et al., 2019). On average, levels of PM_{10} are twice as high during the nine driest months than in the three wet months. AQI interannual evolution does not exhibit a clear pattern, and data deficiencies make it difficult to further identify pollution trends.

As the above suggests, Dakar represents a leading example for Africa in transparently sharing air quality data, in a format that is readily intelligible and freely accessible to the public. This is the case even though the information provided by the network cannot support a comprehensive analysis of local air quality problems due to insufficient data availability. In addition to the numerous power failures the city endures (25.6 electrical outages per month with an average duration of 2.2 h according to Cissokho & Seck, 2013), a lack of maintenance of the analysers and/or other technical problems results in an average data availability far from the target established by CGQA (at least 70-75% availability of valid data). According to the last available report (CGQA, 2018), PM_{10} data availability ranged from five to 67% depending on the station. $PM_{2.5}$ valid data only covered eleven per cent of the year as an average for the two stations that currently monitor this pollutant. In addition to improved data quality, another potential improvement is related to the air quality forecasting capabilities of CGQA, currently based on statistical methods. This is particularly important when it comes to foresee extreme PM events associated to Saharan dust outbreaks. Tools based on numerical models able to forecast such events have been successfully applied in the region (Jenkins & Diokhane, 2017; Gueye & Jenkins, 2019). Although natural hazards cannot be controlled, actions can be taken to reduce exposure and thus, to prevent negative health effects.

As a Party to the UN Framework Convention on Climate Change (since 1992; ratification 1994), Senegal periodically updates its greenhouse gas inventory (MEDD, 2015); this shows relevant trends related to traffic and power generation (Figure 37). Adon et al. (2016) derived NH_3, NO_x and SO_2 emissions for traffic and industry in Dakar from the regional inventory developed by Liousse et al (2014), but no official, regularly updated emission estimates exist.

There are a number of studies that delve further into the pollution levels and its causes in Dakar. Ndong Ba et al. (2019a) reported ambient PM_{10} average concentrations around 100 μg/m³ based on a five-month campaign carried out during the dry season (2017-2018) with portable analysers. Previous campaigns revealed average $PM_{2.5}$ levels of 87 μg/m³ in a traffic location in Dakar, much higher than the concentrations measured in a rural area some 40 km away from the city (32 μg/m³) (Ndong Ba et al., 2019b). The coarser fraction of suspended PM, however, was quite constant in both locations (57 and 56 μg/m³ respectively), probably due to natural dust contributions. A comparison with the results from Dieme et al. (2012) suggests an increase of $PM_{2.5}$ levels in Dakar and its surroundings during recent years. The rate of increase seems to be higher in rural environments, which would be consistent with satellite observations (Figure 40) and the large emission rates of biomass burning (Figure 38). $PM_{2.5}$ composition reported by Ndong Ba et al. (2019b) confirms the influence of traffic and biomass combustion in traffic and rural monitoring sites, respectively. These authors also concluded that the atmospheric particulates in urban areas are more dangerous due to a higher amount of metals and PAH from traffic emissions. Several studies have identified traffic as the main source of air pollution in the city (Schwela, 2012; Sarr et al., 2018). Emissions from traffic are particularly important in terms of health effects, especially for individuals working along major streets (Ndong Ba et al., 2019a).

Adon et al., 2016 monitored the concentration of the main gaseous pollutants in Dakar during two years (2008 and 2009) using passive samplers and found average NO_2 concentration levels of 31.7 ppb at a traffic site – three-fold higher than the corresponding value for urban background areas. In addition to the spatial variability, this study found that NO_2 concentrations over the dry season were 1.5 times higher than those of the wet period (three times higher for SO_2). The authors point out that besides favourable meteorological conditions, the wet period in Dakar coincides with a lower activity period (school vacation) and consequently, less emissions. These findings are consistent with those of Doumbia et al. (2012) regarding particulate matter. That study reported average $PM_{2.5}$ values of 44.4 ± 14.3 μg/m³ between April 2008 and July 2009 at a traffic site in Dakar (Sandaga main market, see Figure 38), with strong seasonal variations of BC airborne concentrations (13.0 ± 3.5 μg/m³ for the dry season and 8.0 ± 3.2 μg/m³ for the wet season). Similarly, they identified traffic as the main pollution source, with an average contribution of 87% and 89% to total BC during the dry and wet season, respectively. The remaining 13%-11% was apportioned to biomass burning emissions.

Besides anthropogenic sources, the contribution of natural windblown dust from the Sahara to PM levels in Dakar is well documented (Oluleye & Folorunsho, 2019). During Saharan dust episodes, PM_{10} and $PM_{2.5}$ ambient concentrations in Dakar can reach values in excess of 800 μg/m³ and 350 μg/m³, respectively (Jenkins & Diokhane, 2017). In addition to respiratory and cardiovascular disease (Zhang et al., 2016), desert dust has been associated with increases of infectious diseases such as measles and meningitis (Diokhane et al., 2016). Natural dust also affects visibility and infrastructure maintenance (Kama et al., 2017). Although natural dust dominates PM concentration in Senegal, the largest burden of asthma and bronchitis in the country is found in Dakar (Toure et al., 2019).

This suggests that urban emission sources also play a vital role on human health, and synergistic negative effects can be significantly diminished by cutting down anthropogenic emissions.

Tackling the issues

In the review provided by Schwela (2012), Senegal was depicted as a country at an intermediate stage of air quality management maturity. Among other gaps, Senegal was noted as lacking a comprehensive air quality management strategy while multi-level governance was considered blurred; a specific urban air quality plan for Dakar was also lacking. Being a country particularly vulnerable to the effects of climate change (Zamudio and Terton, 2016), current action plans pay more attention to GHG mitigation (MEDD, 2015) and adaptation, such as the Dakar Resilience Strategy (Ville de Dakar/100 Resilient Cities, 2016). However, significant advances have been made recently. Some of the most relevant instruments and plans with implications for air quality in Dakar are discussed below.

Air quality standards, regulations and plans

The Department for Environment and Classified Establishments (DEEC), a part of the Ministry of Environment and Nature Protection (MEPN), is responsible for the implementation of the environmental policies. Air pollution regulation in Senegal is based on the national Environmental Code created in 1983 (Act 83-05 of 28 January 1983) and revised in 2001 (Environment Code, Act 2001-01). The Decree 2001 - 282 of 12 April 2001 for the application of the Code focuses on the regulation of industrial emissions by the national government, but provides additional relevant provisions for urban air quality planning and the enforcement of the Code. Sanctions, however, were minimal, giving the Code little immediate leverage over air pollution issues.

At present, up to 50 norms related to atmospheric pollution are in place in Senegal (ASN, 2019). Among these, Rule NS 05-062, released in 2003 and revised in 2018, is the most important. It defines compulsory national air quality standards for SO_2, NO_2, CO, PM_{10} and Pb. While the WHO guidelines have been adopted for SO_2 and NO_2, the standard for PM_{10} is less stringent. The Senegalese Rule NS 05-062 sets a limit value of 260 µg/m^3 (24 h-mean) and of 80 µg/m^3 as an annual mean for PM_{10} (versus 50 and 20 µg/m^3 respectively, per WHO guidelines). Ambient $PM_{2.5}$ concentrations are not currently regulated.

An air quality monitoring network was first envisaged in Senegal by the 1997 National Plan of Action for the Environment (Schwela, 2012). However, air quality monitors are a reality only in Dakar, thanks to the PAMU (see above). Research projects from local universities are testing solutions based on real-time, wireless low-cost sensor networks to complement the official air quality data in Dakar (Ngom et al., 2018). Such initiatives are useful to inform citizens; they also encourage behavioural changes, e.g., promoting less polluting mobility patterns.

Regarding plans, the government of Senegal (Ministère du Plan, du Développement Durable et de la Coopération Internationale) drafted a National Strategy for Sustainable Development (NSSD) in 2007 (MPDD, 2007). This strategy was updated in 2015 by the current Ministre de l'Environnement et du Developpement Durable (MEDD, 2015). The Plan comprised six major axes to create the enabling conditions (i.e., raise awareness, establish governance mechanisms) for the implementation of emission abatement strategies (MEDD, 2015). One axis of the NSSD called for the support of productive sectors in establishing environmental standards, improving waste management, and promoting environmentally friendly modes of transport. NSSD also pointed out the need to improve the efficiency of the State by embracing decentralization and formulating long-term vision policies to create an effective framework for the implementation of sectorial programs.

Currently, the Emerging Senegal Plan (ESP) (MEPC, 2014; 2018) articulates the key strategies aimed at modernizing the country and improving governance and living conditions by 2035. The ESP promotes the structural transformation of the economy, the improvement of livelihoods and the reduction of social inequalities while strengthening security, stability and governance (WB, 2015). Although air quality is not identify as a priority, this strategy addresses some of the root causes of air quality issues (WB, 2015). The ESP development projects include the construction and improvement of large transport infrastructures, enhancement of industrial plants and the modernization of agro-industy (Republique du Senegal, 2014). ESP is also expected to increase technical capacity and raise awareness of the environmental issues faced by Senegal. It includes the development of a second university in Dakar along with other higher vocational education institutions as part of a “city of knowledge”. Senegal has already obtained donor pledges worth USD 14 billion for the implementation of ESP Phase 2 (2019-2023), so some of these projects may soon or already have become a reality.

Senegal's first Intended Nationally Determined Contribution (INDC) (MEDD, 2015) is considered a part of the ESP to specifically target climate goals. Senegal committed to unconditionally reduce its GHG emissions by five percent by 2030, through mitigation actions in the energy, industry, and waste sectors, among others. Some of these measures should also bring benefits for air quality. Of note, Senegal's GHG emissions per capita are relatively low (1.8 t/yr versus 8.5 t/y in Germany or 19.9 t/yr in the USA).

At the local level, in 2010 the City of Dakar launched the Dakar Urban Strategic Plan (Stratégie de Dévelopement Urbain du Grand Dakar - DUSP), with a planning horizon of 2025 (Cities Alliance, 2010). The plan aimed at improving infrastructures and transportation services, especially for under-served neighbourhoods in the context of rapid urbanization. The DUSP also aimed at implementing waste management and sanitation systems. The Dakar's Master Urban Plan to 2035 (MURHLE & JICA, 2016) includes further measures that may help alleviating local air quality issues. The Plan, launched in January 2016 with a total budget of West African CFA 7,255 billion, aims at transforming Dakar into an "inclusive, sustainable, competitive and supportive" capital city. This is a revision of the previous Master Plan (horizon 2025) that sought to implement some of the actions included in ESP Phase I for Dakar. That Plan tried to decentralize and to promote public transport and non-motorized mobility.

