TRANSPORT EMISSION MAPPING, MONITORING AND CAPACITY BUILDING IN 5 SELECTED AFRICAN CITIES

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GROUPE DE LA BANQUE AFRICAINE DE DÉVELOPPEMENT

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GLOSSARY

ADT	Average Daily Traffic
AfDB	The African Development Bank
ADEME	The French Environment and Energy Management Agency
ADMS	Atmospheric Dispersion Modelling Software
AEV	Average Equivalent Vehicle
AQMS	Air Quality Monitoring System
ATSDR	Agency for Toxic Substances and Disease Registry
BNETD	Bureau National d'Etudes Techniques et de Développement
BRT	Bus Rapid Transit
CBA	Cost Benefit Analysis
CCAC	Climate & Clean Air Coalition
CDM	Clean Development Mechanism
CEN	European Committee for Standardization
CER	Certified Emission Reduction
CERC	Cambridge Environmental Research Consultants
CIE	Compagnie Ivoirienne de l'Électricité
CIF	The Climate Investment Fund
COP	Conference of the Parties
DALY	Disability Adjusted Life Years
DEFRA	Department for Environmental Food & Rural Affairs
DICE	Dynamic Integrated Model of Climate and the Economy
DOE	Designated Operational Entity
DQO	Data Quality Objective
DTRSR	Missions de la Direction du Transport Routier et de la Sécurité Routière
EA	Enabling Activity
EAVE	Equivalent Average Vehicle Emission
EDA	Enhanced Direct Access
EF	Emission Factor
EEA	European Environment Agency
EM	Expectation Maximization
FIP	Forest Investment Program
FSP	Full-sized Project
FUND	Framework for Uncertainty, Negotiation and Distribution
GCF	The Green Climate Fund
GDP	Gross Domestic Product

GEF	The Global Environment Facility
GHGs	Greenhouse Gases
GNP	Gross National Product
GSM	Global System for Mobile Communications
HDT	Heavy Duty Trucks
IBRD	International Bank for Reconstruction and Development
IDA	International Development Association
IDL	Instrument Detection Limit
IHME	Institute for Health Metrics and Evaluation
INDC	Intended Nationally Determined Contributions
IPP	Iindependent power producers
ISO	International Organization for Standardization
IT	Information Technology
LDCF	Least Developed Countries Fund
LDV	Light Duty Vehicle
MDB	Multilateral Development Bank
MDL	Method Detection Limit
MSP	Medium-sized Project
NDA	National Designated Authorities
NMT	Non-Motorized Transport
NN	Nearest Neighbor
NO	Nitrogen Monoxide
NO_2	Nitrogen Dioxide
NO_x	Nitrogen oxides ($NO + NO_2$)
OPH	Off-Peak Hours
QA/QC	Quality Assurance / Quality Control
PAGE	Policy Analysis of the Greenhouse Effect
PC	Passenger Car
PIF	Project Identification Form
PM	Particulate Matter
$PM_{2.5}$	Particulate matter (<2.5 μm aerodynamic diameter)
PM_{10}	Particulate matter (<10 μm aerodynamic diameter)
PPCR	The Pilot Program for Climate Resilience
PPG	Project Preparation Grant
PSD	Passive Sampler Device
RM	Reference Method
SCCF	The Special Climate Change Fund

SO_2	Sulfur dioxide
SREP	The Scaling up Renewable Energy Program
SSA	Sub-Saharan Africa
STAR	System for Transparent Allocation of Resources
TEA	Tri Ethanol Amine
TPM	Total Particulate Matter
UNDP	United Nations Development Program
UNEP	United Nations Environment program
UNFCC	United Nations Framework Convention on Climate Change
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

1. INTRODUCTION

1.1 Background

Emissions from transportation are growing significantly in Africa, driven by urban sprawl, rapid motorization and low levels of institutional capacity to manage traffic and its impacts. The World Health Organization (WHO, 2012) has calculated that 176,000 deaths per year in Africa are due to outdoor air pollution. The United Nations Environment Program (UNEP) estimates that 90% of urban air pollution in developing countries is attributable to vehicle emissions.