Vehicle emissions

Road transport represents 95% of total transportation in Senegal (UNEP, 2016). Nearly three-quarters (72.8%) of Senegal's fleet of vehicles circulate in Dakar according to Sylla et al. (2018). The rate of fleet growth has been high in Senegal, particularly in the Dakar area (Schwela, 2012) where 310,000 vehicles were registered in 2015 (UNEP, 2016) and making the rate of car ownership in the Dakar Region one of the highest in Africa. Nearly two decades ago, Bultynck (2001) estimated the cost of air pollution as West African CFA 63 billion per year in Dakar, while the cost of congestion was an additional CFA 41 billion. Both dysfunctions combined represented 4.5% of the national GDP, providing a compelling reason to curb emissions. The inability to control traffic increase in Dakar as a result of the rapid urbanization process was identified as one of the reasons why the PAMU did not result in any improvements in air quality in Dakar (WB, 2009). The constant expansion of the city towards the east brings about massive commuting between the Cap Vert peninsula where employment opportunities are concentrated, and satellite towns and suburbs (Sarr et al., 2018). This produces a funnel effect of traffic that leads to increased congestion that PAMU was unable to substantially address.

Besides an unprecedented increase of the fleet, studies consistently point out the poor maintenance and old age of the vehicle fleet (56.5% are 16 years old or older) as primary pollution causes (Ndong Ba et al., 2019a; Sylla et al., 2018; Aarr et al., 2018). Adon et al. (2016) suggest that the "dieselisation" of the fleet (90% of buses and 33% of private cars run on diesel in Dakar) may be an important factor too, especially regarding NO_2 hotspots in the city. Consequently, some authors suggest that road traffic may be responsible for up to 90% of air pollution in the Senegalese capital (Sylla et al., 2018) and its deleterious effects (Ndong Ba et al., 2019a; Bultynck, 2001).

Senegal has promulgated a series of rules to limit emissions from mobile sources. Rule NS-05-060 sets limit values for exhaust gas emissions (CO and HC for gasoline and smoke opacity for diesel). Lead in gasoline was phased out in 2006 and sulphur content is limited to 5000 ppm in diesel fuel. The importation of used cars more than eight years old is prohibited (Decree 2012-444 of 12 April 2012), and a pre-importation inspection is required for roadworthiness (Mbow-Diokhane, 2019).

There is a car inspection scheme in place in Senegal, administered by the police: cars must be inspected every three years, and buses and taxis every six months (MURHLE & JICA, 2016). As part of the PAMU, two car inspection centres (CCTVA) in Dakar were equipped with automobile exhaust gas analysers to control emission standards. However, these tests have important limitations, and are only applied to a very small percentage of the fleet (Sarr et al., 2018; Mbow-Diokhane, 2017).

In addition to regulations, certain transportation projects are particularly relevant to address air quality in Senegal. A project led by the Global Fuel Economy Initiative, launched in 2017 (UNEP, 2017), promotes the transition to more efficient and clean vehicles. The fuel economy policy is still in progress in Senegal, and the best combination of options (standards, taxes/incentives, voluntary programs and/or labels-based schemes) has yet to be defined.

Public and non-motorized transport

According to a survey carried out by CETUD in 2000/2001, collective transportation absorbed two-thirds of total trips in Dakar. The formally structured bus company (Dakar Dem Dikk), an enterprise co-owned by the Senegalese government (IEG, 2016), is one public transport option in Dakar. Currently only 250 buses are operating due to ageing fleet and maintenance issues (Adon et al., 2016). The light suburban railway line connecting Dakar and Rufisque (Petit train de banlieue, PTB) is another important option, but it has an insufficient capacity to meet travel needs (estimated at 124,000 passengers during the morning peak period) and faces important economic sustainability issues (MURHLE & JICA, 2016).

The inability of these infrastructures to fulfil the mobility demands of Dakar neighbourhoods has given rise to an informal sector that currently transports more than 875,000 passengers daily (Ville de Dakar / 100 Resilient Cities, 2016). About 3,000 car rapide (i.e., local buses) and Ndiaga Ndiaye minibuses absorb approximately 80% of public transport in Dakar (IEG, 2016). They are owned by a large number of small private operators under the supervision of their own association "Association de Financement des Professionnels du Transport Urbain" (AFTU). The PAMU leasing scheme allowed the replacement of 505 minibuses, although most of the remaining vehicles are around 30 years old and are in poor condition. According to CETUD, responsible for the implementation of the fleet modernization national project, more than 1,600 car rapide and Ndiaga Ndiaye have been renewed in Dakar so far.

Walking still plays an essential role in daily mobility in the city (Diaz Olivera et al., 2016). Unfortunately, about 2,500 pedestrian injuries are reported annually, due in part to inadequate separation of vehicular and pedestrian traffic (IEG, 2016).

The on-going Supporting Transport and Urban Mobility project (PATMUR), a USD 55.0 million budget initiative funded by the World Bank, intends to continue the PAMU. The project includes specific goals to enhance public urban transport in the Dakar metropolitan area and to reinforce CGQA's capacities (UNEP, 2016) as a necessary mean to assess the impact of future interventions. PATMUR also funded the studies needed for the development of the Bus Rapid Transit (BRT) system in Dakar, one of the 27 key infrastructure projects included in the ESP. At present, the BRT infrastructure consists of an 18.3 km separate corridor (currently serving 144 buses), with 23 BRT stations and three terminals covering Dakar Plateau and Guédiawaye. The project completion is envisaged for 2023; it is expected to reduce private cars mileage by four per cent and to confer significant air quality and economic benefits (IISD, 2019a). The BRT mass transit project is conceived as a public-private partnership that may be the key to a holistic urban transformation (WB, 2017). PATMUR also promotes non-motorized transport (Mbow-Diokhane, 2019).

This vision is well aligned with the new Dakar Master Plan (MURHLE & JICA, 2016), with a time horizon 2035. This Master Plan calls for the correction of the mono-polar structure of the metropolis and the coordination of transport and land use planning to improve environmental conditions and reduce social disparity.

Industrial emissions

Industrial activity contributes 23% of national GDP; it includes agricultural and fish processing, phosphate mining, fertilizer production, petroleum refining, iron ore, zircon, and gold mining, construction materials, and ship construction and repair, among other activities (UNEP, 2016). The principal sources of pollution from industry in Dakar are likely from the production of electricity, the 27,000 barrels/day-capacity oil refinery, and the building materials industry, mainly cement. Ninety per cent (90%) of the electricity production in Senegal comes from fossil fuels (UNEP, 2016). Given the accelerated urban growth, the demand for cement is rapidly increasing in Africa, and the 18.5 million GJ/year of power that the Senegal's cement industry uses comes mainly from coal (Larionov & Demir Duru, 2017). Secondary activities in Dakar concentrate in the northwestern part of Dakar Port, Sodia Industrial Zone and some areas along the Hann Bay (Figure 39). Adon et al. (2016) estimated that industry and power plants in Dakar largely dominate the emissions of SO_2 (around 1,400 t/yr), resulting in the ambient concentration levels found (CGQA, 2018). Total NO_X emissions from power and industrial plants were estimated around 2,300 t/yr in the abovementioned study, a similar amount than that emitted by traffic.

The Environmental Code provides the legal framework for the regulation of industrial emissions, while specific threshold values, along with instructions for stack height calculation, etc., are set by the NS-05-062 standard. Although a comprehensive regulation exists for the industrial activities in Senegal, no surveillance and reporting system is currently in place due to insufficient resources. In the absence of a more focused strategy, the Emerging Senegal Plan noted above is the key instrument for the future of the industrial sectors in the country. ESP aims at increasing the international competitiveness of Senegal's industry; among other measures, it integrates previous national energy efficiency promotion instruments and specific projects that should favour emissions savings.

The Energy Sector Policy Development Letter 2012-2017 (within ESP) set an objective of 20% installed electrical capacity from renewable energy by 2017, attainable through the promotion of projects such as the 159 MW N'Diaye windfarm nearby Dakar (IISD, 2019b). A mandatory energy audit for large companies and energy study for new industrial installations is introduced by Senegal's first Intended Nationally Determined Contribution (INDC) (MEDD, 2015), also integrated in ESP. The Ministry of Industry has implemented a grant scheme to support diagnostic studies and energy investments in small and medium enterprises (IBP, 2017). Although no specific emission abatement objectives are set, it is expected that these modernization policies will help to control industrial emissions.

At the local level, the 2016 Master Plan for the Dakar area also seeks to boost industrial activity. That implies the rehabilitation of industry-related infrastructures, the relocation of existing facilities and the establishment of effective links to national schemes to promote clean production practices and improved technical and vocational education (MURHLE & JICA, 2016). Some initiatives already in place are particularly interesting from an environmental perspective such as the co-incineration of agricultural waste in cement plants. For instance, Larionov & Demir Duru (2017) estimate that this industry could substitute at least 25% of its thermal energy demand with municipal solid waste and/or used tires.

Open burning of waste

Waste collection in Dakar has effective collection rates that range from 90% in the Dakar department to 15% in the suburbs. According to Yaah (2018), only about 30 % of the households in Dakar pay waste collection fees. Some 80% of total waste in Dakar is originated in the domestic sector. The current collection system requires the residents to discharge waste directly into the dump trucks at designated points. Inefficiencies and inadequate waste management practices has led to a proliferation of illegal dumpsites all around the city (Ville de Dakar / 100 Resilient Cities, 2016). All the collected residues (approximately 1,700 ton/day) are disposed at the overburdened Mbeubeuss Landfill Site. Occasional burning to provide space for incoming waste and auto incineration has been reported (Yaah, 2018). Despite the lack of specific studies to quantify air pollution from this sector in Dakar, regional low-resolution inventories show a large contribution to PM emissions (Figure 37).

So far, neither separation at source nor intermediate treatment of waste has been conducted in Dakar (MURHLE & JICA, 2016). However, recycling has been identified as a potentially profitable option given the composition of waste in the city and some successful pilot projects (Yaah, 2018). At present, some recovery and recycling of reusable fractions is carried out by the informal sector. More than 800 people work as scavengers in Mbeubeuss Landfill Site looking for scrap metal, plastics and nonferrous metals such as copper and aluminium to be sold to the wholesalers (MURHLE & JICA, 2016).

Waste management is regulated in Senegal since 1974 by Decree 74-338, and open burning of waste is implicitly banned by the Environment Code (2001). A coordinating agency responsible for waste management policy at a national level and operational management in the Dakar area has been set up by the Ministry of Planning and Local Governance (Larionov & Demir Duru, 2017). A Solid Waste Management Coordination Unit (UCG) is in charge of the development of a sustainable strategy for waste management. It takes over from the CADAK-CAR (Communauté des Agglomérations de Dakar - Communauté des Agglomérations de Rufisque), previously in charge of waste management in the city; this entity was ineffective due to dysfunctional organization and governance and thus dissolved (Decree 2015-1703 of October 26th, 2015).

Other specific regulations are targeted to raise awareness and reduce waste generation, such as the ban on plastic shopping bags imposed by the Senegal's National Assembly in 2015 (Mbow-Diokhane, 2019).

Some of the climate-related measures included in Senegal's initial INDC (MEDD, 2015) should help improve air quality in the country; among them, the construction of three integrated centres for waste recycling and the rehabilitation of uncontrolled landfills (Ba, 2018). In Dakar, the UGP has allocated USD three million for the first stage of the Project for Integrated Management and Economic Processing of Solid Waste (PROMOGED) (WB, 2019b). A Sorting and Transport Center (CTT) will be built in Mbao, some 20 km away from Dakar city centre (Figure 38), for separating recyclable waste. The city has also agreed to close and rehabilitate Mbuesbuess Landfill Site and to resume the operation of a new landfill developed in Sindia; its operation had been delayed due to strong opposition from residents (MURHLE & JICA, 2016). The Master Plan also advocates for the promotion of systems to cogenerate electricity and heat from waste as a way to improve the livelihoods related to this sector.

Indoor air quality

Poor indoor air quality has been identified as a leading cause of premature death in Senegal. De la Sota et al. (2018) reported average indoor concentrations in rural Senegal of 99 µg/m^3 and 160 µg/m^3 for $PM_{2.5}$ and PM_{10}, respectively, while maximum peaks during cooking periods may reach concentrations of around 2,000 µg/m^3. Ndong Ba et al. (2019a) also reported larger toxic VOC concentrations inside households than outdoor. Poor indoor air quality particularly affects women and children (WB, 2018).

These elevated indoor levels are largely due to the widespread use of household biomass burning (UNEP, 2016). Wood is still the dominant fuel choice (45%) for domestic cooking in Senegal as a whole (UNEP, 2016), reaching an 83% share in rural villages (WB, 2013). Adon et al. (2016) estimated that domestic combustion (wood, charcoal or animal waste) in Dakar emitted around 500 t/yr of NO_X, 200 t/yr of SO_2 and as much as 700 t/yr of NH_3, an important precursor of secondary PM. At the same time, in Dakar Ndong Ba et al. (2019a) found higher indoor PM_{10} concentration levels at heavily trafficked urban sites (200 µg/m^3 compared to 30 µg/m^3 at rural sites); this demonstrates the additional influence of mobile sources within the city. That study showed that the interior of a typical bus was more polluted than the market and urban households, with PM_{10} concentrations of 300 µg/m^3 and NO concentrations as high as 0.1 ppm. These findings are consistent with the study by Sylla et al. (2018) that found higher prevalence of chronic respiratory diseases and decreased lung function in bus drivers.

Despite a lack of specific regulations, there have been many projects to improve air quality inside Senegalese households since the 1980s, in collaboration with the international community. In 2008, the Government of

Senegal issued a Development Policy Letter for the household energy subsector to promote efficient cooking stoves and diversification of energy sources. To support this letter, the Projet de Gestion Durable et Participative des Energies Traditionnelles et de Substitution (PROGEDE I), and follow-up project PROGEDE II were launched. The PERACOD/GIZ Senegal improved cooking stoves program (FASEN) also succeeded at disseminating more than 600,000 cooking stoves between 2006 and 2015 (UNEP, 2016). Very satisfactory results have been reported from the PROGEDE projects (WB, 2019c).

A comparative analysis of improved stoves in Senegal (de la Sota et al., 2018) highlights the potential of this technology for rural areas, with emission abatements up to 75% for fine particles, although site-specific analyses should be undertaken to identify the optimal approaches (de la Sota et al., 2019). In addition, Mazorra et al. (2020) propose that providing access to clean cooking solutions may bring about gender co-benefits as well. One of the main challenges to reduce this source of pollution seems to be cultural, as domestic biomass burning is deeply rooted in culinary habits. Therefore, education and awareness-raising must accompany the introduction of improved cooking technologies (de la Sota et al., 2018).

Many of the projects under the ESP reported in previous sections are expected to alleviate indoor air pollution throughout the country. In particular, the Sustainable Energy for All (SE4ALL) initiative sets the target of achieving universal electricity access in Senegal by 2025 (WB, 2018), as a continuation of the Rural electrification emergency program (Programme National d'Urgence d'Electrification Rurale, PNUER), that electrified 2,300 localities between 2012 and 2018. Such initiatives may reduce PM emissions in the surroundings of Dakar (Figure 38), with corresponding improvements in local air quality.

Conclusions and recommendations

Dakar is aware of the challenge that rapidly increasing traffic poses to meet air quality standards in the city. Furthermore, officials understand that the transport and waste management problems cannot be seen exclusively from a technological point of view but must also be addressed from an urban planning perspective. Despite interesting recent initiatives and promising prospects, urban air quality issues are not yet receding. The main conclusions drawn and recommendations within the six key guidance framework areas of Air Quality Management Planning (AQMP) can be summarized as follows:

1. Air quality standards and monitoring

Dakar is one of the few cities in Africa, and the only one in Senegal, that maintains a continuous air quality monitoring program supported by a network that uses reference analytical methods. This system provides an example of how the international community can help to develop monitoring capabilities as a first step towards improved air quality. Nonetheless, this case study also illustrates the need to assign sufficient budget and human resources to keep the system operational when external assistance concludes. The current performance of the CGQA in Dakar is insufficient due to power failures and underfunding.

Recommendation: Grant more economic and technical resources to the CGQA to guarantee the sustainability and usefulness of the air quality monitoring network.

Recommendation: Enhance $PM_{2.5}$ monitoring capabilities, including of the physico-chemical characterization of particles, to help distinguish manmade pollution sources and assess the impact of alternative emission abatement strategies.

All the major pollutants in Senegal are included in the national air quality standards, except $PM_{2.5}$ -- an important gap considering its links to human health (Burnett et al., 2018) and the available scientific studies for Dakar. As for emission standards, Senegal has a rather comprehensive set of rules to regulate industrial activities, while current standards for vehicle emissions are limited to CO and HC for gasoline and smoke opacity for diesel.

Recommendation: Promulgate $PM_{2.5}$ standards as a necessary step in the development of Senegal's air quality management system.

Recommendation: Consider a scheme to exclude natural contributions, to better assess compliance with PM_{10} standards and better measure progress.

Recommendation: Introduce NO_x emissions standards to improve the efficiency of current inspection schemes. This is relevant for Dakar considering the large proportion of diesel vehicles and the elevated average age of the fleet.

2. Emission inventories and modelling

Dakar lacks a comprehensive city-scale emissions inventory. Undertaking such would be an appropriate task for the CGQA (Schwela, 2012) and transport should be the primary target. As discussed in the "Communication" recommendation below, an air quality forecast system could be particularly valuable for Dakar.

Recommendation: Compile a comprehensive urban emission inventory to provide an evidence base for informed decision making regarding the air quality agenda. Base this in part on data gathered earlier by relevant projects (PAMU and PATMUR among others).

Recommendation: Increase modelling capabilities within CGQA in cooperation with research centres and local universities, to support the design and assessment of plans and policies and to develop a forecasting system.

3. Health and other impacts

Available data indicate that negative health impacts in Dakar are associated with PM exposure. As noted above, the unhealthiest environments are adjacent to major roads and streets due to traffic emissions. This circumstance hurts pedestrians (including members of the informal economy) as well as public transport riders and workers. At the same time, indoor air quality has been reported as the leading cause of premature death in Senegal (UNEP, 2016), affecting especially women and children (WB, 2018) in households that still rely on solid fuels such as wood.

Recommendation: Provide safe and reliable alternatives to private transportation in accordance to PATMUR and the Dakar Master Plan priorities.

Recommendation: Further investigate the relationship between health impacts and PM physio-chemical properties, to identify the interventions with the potential to yield highest benefits.

Recommendation: Intensify current efforts to connect rural areas to the electric grid, as well as to promote the use of cleaner fuels and uptake of improved cooking technologies, with health, equity and climate co-benefits expected.

4. Communication

Despite the technical limitations previously discussed, Dakar's air quality system offers an encouraging example of transparency and environmental data dissemination in sub-Saharan Africa. The AQI developed daily by CGQA and communicated to decision-makers and the general public represents a straightforward and effective way to convey the essential information about air quality to non-specialists. In addition to current air quality forecasts based on statistical models, the technical capabilities needed to apply advanced numerical models appear to already exist. Since such models do not depend on complex anthropogenic emission inventories, they may be implemented in the short term as a complementary forecasting tool.

Recommendation: Enhance the capabilities of CGQA official website to provide access to hourly historic data series, for improved analyses and applications by the scientific and technical community.

Recommendation: Upgrade the air quality forecasting capabilities of CGQA by implementing numerical models that are able to foresee extreme PM events associated to Saharan dust outbreaks along with a suitable information platform.

Most of the many projects recently developed or currently ongoing in Senegal and Dakar recognize the value of increasing the level of awareness and education of stakeholders and general society. Indeed, such awareness-raising represents Strategic Focus No. 1 of the National Strategy for Sustainable Development (MEDD, 2015). Such measures can increase citizen acceptance of new emission abatement measures, with an increased likelihood of their acceptance.

Recommendation: Reinforce information and public participation processes as essential components of existing and future plans and programmes.

5. Clean Air Action Plans

Socio-economic plans such as the Emerging Senegal Plan (ESP) at the national level or the Dakar Master Plan Horizon 2035 at the local level are key instruments to improve living conditions; they are expected to provide substantial environmental improvements by, e.g., addressing the urban mobility crisis. Previous mobility plans (e.g., PAMU) have already contributed to reduce emissions in Dakar and to strengthen local institutions (IEG, 2016); however, the absence of explicit air quality targets in such plans and a corresponding lack of focus on this issue may diminish their impact in this area.

Recommendation: Develop a national strategy to coordinate cross-sectoral emission abatement measures and prioritize health benefits that may multiply the potential benefits of ESP as a whole.

Recommendation: Develop a specific Air Quality Plan for Dakar that takes into account the rapidly changing reality of the city and surroundings aligned with the city Master Plan.

Recent studies suggest that improved policies in the transport sector can yield substantial air quality benefits (Ndong Ba et al., 2019a; Sylla et al., 2018); such measures should be prioritized in this sector.

Recommendation: Reinforce fleet renewal schemes already in place for the public transportation sector with the involvement of associations and other relevant stakeholders, in particular the Association de Financement des Professionnels du Transport Urbain (AFTU).

Recommendation: Strengthen the executive capacities of the Conseil Executif des Transports Urbains de Dakar (CETUD), which remains insufficiently equipped and supported.

Recommendation: Enforce more stringent standards for public buses as, arguably, the most efficient, cost-effective measure, both in terms of ambient air quality and health impact.

Recommendation: Improve emission testing procedures as a necessary step to enforce vehicle emission limits and facilitate the adoption of future fuel economy standards.

Recommendation: Promote low-cost measures with high potential health benefits in the short term, such as an adequate separation of pedestrians from vehicular traffic.

The legal framework to manage industrial emissions is already available in Senegal, but monitoring and reporting procedures are not fully developed. Certain efforts aimed at improving energy efficiency, e.g., the co-incineration of waste in the cement industry, may yield air quality co-benefits. Waste-to-energy projects in general merit consideration in Dakar. Interventions in the domestic sector through improved cooking systems have demonstrated substantial air pollution and gender benefits.

Recommendation: Consider emission-specific goals along with other goals when formulating measures to improve industrial energy efficiency; develop a correspondingly integrated framework for monitoring and reporting results.