High pollutant concentrations can be found in transport corridors, due to the road traffic congestion (especially during rush hours) and the aging vehicle fleet commonly found in developing countries and more specifically in sub-Saharan African (SSA) cities. Engine exhaust, evaporation of fuel, brake and tyre wear, and unpaved roads can generate different air pollutants, including dust and gaseous compounds.

The United Nations General Assembly recently adopted the post-2015 development agenda with 17 Sustainable Development Goals (SDGs). Proposed actions for achieving air quality targets include assistance for easing traffic congestion, outlawing importation of over-aged vehicles and the promotion of non-motorized transport. Beside these technical transport solutions, actions are proposed for strengthening countries capacities in air quality monitoring and air quality management. According to a recent article published in the Environmental Pollution Journal (Amegah and Agyei-Mensah, 2017), there is a clear lack of urgency from SSA governments in addressing the worsening urban air quality situation in the region possibly owing to the absence of (1) reliable data on air pollution levels due to weak and non-existent air quality monitoring networks in countries, and (2) local evidence of the environmental and human health impact of air pollution, and the magnitude of the associated health risk.

Emissions from transportation related sources are a major cause of chronic respiratory related illnesses and pre-mature deaths in Africa. In addition to human health problems, it is now common knowledge that, emissions are major drivers of global warming and climate change. The consequences of climate change are increasingly being felt on food security, and via negative impacts on economies in general. In many cases, low income people, women, and the disabled typically bear a disproportionate share of the burdens and fewer of the benefits when transportation policies and investments are implemented.

In the transport sector, a new paradigm for sustainable transportation and management is taking hold, by reducing the need to travel through efficient land-use planning; smarter travel planning; shifting travel to more efficient and greener transportation modes; improving the quality of vehicles and fuels; and optimized traffic network management. Key stakeholders in many cities in Africa are not sure where best to start to address their transport emission problems because of lack of local data and expertise, a situation which results in holding back progress on green and sustainable transport initiatives.

To address this gap, there is a need to develop a systematic approach and assessment to orient governments, key municipal stakeholders, and policy-makers on effective ways to collect, store and analyze data and map air pollution levels within cities. This will facilitate monitoring of air pollution trends in cities; projection of the impact of investments on air pollution and carbon-finance benefits; efficient planning of land-use and transport systems; and most importantly, ensure that emissions levels are contained within internationally acceptable thresholds.

Against the above background, the African Development Bank commissioned Ramboll Environ in 2016 to carry out a pilot project in five selected cities based on regional diversification and ongoing transport projects namely; Abidjan (Cote d'Ivoire), Rabat (Morocco),Yaounde (Cameroun), Dar Es Salaam (Tanzania) and Lusaka (Zambia) to build capacity in concerned government agencies in transport emissions monitoring, raise awareness of options for financing low emission transport technologies and facilitate the quantification of the wider benefits of low emission transport.

This project is within the Bank's Ten-Year Strategy (2013 - 2022), which seeks to help Africa gradually transition to "green growth" that will help protect livelihoods; improve food security; promote innovation and sustainable use of natural resources; and economic development.

1.2 Objectives

The overall objective of the study is to develop a system for African cities to produce accurate transport emissions maps and to build capacity in traffic emissions mapping and monitoring in selected countries in Africa with a view to rolling out the system to the entire continent.

The specific objectives of the project are:

- Build the capacity of government transport and environmental agencies in data collection, transport emissions modelling, forecasting and monitoring transport related emissions;
- Build expertise in financing and Cost Benefit Analysis (CBA) in the urban transport sector as well as the government environmental agencies;
- Review and recommend environmental policies, legislation and institutional frameworks to strengthen monitoring of air pollution, including budget requirements;
- Raise awareness of financing options for low emission transport systems and help countries to quantify the wider benefits of these technologies.