Recommendation: Involve both the formal and informal sectors in the implementation of any waste-to-energy projects so as to preserve livelihoods, thus contributing to a more balanced social development.

Recommendation: Continue to promote cleaner household cooking solutions.

6. Governance

The democracy in Senegal is one of the oldest in Africa, and the country has been among the most stable countries in the continent (Zamudio and Terton, 2016). The decentralization law launched in 1996 by the Senegalese Government materialized in city contracts and the reinstatement of municipal borrowing, contributing to good governance (WB, 2015). These reforms favoured the strengthening of local administrations and the adequate use of investment and international funds mobilized for a range of projects. According to Transparency International (2019). Senegal ranks 114 out of 180 in the list of corruption (a better ranking than any other of the countries considered in this report).

At present, in the Emerging Senegal Plan, Senegal seems to have a comprehensive and well-structured strategy to keep strengthening its governance and to foster collaboration with private stakeholders and the international community. A recent study (OECD, 2018) concluded that the priority is to support the Government of Senegal to transform policy recommendations into action. They considered that a successful implementation of the national strategy should be rooted in the improvement of the education system and the revision of a dysfunctional tax system and administration. Similar key strategic actions have been suggested as the best option to put in motion local development strategies (Ville de Dakar/100 Resilient Cities, 2016). The Ministry of Local Governance may play a relevant role in this task. Many of the current strategies identify public-private partnerships as the cornerstone of effective and sustainable interventions.

Recommendation: Strengthen the institutions needed to realize the ESP as a key enabling instrument, paving the way for a comprehensive air quality management system in Senegal.

Recommendation: Introduce sustainable financial and economic instruments to involve private partners in public infrastructure and service provision schemes.

Nairobi, KENYA

A case study on Kenya's capital – its rapid expansion and air quality

Highlights

- Emissions from poorly maintained motor vehicles, household sources, waste management and natural dust give rise to hot-spots around the city that experience elevated levels of particulate matter. Low-income neighbourhoods are particularly affected.
- The case study highlights the critical need of continuous air quality monitoring; such monitoring can provide insights in real time as to deteriorating air quality levels. At the same time, the case study also shows some of the technological limitations of using low-cost sensors for monitoring.
- Although fragmented and partially overlapped, the necessary national-level legal instruments and regulations are already mostly in place. The paucity of administrative and enforcement capacity is the main threat for an effective implementation of air quality policies.
- The Nairobi Integrated Urban Development Master Plan (NIUPLAN) and Air Quality Action Plan (2019-2023) provide the necessary link to implement national regulations and the framework to improve air quality in this rapidly growing metropolis.
- Urban air quality issues should be addressed in the wider context of cross-cutting strategies to improve social conditions, reinforce good governance and promote education and public awareness towards improved environmental and health outcomes.

Introduction and background

Nairobi, the capital and largest city of Kenya with 3,913,512 inhabitants, is a major hub for business and culture in sub-Saharan Africa that has attracted a multitude of companies and international organizations. The city is rapidly growing, at a 3.8% annual rate in the 2000-2015 period; it is expected to grow at an even higher pace in the future (3.9% annual rate for the 2015-2030 period) due to high birth rates and urban migration, reaching 7,030,891 inhabitants by 2030. Urban expansion has not been accompanied by a balanced development of economy and planning. This circumstance has resulted in large, high-density slums, such as those in Kibera (Figure 40). According to Nthusi (2017), more than 60% of city's population lives in informal settlements.

The city has a subtropical highland climate controlled by the Inter-Tropical Convergence Zone (ITCZ). Being located very close to the equator, temperature presents very slight changes throughout the year, although it shows considerable daily variations. There are typically two rainy periods, reaching their peaks around May and November. Nairobi is in a mountainous area near the eastern edge of the Great Rift Valley. The annual average temperature is 19.3º C, with an average of 933mm of rainfall per year (Figure 41).

As for the national context, Kenya is a lower-middle income nation with a GDP per capita of USD 3,461 in 2018 and a poverty ratio (population under the threshold of USD 5.50 a day) of 86.5%. Total national population reached 52,573,967 inhabitants as of 1 July 2019. UN projections estimate that 64.8-68.1 million people will live in Kenya by 2030. Currently 63.8% of the total population enjoys access to electricity, while the share of people with access to clean fuels and technologies for cooking is only 13.4%. A total of 14,287 kt of CO_2 were released in 2014 (0.31 t per capita), distributed as shown inFigure 42.

Figure 42: Population density (persons/km^2) -left- and man-made impervious surface (%) –right- in Nairobi and surroundings

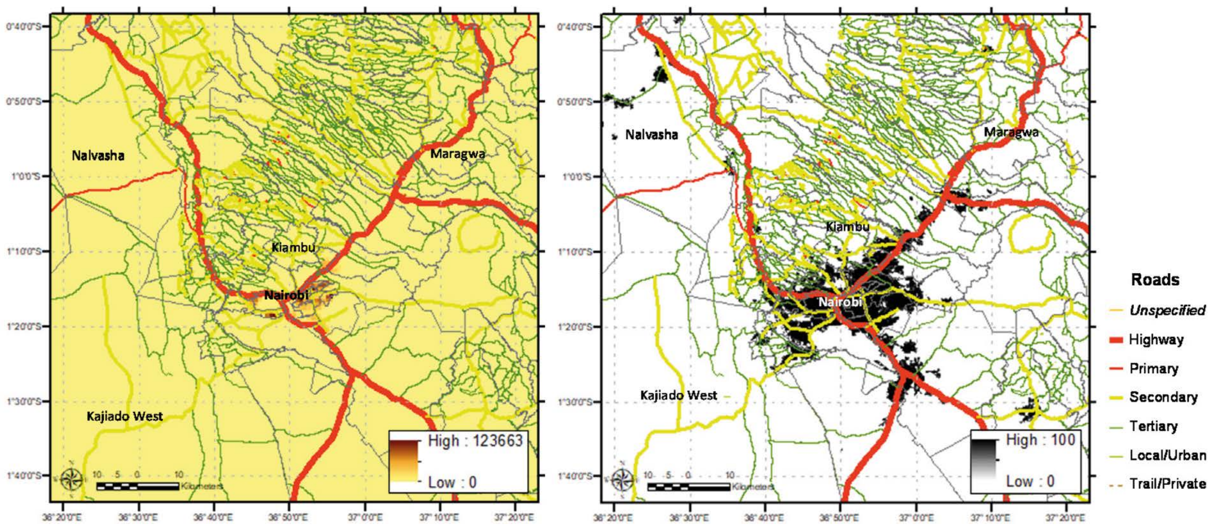


Figure 43: Monthly average temperature (°C) -left- and monthly average accumulated precipitation (mm), according to Nairobi/Jomo Kenyat meteorological station (WMO station 63740; long = 36.916° E, lat = 1.317° S, altitude = 1624 m). The 95% confidence intervals are shown

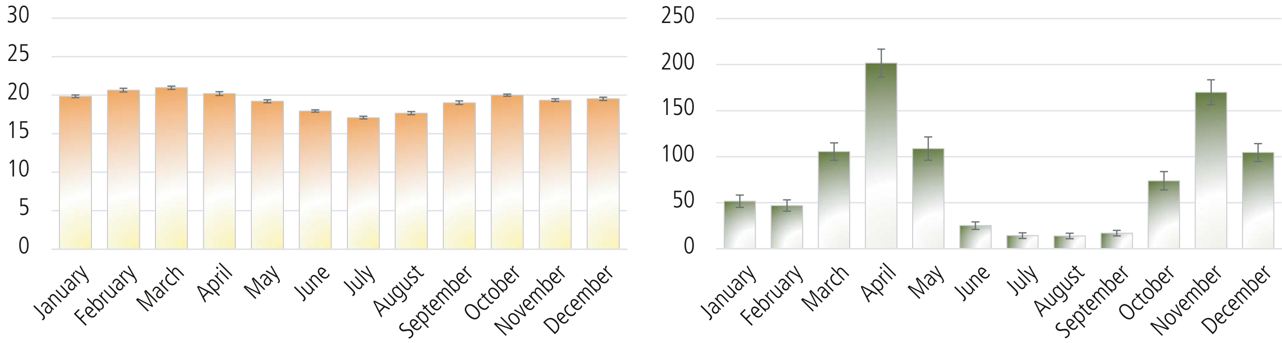


Figure 44: Breakdown of CO_2 emissions in Kenya (14,286 kt in 2014)

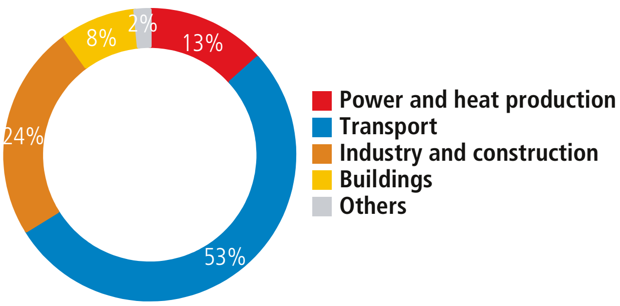
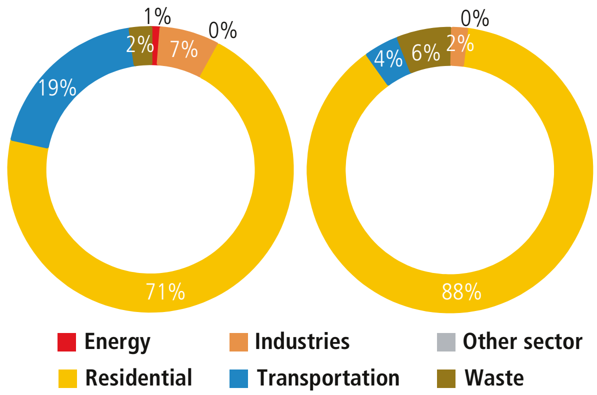


Figure 45: Breakdown of PM emissions in Nairobi



Current life expectancy at birth in Kenya is 66.2 years; this level is expected to increase to 68.6 years by 2030. At present, the mortality rate attributed to joint effects of household and ambient air pollution is 7.8 cases by 10,000 population (95% confidence interval 6.9, 8.6). That implies more than 36,000 premature deaths in the country annually, mainly related to lower respiratory infections (47.5%), ischemic heart disease (21.4%) and stroke (18.4%).

Emissions and air quality in Nairobi today

Air pollution at a glance

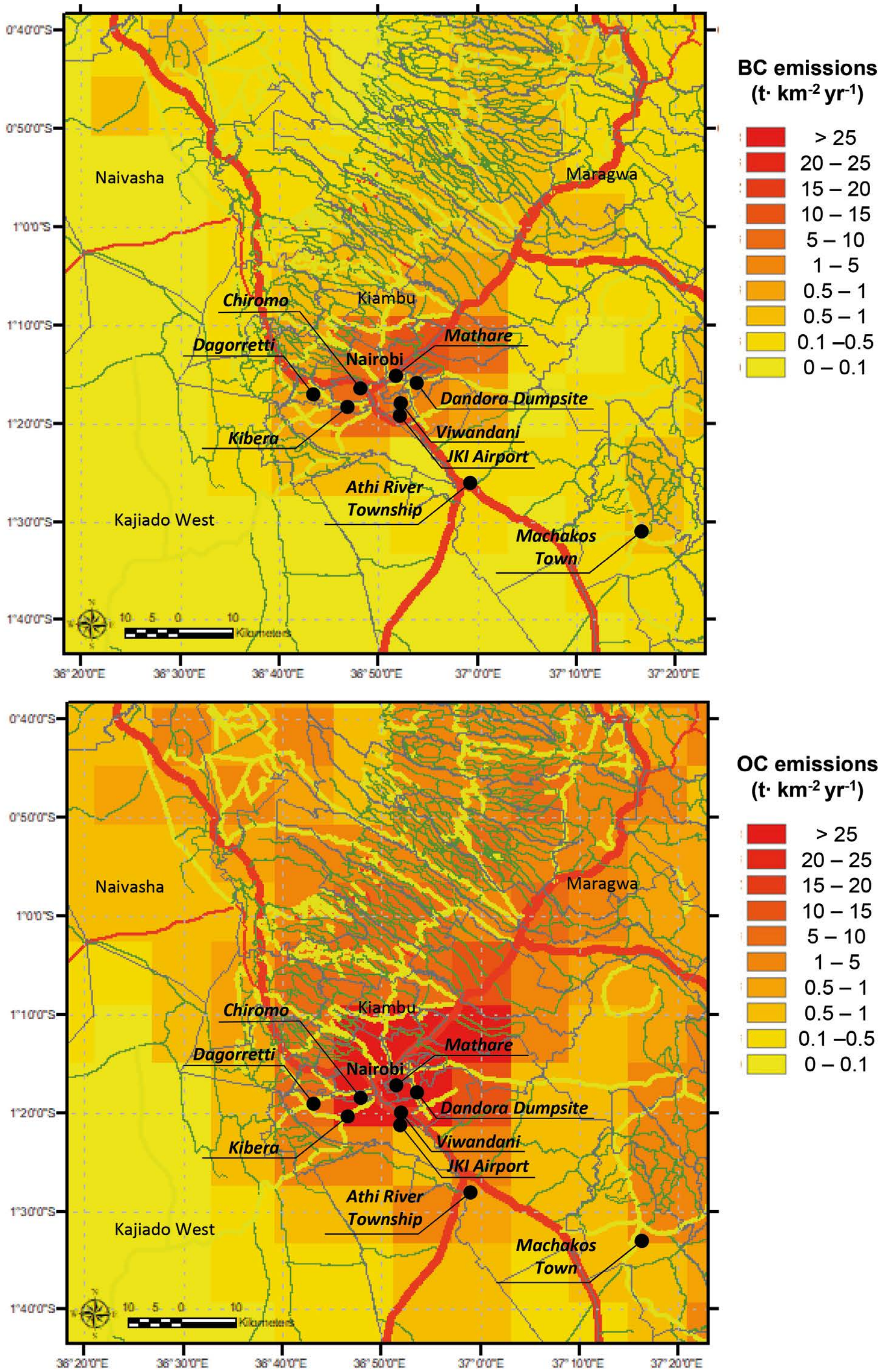
Total emissions of the main components of particulate matter in the Nairobi area are shown in Figure 43. OC emissions are completely dominated by the residential sector and are mostly related to open air burning of household wastes, wood and charcoal. The same applies to BC although the contribution of road traffic is more relevant. The emissions from transport concentrate in the city centre, but PM emissions, especially OC, are widely spread throughout the urbanized surroundings, as shown in Figure 44.

As for air quality: satellite observations (Figure 44) show average regional levels of anthropogenic $PM_{2.5}$ (sea salt and mineral dust removed) of around 10-15 µg/m³ in most of the greater Nairobi area (Figure 45). The average concentration changes between 2000 and 2016 do not exhibit a strong trend in the region. While ambient concentrations have remained constant or even decreased slightly in some areas, such as Machakos Town (south-east of Nairobi), general trends go in the opposite direction, showing increases of around 2-3 µg/m³ over the last 15 years in most of the Nairobi metropolis and surrounding rural areas.

A closer look

Despite the introduction of air quality regulations such as in the Environmental Management and Coordination Act (Air Quality) Regulation of 2014 and the Nairobi City County Air Quality Policy and Action Plan (2020), Nairobi does not have a comprehensive air quality monitoring system. Pollution monitoring activities in Nairobi can be said to have started in 1996 when the Kenya Meteorological Department (KMD) installed a vertical ozone sonde sounding system at Dagoretti (Shilenje, 2014). Ground level O_3 measurements began in 2012 at this same location, reporting ozone monthly mean levels from 16 to 23 ppb. There is another fixed monitoring point at the Jomo Kenya International Airport (JKIA). In addition, a monitoring station to measure O_3, aerosol GHG and

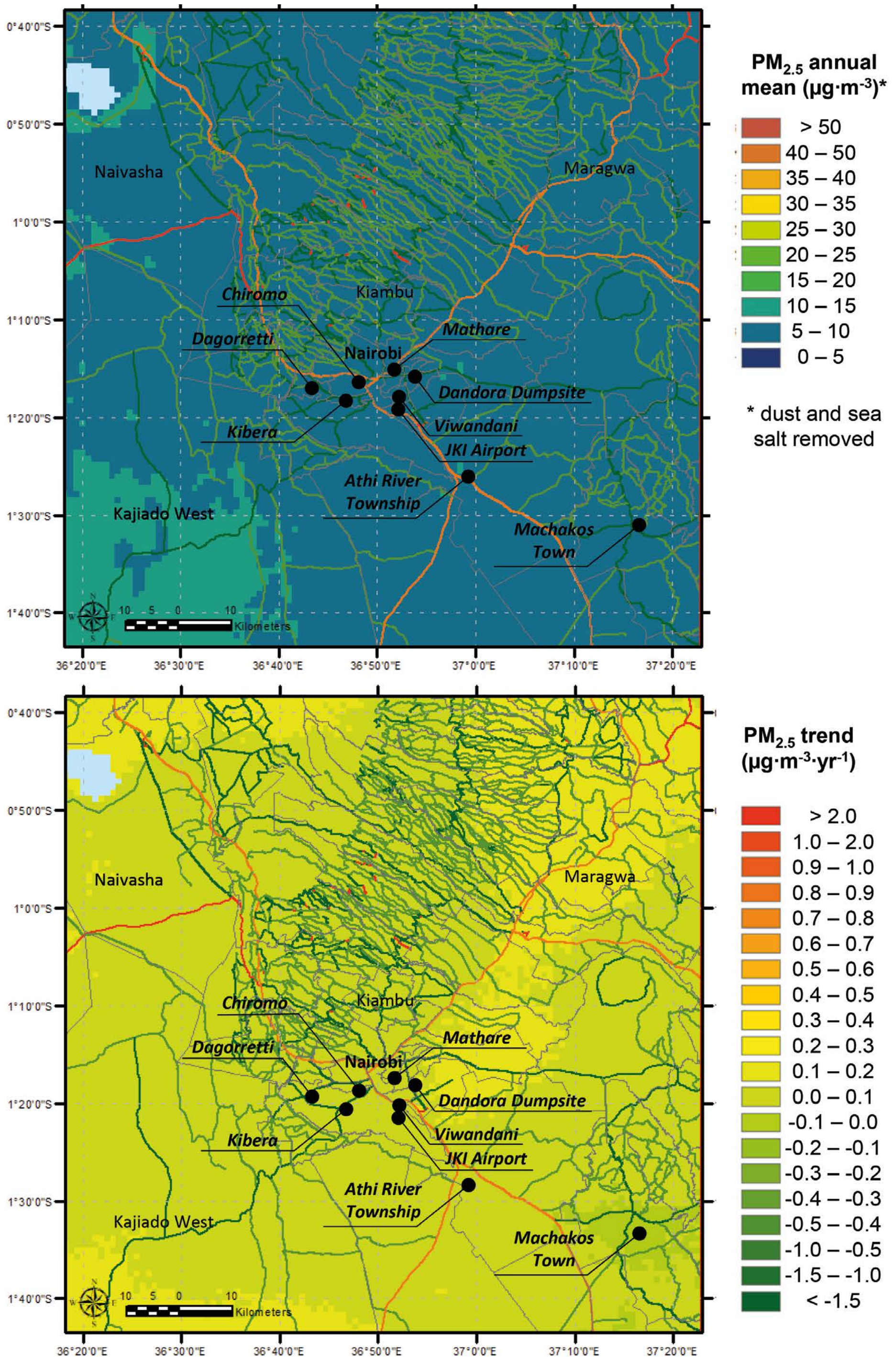
Figure 46: Annual emissions of PM (black carbon –top- and organic carbon –bottom-) in Nairobi (t/km²)



meteorological parameters was installed at the top of Mt Kenya, some 140 km northeast of the Nairobi in 2009 (the highest altitude station in Africa). While this location provides interesting information to study climate change and regional background trends, it does not provide relevant data regarding urban air pollution. The KMD has also a full-equipped mobile laboratory (Van Laboratory) able to measure O_3, SO_2, BC, NH_3 and PM by means of reference analysers. This entire network is operated by KMD in collaboration with the United Nations, Stockholm Environment Institute (SEI) and the University of Nairobi (UoN); however, the network lacks a common reference for standardized measurement and a unified reporting framework. In addition, some stations do not provide continuous and reliable data and the information is not made publicly available on a regular basis.

Despite the lack of a comprehensive, consistent and transparent city-wide monitoring strategy, some monitoring campaigns and pilot projects have been undertaken in Nairobi. United Nations Environment Programme (UNEP) has promoted the use of affordable air quality monitoring technologies aimed

Figure 47: Annual mean of $PM_{2.5}$ ambient concentration (excluding natural sources) (µg/m³) –top- and recent concentration trend (µg/m³ per year) –bottom-in Nairobi



at a cost-effective evaluation of air quality and related health impacts, based on the use of novel sensor technology (Kumar et al., 2015). A demonstration six-unit network started running in Nairobi in May 2016. This affordable monitoring network measures PM (PM_{10}, $PM_{2.5}$ and PM_1), NO_2, NO and SO_2 in real time in four schools across the city, UNEP headquarters and a community centre. The measurements from these low-cost sensors are included in a Real-Time Air Pollution Map. This is an initiative launched by UNEP together with UN-Habitat and IQAir, a Swiss air quality technology company (IQAir, 2020) that seeks to construct the world's largest urban air quality data platform.

The results reported by de Souza et al. (2017) show that average $PM_{2.5}$ concentration over an eight-month period (May 2016 to January 2017) ranged between eleven and 23 µg/m³ across these six locations, while PM_{10} observations averaged between 26 and 59 µg/m³. The NO_2 observed level oscillated between eight and twelve ppb in all six sites where observations were taken. The highest mean level of SO_2 was recorded at Viwandani (40 ppb), an informal settlement in the industrial area of Nairobi. These values should all be taken with caution since the network has not been calibrated with reference air quality monitors (de Souza et al., 2017); nonetheless, they point out that pollution levels are usually higher in Kibera and Viwandani slums (Figure 45). This is consistent with previous studies (Gulis et al., 2004; Egondi et al., 2016) that highlight that air quality issues are particularly serious in deprived neighbourhoods of Nairobi, a pattern also found in other African urban areas as discussed elsewhere in this report (also see Dionisio et al., 2010).