1.3 Scope of Work

In order to meet the objective and according to the initial Terms of Reference (ToR), the following activities have been completed by Ramboll Environ:

- Identification of cost effective instrumentation and software specifications suitable for monitoring air emissions/concentrations in developing countries together with working with the executive agency(ies) to make procurements of instruments and software;
- For a pilot project, along planned transport projects, production of baseline and forecast emissions/concentrations maps;
- Use of appropriate traffic emission/concentration modelling and mapping programmes designed to provide detailed estimates of vehicle emissions and concentrations on urban road networks;
- Preparation of procedures and manuals and provision of staff training in data collection, pollution monitoring, emissions/concentrations calculation and cost benefit analysis (CBA);
- Analysis of deficiencies in monitoring air pollution in selected countries/cities with respect to policies, legislation and institutional framework to allow appropriate recommendations including budget requirements and sustainable sources of financing to be made;
- Analysis of existing transport, energy and environmental policies and identification of potential sources of domestic and international finance in one of the host countries and compilation of an economic cost benefit analysis for their adoption.

1.4 Content of this report and limitations

This document is a project completion report for the activities presented above. It includes the following parts:

1. <u>Identification and Procurement of Cost Effective Equipment</u>
   This preliminary chapter presents briefly the different monitoring, mapping and modeling methods, identifies the most suitable equipment and software for developing countries, provides technical specifications and gives a summary of the procurement phase carried out by Ramboll Environ during this project.

2. Emissions and Air Quality Mapping
   The methodology implemented for traffic assessment, air quality monitoring, emissions calculation and air quality mapping is detailed in a first section of this chapter. The data collected and assumptions are presented for each of the 5 cities, as well as the predicted pollutant concentrations maps in transport corridors. For each city, a first set of recommendations is provided to scale-up the approach to a complete city scale.

3. Socio-economic Analysis for Abidjan and Côte d'Ivoire
   This socio-economic chapter contains an analysis of transport and energy subsidies related to low emission transport technologies in Abidjan, the selected pilot city for this specific activity. The recommended Cost Benefit Analysis (CBA) model is described, and a manual for conducting similar CBA is provided. Originally and according to the terms of reference a significant part of this socio-economic study was on the "determination of carbon tokens and financing of projects", but as changes in the carbon emission market has left this with little relevance, the manual and training has focused on the economic Cost Benefit Analysis of low emission transport technologies with an emphasis on the economic benefits of reduced emissions and traffic congestion.

4. Review of Regulatory and Institutional Framework
   This chapter assesses the existing regulatory and institutional framework in the five cities. The assessment is mostly based on a desktop review of existing legislation, policies and available organisational descriptions supplemented by brief interviews conducted on the ground with key stakeholders in the five cities. A gap assessment was performed using a number of pre-defined indicators, elaborated in a specific methodology section. The assessment part is followed by a recommendations part where the identified gaps are addressed through a number of policy, regulatory and/or institutional initiatives which apply to a number of the five cities.

5. Training and Manuals
   This activity concerns the training of relevant staff within each of the five cities, in data collection, pollution monitoring, emissions/concentrations calculation and cost benefit analysis (CBA). It also includes preparation of specific manuals and training material.

6. Main Findings and Recommendations
   This last chapter summarizes the main findings resulting from the project, focusing on the capacity assessment of the local agencies and on the institutional framework of each city/country. Finally, a set of recommendations and a follow-up program for scaling-up the pilot project to the whole city and all other cities in African developing countries is provided.

2. IDENTIFICATION AND PROCUREMENT OF COST-EFFECTIVE EQUIPMENT

2.1 Introduction

This preliminary chapter presents briefly the different monitoring, mapping and modeling methods available, identifies the equipment and software that are most suited for developing countries, provides technical specifications, and summarizes the procurement phase carried out by Ramboll Environ during this project. This chapter also presents the equipment ultimately chosen and bought on behalf of the Bank.