This low-cost network constitutes an important milestone also in terms of data accessibility. One-minute ambient concentration data can be downloaded from the Clean Air Nairobi website (http://senseable.mit.edu/cleanair-nairobi). Despite technical limitations and issues related to data quality (WHO, 2018), the network can provide indicative measurements of air quality that are valuable to local communities; they can contribute to increase awareness and thus engender support for more effective air quality regulation (Ngo et al., 2017).

Pope et al. (2018) also used low-cost sensors (calibrated against gravimetric measurements, in this case) to monitor PM levels in Nairobi during a two-month period (February-March 2017). According to this study, the average $PM_{2.5}$ concentration at a roadside site was 36.6 μg/m^3; considerably higher than the 24.8 μg/m^3 observed in an urban background site and the 8.8 μg/m^3 measured in a rural location more than 100 km away from the city. Diurnal variations of PM concentrations captured also suggested that air pollution in the city is strongly affected by traffic; traffic may be responsible for some 47.5% of total $PM_{2.5}$ loading. The relevance of traffic to PM levels in the city was also pointed out by Kinney et al. (2011). They estimated a 24-hour average $PM_{2.5}$ personal exposure of 45-85 μg/m^3 along busy roads in Nairobi. Such levels could have severe health implications for population groups that are highly exposed to roadways such as pedestrians, cyclists, the drivers and passengers of matatus (Nairobi's minibuses) and street vendors, as well as car drivers themselves. Similarly, according to measurements made in a previous experimental campaign (February 2006), van Vliet and Kinney (2017) estimated that roadway concentrations of $PM_{2.5}$ in Nairobi were approximately 20-fold higher than urban background $PM_{2.5}$ levels (around 20 μg/m^3); black carbon concentrations differed by ten-fold. They reported strong horizontal concentration gradients: from 129 μg/m^3 to 19 μg/m^3 at a location over 100 meters downwind from a major intersection. In addition, they also found large vertical pollution variations, from 120 μg/m^3 at ground level to 43 μg/m^3 at the rooftop of a three-storey building Kinney et al. (2011). Such concentration gradients (which are typical of urban areas) underscore the need to establish a well-designed monitoring network to gain a clear picture of urban air pollution. These results were confirmed recently by Gatari et al. (2019). They found that BC represented 34-56% of the total $PM_{2.5}$ mass during a one-month monitoring campaign (July 2019), with levels reaching 24-hour average values as high as 43 μg/m^3. This demonstrates that road traffic emissions are the dominant source of airborne $PM_{2.5}$ in curb- side locations.

The proximity to traffic emissions was also found to be a key factor by Ngo et al. (2015). They found that a large fraction of $PM_{2.5}$ consisted of BC (vehicle smoke) due to poor engine maintenance of Nairobi's fleet. They further found that women in the Mathare slum (Figure 44) experienced exposure to $PM_{2.5}$ at levels similar to roadside mechanics and street vendors (hawkers), since they spend a substantial amount of time near roadways. This study also suggests that matatu drivers, hawkers and mechanics experience two-to-five times the $PM_{2.5}$ levels of bus or truck drivers in cities that follow strict air quality regulations. This is again directly related to environmental justice since poor pedestrians who cannot afford motorized transport are forced to walk long distances near traffic emissions (Klopp, 2012).

Egondi et al. (2016) conducted measurements of $PM_{2.5}$ in two urban informal settlements of Nairobi (Viwandani and Korogocho; near Mathare), from February 2013 to October 2013. The results show that residents in both slums are continuously exposed to $PM_{2.5}$ levels exceeding hazardous levels according to World Health Organization guidelines. During the study period the average $PM_{2.5}$ concentration was 67.7 μg/m^3 and 166.4 μg/m^3 respectively, considerably higher values than those reported in other studies, even at curb side sites (Pope et al., 2018; Kinney et al., 2011). The differences in concentration in these two poor neighbourhoods in Nairobi may be attributed to very local sources, such as street markets that increase traffic as well as street cooking using biomass fuels. The strong seasonality of pollution that peaks during the dry season (July in particular) suggests that PM levels may also be affected by dust transport and PM resuspension processes.

The longest period of recorded ambient PM concentration in Nairobi is that reported by Gaita et al. (2014). They performed $PM_{2.5}$ daily measurements between May 2008 and April 2010 to characterize urban background and suburban pollution levels. The average $PM_{2.5}$ concentrations found were 21 (± 9.5) μg/m^3 and 13 (± 7.3) μg/m^3, respectively. It should be noted that monitors were located at 17 m and ten m above the ground level, so these values are not directly comparable with AQ standards or WHO guidelines. This study included a source apportionment analysis that indicated that traffic was the largest contributor to airborne PM (39%). Despite the large emission share attributed by regional inventories (Figure 43), waste burning, open fires and charcoal burning, typical of low-income households were responsible for six percent of total $PM_{2.5}$ observed in these background monitoring sites. In addition to biomass burning and emissions from road traffic, people living in slums are particularly affected by inadequate waste management practices, such as burning of plastics. Many informal settlements in Nairobi are near dumpsites, such as the already overburdened 30-acre Dandora Dumpsite (Figure 44). Such cases can foster discussions on environmental inequalities and injustice. Gaita et al. (2014) also highlighted the very high contribution of mineral dust, presumably from unpaved roads (35% as an average; up to 74% of $PM_{2.5}$ in Nairobi during the dry season). Seven percent (7%) of PM loading was linked to industrial activities around Nairobi.

Regarding the influence of industrial activities, Shilenje et al. (2015) measured $PM_{2.5}$ by means of the KMD van laboratory in Athi River Township, some 20 km southeast of Nairobi County (Figure 45). Several large-scale commercial and industrial activities, including manufacturing, steelworks, cement production; incinerators, salt production, long haul transport and quarrying are found in this area. This study found average $PM_{2.5}$ over a two-month period (December 2014 and January 2015) of 30.7 µg/m^3, slightly higher than the WHO 24 hr AQG (25 µg/m^3) (WHO, 2016), but well below the national standard (75 µg/m^3; see below). Relatively low concentrations were found for other relevant pollutants such as NO_2, SO_2 or O_3 (4.4 ppb, 0.8 ppb and 18.5 ppb respectively).

Tackling the issues

Kenya lacks a comprehensive urban air quality management programme. Air quality management responsibility is with the Ministry of Environment and the National Environment Management Authority (NEMA), in collaboration with other partners. Despite weaknesses detected in terms of enforcement and compliance practices (Schwela, 2012), there are some recent actions undertaken by the national government as well as local initiatives that are expected to benefit air quality in Nairobi. Regulations and initiatives can be summarized as follows:

Air quality standards, regulations and plans

According the Constitution of Kenya (Article 42, Chapter 4 - the Bill of Rights), every person resident in Kenya has the right to a clean and healthy environment. The Kenyan National Environment Management Authority (NEMA), a semi-autonomous government agency located under the Ministry of Environment and Forestry (MoEF) and established under the Environmental Management and Co-ordination Act (EMCA) No. 8 of 1999, oversees implementation of all environmental regulations and policies in the country, including those that affect air quality. As one impetus to action, in 2008 Kenya signed the Eastern Africa Regional Framework Agreement on Air Pollution (Nairobi agreement) (UNECE, 2011).

In 2014, per Section 147 of the EMCA, the Cabinet Secretary introduced the Environmental Management and Coordination Act (Air Quality) (MoEF, 2014). Prior to that, the original Air Quality Regulations of 2008 did not set any air quality guidelines but instead merely proposed their formulation. The current 2014 regulation aims to provide for the prevention, control and abatement of air pollution to ensure clean and healthy ambient air. It provides for the establishment of emission standards for both mobile and stationary sources. The 2014 regulations also specify the procedure for designating controlled areas and defining the objectives of air quality management plans for those areas. They set ambient air quality standards for SO_x, NO_x, CO, Pb and PM_{10} for i) industrial; ii) residential, rural and other; and iii) controlled areas that are similar to those in force in Europe (2008/50/EC Directive). Additionally, O_3 and $PM_{2.5}$ standards are set for industrial areas only. For the latter pollutant, the annual mean and 24-hour concentration mean should be below 35 µg/m^3 and 75 µg/m^3, respectively.

While, as indicated, there has been significant progress in formulating guidelines, no national air quality monitoring programme is in place. The Kenya Meteorological Department (KMD) under MoEF is mandated with both weather and air quality observations. Although this institution operates a number of air quality monitoring stations, air quality monitoring is mainly undertaken in conjunction with ad hoc, short-term experimental research campaigns led by academic institutions (Nthusi, 2017) such as those discussed above.

In addition to the air quality regulations there are other relevant laws, including the Environmental Policy (2013), the Kenya Standards Act, Cap 496 and the Kenya Standard (KS 1515), the Code of Practice on Inspection of road vehicles, the Occupational Health and Safety Act (2007), the Public Health Act, Cap 242, the National Transport and Safety Act (2012) and the Energy Act (2006). The legal framework for collaborations among national and local administrations (County Governments) is given in the first instance by the Constitution of Kenya (2010). The Fourth Schedule (Articles 185(2), 186(1) and 187(2)) conferred the responsibility to control air pollution to counties, as well as to implement the standards and regulations defined at national level. Since this represents a fairly new role for the County Government, action towards the reduction of air pollution remains limited; a strong support from the national level is required. NEMA is expected to further assist the local governments with technology, capacity, and policy direction. In 2017, the MoEF established an Air Quality Management and Coordination Committee, which brought together a number of stakeholders. This committee identified six thematic areas for interventions: 1. Sustainable development Goals, Research and Inventory; 2. Emission Testing and Licensing; 3. Indoor air pollution; 4. Monitoring, data and Instrumentation; 5. Regulatory and institutional framework; and 6. Communication and Outreach.

The city-level policy response to air pollution in Nairobi is embodied in different policies and strategies including the Nairobi Integrated Urban Development Master Plan (NIUPLAN) (NCC & JICA, 2014). This plan tries to integrate all existing sectoral plans in the city under a common vision to coordinate urban development, with a temporal horizon of 2030. It addresses unsolved issues such as traffic congestion, uncontrolled expansion of slum areas, insecurity, poor governance and environmental deterioration. The NIUPLAN identifies five priority programs for the development of short-term (starting 2018) priority projects:

- Urban Development Programme (improvement of the central business district and development of sub-centres to de-centralise economic activity in the city)
- Urban Transport Development Programme (road infrastructures, public transport, ITS development)
- Infrastructure Development Programme (water supply, power and telecommunications)
- Environment Improvement Programme (storm water drainage and sewerage, solid waste management, city-wide air quality monitoring program, AQM)
- Urban Development Management Strengthening Programme (strengthen institutions and human resources).

Projects in all of these areas may have a measureable impact on air pollution. The fourth programme specifically aims at implementing a city-wide AQM programme. This project would carry a total cost of USD 10 – 20 million, including to develop management structures, build capacity, install monitoring equipment, upgrade legal framework, and increase public awareness. The NIUPLAN also aims for improvements in vehicle fleet, industries, cooking fuels, and waste treatment practices as key sources of pollution. It also proposes that the monitoring system be expanded so that it can monitor air quality at roadsides, as well as at industrial and waste disposal sites.

Other key policies to provide for improved air quality improvement in Nairobi are the Air Quality Action Plan (2019-2023) (NCC & UNEP, 2019) and the Nairobi City County Air Quality Policy (NCC, 2020). The AQ Plan was developed by the Nairobi City County (NCC) Government in partnership with UN Environment and the Environmental Compliance Institute (ECI), together with a multi-stakeholder technical committee. It was developed as part of UN Environment's pilot project to support three African cities – Addis Ababa, Kigali and Nairobi – to develop better air quality management strategies in order to protect public health and the environment. The Action Plan outlines priority actions to reduce harmful air pollution in the city. It defines the basic strategy, responsibilities, resources needed and links to other relevant plants to achieve four main goals (NCC & UNEP, 2019):

- Build scientific evidence for policy, legislative and regulatory interventions for air quality management in Nairobi City. This implies the development of an urban emission inventory and projections both for air quality pollutants and GHGs, and the development of a formal AQ monitoring network.
- Raise public awareness on health and environmental impacts of air pollution in Nairobi City through the development and implementation of a communication and public participation strategy.
- Develop effective mechanisms to adopt policy, legislative and regulatory options for air management that incorporate mandatory requirements, voluntary and market-based approaches.
- Build an effective implementation and enforcement programme for Nairobi City's air quality legislation by enhancing the executive capacity of the city government. It contemplates setting up a specific, properly trained air quality unit.

The Policy proposes an integrated approach in all sectors and institutions to air quality management in Nairobi, while strengthening the institutional capacities and legal/institutional framework to provide for effective coordination and management of air quality. It also aims to promote education, public awareness and research, as well as participation of key stakeholders in air quality management.

In addition to these strategies, there have been various collaborative pilot activities to collect air quality data. One of them, "Improving Air Quality in Nairobi and Kiambu County through Place-Making and Open Street Activities", represented a collaboration of UN-Habitat and UN Environment with the County Governments of Nairobi and Kiambu. During those pilot activities, undertaken in 2016, 2018 and 2019, low-cost sensors were mounted along streets temporarily closed to traffic during and after the activity, to measure the impact of those closures on air quality. Although the immediate impact of such interventions is limited (Nthusi, 2017), they have been found beneficial to advocate for greener and more inclusive cities and to increase public awareness and involvement. Other initiatives such as "Sensors AFRICA", a transnational African network of citizen sensor projects (including one in Nairobi), also seek to raise air quality in national governments' agendas. This project is backed by "Code for Africa", a continent-wide federation of civic technology and open data laboratories.

Vehicle emissions

As suggested above, Nairobi's NIUPLAN identified traffic as the main air quality concern (NCC & JICA, 2014). According to this document, between 2004 and 2013 total traffic volume increased by 69%, with corresponding increases in the car ownership rate. These rapid rates of increase have continued: as of August 2018, Kenya had 3,135,573 registered vehicles, a full 55.8% more than in 2013 (NCC & UNEP, 2019). Such increases obviously intensify traffic-related pollution problems (Nthusi, 2017), giving rise to air pollution hotspots throughout the city (Pope et al., 2018; Ngo et al., 2015.; Kinney et al., 2011). Much of this increase is due to a constant stream of second-hand cars imported from Europe and Japan (99% of vehicles in Kenya are second-hand according to Mbandi et al. (2019)), most of them diesel (Gatari et al., 2019). Researchers have determined that, on average, in terms of fuel efficiency, the current Kenyan fleet is two-three times worse than that in Japan, Europe, India or China, with implications for air quality (see Figure 42).

The Kenyan government has taken some environmental action in the transport sector. The use of lead in gasoline was phased out (effective January 2006), and the standard limit of sulphur in fuel has been limited at 50 ppm as of January 2015. This has reduced Pb concentrations in $PM_{2.5}$ and hence reduced toxicity risks for urban inhabitants (Gaita et al., 2014). To prevent importing obsolete and outdated vehicle technologies into the country, the government set a maximum age of eight years for imported cars as of 2003. Additionally, the schedule of excise duties encourages the importation of newer cars (KES 150,000 for less than three years and KES 200,000 for vehicles between three and eight years old). While tail pipe emissions from motor vehicles were stipulated in EMCA fossil fuel emission control regulation of 2006 (degazetted under Reg 78 of the Air Quality Regulations, 2014), tampered-with or non-functional pollution control systems as well as adulterated fuels are common (UNEP, 2016). This is partly a consequence of the fact that no specific environmental section within NCC has authority to properly enforce vehicle inspection and maintenance (NCC & UNEP, 2019), so no vehicular exhaust emission measurements are actually carried out.

Public and non-motorized transport

Despite the unprecedented increase of private cars on the road (NCC & JICA, 2014), the vast majority of commuters in Nairobi either walk, bicycle or take collective transport, with an average commuting time of 30 minutes. Some 60% of commuters rely on matatus (Salon & Gulyani, 2019). In many cities this would be a desirable modal share; however, matatus are actually a major source of pollution, due in part to poor maintenance. Mbandi et al. (2019) concluded that matatus are responsible for the largest share of vehicle kilometres travelled (VKT) in the city and present the highest fuel consumption (up to 63.2 ± 9.9 l/day for a 33- to 51-seater matatu). While the matatus provide the backbone of public transport in Nairobi, most of these collective transport vehicles are in poor condition and are large emitters of black smoke (BC) (NCC & UNEP, 2019). The lack of incentives for private sector participation may partly explain the deterioration of urban traffic. At the same time, associations of matutu owners have become a strong lobby in Nairobi (Salon & Gulyani, 2019). Some have argued that their opposition has hindered the government's efforts to better regulate the transportation market and/or invest in other forms of public transport, while others note that the matatu industry has actively participated in discussions about the future of public transport, i.e., a proposed Bus Rapid Transport (BRT) for Nairobi (GLI, 2019). In any case, it is widely accepted that matatu business owners and drivers are key stakeholders to involve in any plan or strategy.

In addition to a cleaner fleet, there is a need for infrastructure investment to be complemented by appropriate policies, laws and regulations to meet the challenges of congestion (Rajé et al 2018). Kenya National Government has engaged in major infrastructure projects to ease traffic flows, such as the National Urban Transport Improvement Project led by the World Bank, and the Mass Rapid Transit Network for the Metropolitan Area of Nairobi initiative. Progress has been made in piloting a proposed Bus Rapid Transit, including by establishing designated lanes on the Thika Superhighway. Plans call for full BRT implementation over the next few years. The Government has also undertaken other, more conventional roadway improvements. The EU and the Government of Kenya have also jointly funded the Nairobi Missing Link Roads and Non-Motorized Transport Facilities Project, implemented by the Kenya Urban Roads Authority (KURA), a project that intends to create synergies with the National Road Safety Action Plan 2018-2023. The Government has completed construction of three by-passes to decongest the city Centre. This is aligned with the strategy of the NIUPLAN (NCC & JICA, 2014) for a less centralized development of the city that should be accompanied by the upgrade of the railway system.

Over the past decade, the City of Nairobi has tried to develop a more integrated transport strategy. The Nairobi County Manifesto (2017) proposes various interventions around sustainable urban mobility. In particular, NCC proposed decongesting the city in part by promoting walking and cycling through non-motorised transport (NMT). NMT strategies can be particularly effective in urban areas with high population density such as parts of Nairobi (WHO, 2011). NCC earmarked around USD two million for NMT projects in 2019, and with EU support it is developing a walking and cycling plan for the city (UNEP, 2019). It is hoped that the newly-established Nairobi Metropolitan Services (NMS) agency will prioritize non-motorised transport.

Industrial emissions

Industry represents a relatively small share of national GDP (17 %). Its current impact on urban air quality is not particularly large (Gaita et al., 2014), although industrial emissions are expected to grow in coming years. Key industrial activities in Kenya include cement manufacturing, cigarette production, incinerators, ferrous and non-ferrous metal recycling facilities, sugar factories, galvanized steel production and agricultural products processing. Most emissions are associated with combustion facilities within industries and power plants (UNEP, 2016); collectively, these sources account for 37% of the country's CO_2 emissions (Figure 43).

The main legislative initiatives that address industrial emissions aim at the reduction of GHGs. The Energy Policy and Act (2004) encourages the development of renewable energy sources to enhance the country's electricity supply capacity (currently serving less than two thirds of the population). The policy is implemented through the Energy Act of 2019, which provides for mitigation of climate change. Additionally, the Feed in Tariffs (FiTs) energy policy of 2008, and its later 2012 revision, also seek to foster renewable sources (geothermal, wind, small hydro, solar and biomass). It should be noted, however, that Kenya is the country with the lowest CO_2 emissions per-capita (0.31 t/yr) surveyed in the present report.

As for air quality-related pollutants, the EMCA Air Quality Regulations (2014) identify some industrial sources as 'controlled facilities'; however, these regulations are not yet operational (UNEP, 2016). Kenya has launched several initiatives to improve industrial environmental performance. Tax waivers seek to encourage clean production and installation of pollution prevention technologies (Section 57; EMCA, 2015). Other relevant actions are the enforcement of the Environmental Audit regulations (2003), surveillance of suspect emitters, and measures to encourage the adoption of ISO 14,000 environmental management systems. In 2015 EMCA raised the minimum penalty for an environmental crime to two million KES, on top of the fines considered for fuel adulteration by the Energy Regulatory Commission (one million KES). The impact of such measures in the absence of effective monitoring and enforcement schemes, however, remains unclear.

Open burning of waste

Nairobi produces more than 3,000 t/day of solid municipal waste, of which 62% are disposed of illegally (NCC & UNEP, 2010). Solid waste burning has been defined as a relevant emitting sector in Nairobi (NCC & JICA, 2014) since this practice is thus still common. Although, globally, open burning activities contribute only to six per cent of total $PM_{2.5}$ urban background concentration levels (Gaita et al., 2014), uncontrolled burning has the potential to release extremely dangerous persistent organic pollutants (POPs), including dioxins and furans (IPEP, 2005). One reason why this means of disposal persists in Nairobi is the absence of a comprehensive system of waste management. In addition, there is a lack of public awareness about this practice's harmful impacts. For instance, residents of Korogocho and Viwandani slums have indicated that they do not fully understand the implications of trash burning and do not perceive air pollution as a major threat to their health (Muindi et al., 2014). Uncontrolled burning is a particular concern for people living in the vicinity of dumpsites, such as the Dandora Municipal Dumpsite (Figure 44), which receives most of the city's solid waste and it is surrounded by low-income residential areas. The closure and decommissioning of this dumpsite is long overdue.

EMCA regulations of 2006 provide the basic legal framework for waste management in Kenya; the open-air burning of waste was explicitly outlawed by the 2014 air quality regulations. Those regulations also stipulated emission limits for incinerators. The NIUPLAN called for integrated waste management; however, properly implementing this strategy will require large scale metropolitan infrastructures and significant investments, estimated at USD 250 million. Even before that, the Integrated Solid Waste Management Plan for Nairobi City (NCC & UNEP, 2010) called for a more comprehensive city-scale solution for waste management. This plan highlighted the need for public-private partnerships and education around circular economy precepts, among other measures; it called for a halt to the open burning of waste. The Kibera Integrated Water, Sanitation and Waste Management Project (WATSAN) of UN-Habitat included small scale demonstration activities related to waste collection and recycling. Other projects in the wider scope of the Kenya Slum Upgrading Program (KENSUP) (Government of Kenya and UN-Habitat) are also expected to promote good waste practices and curb open burning.

Indoor air quality

According to regional inventories, household biomass burning strongly dominates PM emissions in Nairobi (Figure 44). Ezzati et al. (2000) found that the exposure to $PM_{2.5}$ in rural Kenya was dramatically increased for individuals (mostly women) involved in indoor cooking. Even in urban areas, the access to electricity or relatively clean fuels such as liquefied petroleum gas (LPG) is unacceptably low. A recent study revealed that dwellers of Nairobi informal settlements such as Korogocho and Viwandani still heavily depend on kerosene (52.8%) as well as charcoal and wood (30.6%) (Dianati et al., 2019). This share reaches 96% in rural areas (WHO, 2018b).

While indoor air quality is not regulated, the Kenyan Government is working to increase electrification rates in both urban and rural areas, and to reduce dependency on polluting fuels. As part of its national Vision 2030, Kenya aims to increase rural electricity access to 40% by 2024 (Government of Kenya, 2018). Universal access to modern energy by 2030 is the ambitious target set by Kenya's Sustainable Energy for All (SE4All) Action Plan (MoEP, 2016). The government plans to subsidise LPG in a bid to make this fuel more affordable and attractive for its citizens. Dianati et al. (2019) find that the current take-up rate of clean stoves is extremely slow, even though the cost of clean household energy has become competitive in urban and peri-urban areas (WHO, 2018b). They suggest that meeting WHO guidelines for air pollution in Nairobi's households will be unattainable in the foreseeable future without (among other needed measures) adequate investment in monitoring and health impact assessment studies. While recognizing the importance of taking into account the particularities of each soci- economic environment, WHO (2018b) experts suggest that the examples of other countries that have increased the supply of clean household fuels, such as Ethiopia and India, should be considered.

Conclusions and recommendations

The Nairobi case study illustrates the challenges that fast-growing cities in the Global South (and elsewhere) face in addressing air quality amidst a plethora of challenges. Interventions are required in various sectors, as are inter-sectoral strategic partnerships with lead agencies and departments at various levels on transport, energy, waste, industry, health, weather, climate change, finance and so on. The main conclusions drawn and recommendations made within the six key guidance framework areas of Air Quality Management Planning (AQMP) are as follows:

1. Air quality standards and monitoring

National air quality standards for the main pollutants (SO_X, NO_X, CO, O_3, Pb, PM_{10} and $PM_{2.5}$) have been provided for industrial, residential and rural areas as well as other controlled areas. In some cases these standards are as stringent as those of Europe; however, they haven't shown a real impact on air pollution levels since the Nairobi local government (NCC) lacks the capability to enforce them.

Pilot studies using low-cost sensors, coupled with readings from fixed monitoring points, have provided at least an indicative understanding of the air pollution phenomena in Nairobi. These experiments illustrate the possible benefits of using low-cost sensors for supplemental monitoring of air quality. However, such approaches still have considerable technical limitations (WHO, 2018) and cannot support enforcement actions. The need to systematically monitor emissions from industry and traffic has been consistently pointed out by studies and official reports. In particular, the inclusion of emission controls as a part of annual vehicle inspection has been suggested as one of the measures with the highest potential public health benefits.

Recommendation: Develop a comprehensive monitoring strategy based on a reliable permanent air quality monitoring network. Undertake this in cooperation with NEMA, building on the capabilities and experience of KMD and based on the monitoring strategy sketched out in the NIUPLAN, which is consistent with the findings of scientific studies in Nairobi.

Recommendation: Coordinate and upscale long-standing international collaborations (SEI, UNEP, etc.), research projects and pilot studies to properly train and build the capacity of dedicated staff.

Recommendation: Strengthen the capacities of NEMA and NCC to enforce EMCA regulations on vehicular emissions (Kenya Standard KS 1515), particularly on Nairobi's matatus.

2. Emission inventories and modelling

There are no local inventories to support city-scale analysis and to inform on the priorities of the air quality agenda. This gap is identified by Nairobi's Air Quality Action Plan (2019-2023) (NCC & UNEP, 2019), which calls for the development of an urban emission inventory and projections both for air quality pollutants and GHGs. Similarly, there is a complete lack of modelling studies to support the evaluation of interventions and related cost-benefit analyses.

Recommendation: Compile a local emission inventory focussing on road traffic (using already- available data regarding fleet composition and total mileage estimates), household combustion and the waste sector, particularly open burning practices.

Recommendation: Develop modelling capabilities in cooperation with local universities and international collaborators to carry out the assessments called for in the Nairobi Air Quality Action Plan.

3. Health and other impacts

Available research indicates that direct exposure to emissions from roads, household combustion of solid fuels and kerosene and waste open burning have a strong impact on health. Furthermore, studies demonstrate that this is a problem of environmental justice since vulnerable groups are often the main victims of high pollution levels. Current investigation suggests that walking represents a large share of mobility in Nairobi; these pedestrians are often exposed to high roadside pollution levels.

Recommendation: Engage the authorities responsible for health care to provide a clearer connexion between air pollution and its effect on human health. Establish relevant and well-articulated health-environment indicators.

Recommendation: Develop adequate formal financial models and regulations (e.g., zero-rated duties on solar panels) and a corresponding framework for stakeholder collaboration, to move from dirty to cleaner fuels at the household level.

Recommendation: Provide for the necessary enabling conditions to reduce accidents and minimize roadside exposure of pedestrians; this is a very effective strategy in terms of health.

4. Communication

The effective communication of environmental data to the public and decision makers is as important as an adequate monitoring strategy itself. Open access platforms are steps in the right direction; they should be set up and used to help disseminate monitoring data. Recent initiatives indicate that involving citizens in small-scale demonstration projects may be an effective tool to increase their awareness about air quality, which is currently very low in Nairobi (Ngo et al., 2017). Attitudes towards pollution are critical to effect the behavioural changes needed to reduce exposure (Muindi et al., 2014). Moreover, the perception of air pollution influences the response to interventions and, in turn, the willingness of national and local government officials to develop air quality plans and implement priority measures.

Recommendation: Consolidate and encourage collaborative open-source, low-cost, sensor-based initiatives such as “Clean Air Nairobi”, to raise awareness and engage the population.

Recommendation: Develop communication mechanisms for health indicators and other advocacy instruments that target policy makers as well as the public, especially low-income communities that disproportionally suffer the effects of poor air quality.

Recommendation: Increase communication and consumer awareness to overcome cultural barriers and provide for the greater penetration of clean cooking and heating domestic technologies.

Recommendation: Strengthen information and communication campaigns for current and future air quality plans. Include this topic in academic curricula for a more effective promotion of environmental concern among young people.

5. Clean Air Action Plans

There is a profuse and fragmented environmental regulation in Kenya that has hindered the effective linkage with operational programs and strategies at the local level, making effective air quality management difficult (Shilenje, 2014). Nairobi now has the necessary regulatory framework and instruments to tackle air quality issues in the city (until fairly recently, any such efforts could only be undertaken at the national level). The Nairobi Integrated Urban Development Master Plan (NIUPLAN) (NCC & JICA, 2014) includes a comprehensive and accurate diagnosis of the environmental challenges in the city. It also sets forth an overall strategy for a balanced and sustainable urban development in line with the general national strategy articulated in Kenya’s Vision 2030 (Government of the Republic of Kenya, 2018). More recently, the Air Quality Plan 2019-2023 (NCC & UNEP, 2019), was launched to focus on air quality issues, a major milestone in the scope of AQM in Kenya and Nairobi.

Recommendation: Further develop and begin to implement the actions included in the Nairobi's new air quality plan to establish tangible goals, define implementation means and secure the resources needed.

Recommendation: Implement an inspections scheme to make the existing regulations for vehicle emissions operational and ensure the proper maintenance of the fleet, particularly matatus.

Recommendation: Consider setting up a single, professional operator to lead implementation of the Mass Rapid Transit System (MRTS) plan and other public transport strategies, with the active involvement of current operators of buses and matatus and their associations.

Recommendation: Develop a city-wide network plan for NMT infrastructure, and otherwise scale up and expand walking and cycling networks, particularly to low-income neighbourhoods.

Recommendation: Continue to work towards fully eradicating illegal waste management practices.

Recommendation: Carry out a comprehensive analysis of the current air quality plan in the wider scope of the national strategy (Kenya's Vision 2030), as well as climate policies, to prioritize actions with the highest health benefits and co-benefits.

Recommendation: Draw closer links between measures to improve air quality and other strategies (e.g., urban planning, transportation, sanitation), to maximize positive "win-win" outcomes in the context of a rapidly growing metropolis.

6. Governance

As discussed, the legal instruments and regulations needed to address air pollution in Kenya are largely in place. Plans and sectoral reports consistently point out that the lack of public awareness/support and monitoring capacity are two major barriers to the actual enforcement of these regulations. A third important obstacle involves the lack of administrative capacity and the weakness of institutions. In addition, corruption has been identified an essential obstacle to progress in Kenya. According to Transparency International (2019), Kenya ranks 37th out of 180 in the list of corrupt countries (the worse ranking of all the countries considered in this report). For instance, the misappropriation of funds has been described as one of the major challenges to the successful implementation of Kenya's Vision 2030 (Rajé et al 2018). This circumstance contributes to the dysfunctions in environmental management encountered in Nairobi. At the same time, some authors suggest that an effective approach to tackle urban issues needs to consider the improvement of economy and life conditions in all Kenya.

Recommendation: Strengthen relevant public institutions. Provide the enabling conditions for effective multi-level governance and a more fluid coordination between national and local administrations. More specifically, provide for coordination mechanisms to co-develop multi-level strategies that focus on local air pollution, but within a wider context of socio-economic vulnerability and general economic development.

Recommendation: Increase the support of the national government to local administrative entities such as NCC, to gradually develop and devolve full monitoring and enforcing capabilities.

Recommendation: Following guidelines proposed by NIUPLAN, develop mechanisms to provide for the meaningful engagement of stakeholders (including from the private sector) in relevant international cooperation projects, in support of strategic development initiatives in Nairobi.

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