2.2 Identification of Cost-Effective Equipment

2.2.1 Monitoring Equipment

Different methods for air quality monitoring have been extensively investigated in the framework of this project, and are detailed broadly in a dedicated Manual presented in Chapter 6 of this report.

In summary, monitoring devices can be classified in two main categories:

- Active Sampling Devices: Reference Methods (RMs) or indicative methods including microsensor monitoring systems. Such instruments involve the use of an air sampling pump or fan to actively pull air through a collection device.
- Passive Sampling Devices (PSDs) that generally rely on the unassisted molecular diffusion of pollutants through a diffusive surface onto an adsorbent.

Focusing on transport corridors, pollutants of interest are particles and main gaseous compounds emitted or generated by traffic. The most important pollutants to monitor include:

- Nitrogen dioxide (NO_2);
- Particulate Matter (PM) or dust;
- Sulfur dioxide (SO_2).

Less sensitive pollutants can be added to this list, such as benzene and carbon monoxide (CO).

When an air pollution measurement device is designated as a Reference Method (RM), this signifies that it meets a clearly defined measurement standard for a specific criteria pollutant and has completed a rigorous testing and analysis protocol. Successful completion of this process and designation as an RM indicates that the instrument is the best available technology for monitoring compliance of a pollutant with respect to the appropriate regulatory standard.

These reference methods are generally used for stationary and continuous measurements required by national air quality regulations. The cost of such sensors is generally high, and the equipment needs to be protected, frequently calibrated, and kept within a fixed temperature range. Generally, monitoring equipment is gathered and placed in a fixed station, also called an Air Quality Monitoring System (AQMS). Such a system can also become mobile when embedded in a mobile device (i.e., truck, trailer). However, the cost of such AQMS generally ranges between 100 k€ and more than 200 k€, which is clearly a limitation within the framework of this project.

Passive Sampling Devices (PSDs) are relatively inexpensive methods, requiring only modest hardware and infrastructure for use in the field. The greatest expense associated with PSDs is the laboratory analysis of the exposed sampling media. PSDs are small, lightweight, unobtrusive, and do not require power to operate. These characteristics allow PSDs to be more easily deployed across large areas, where a relatively large number of devices can be implemented near numerous road segments at almost any location (also called "Saturation approach" in the literature).

However, there are some limitations for using PSDs in the selected cities associated with this project. First, PSDs need long exposure times to collect representative data, which can be a serious limiting factor for near-road applications because PSDs are not able to measure short-term concentration peaks, and more generally, time-evolution of concentrations. Moreover, passive devices cannot be used for PM measurements and each diffusion tube used for sampling must be analyzed by an accredited laboratory, which are not often present in African countries.

The most cost-effective equipment identified for this project are compact air quality stations that use micro-sensors. Such methods (called "indicative" by EU regulation) are well adapted to assess pollution levels close to traffic. Several compact monitoring stations and portable samplers that are commercially available may be useful for characterizing air pollution across large areas. These stations and samplers can also be used to conduct more focused studies on a small set of road segments to further evaluate potential near-road monitoring sites. Many of these samplers are battery-operated and have many of the same advantages of passive devices, including the flexibility of making monitoring possible at almost any location. These samplers are more expensive than passive devices; however, generally cost significantly less compared to reference equipment (typically by at least a factor 3). These samplers can also collect real-time, near real- time, or otherwise integrated data, so that the data collected from these samplers may be used for short-term concentration analysis. There are two general sensor measurement types/categories: gas and particle. The current generation of gas sensors operate using either electrochemical, metal oxide, or spectroscopic technologies. Particle sensors sample particulate matter (PM) by measuring particle mass directly or indirectly by light absorption, which can be a surrogate for black carbon and 'brown' carbon (e.g., dust, soil, organic matter).

These micro-sensors are small, inexpensive monitoring devices representing a 'relatively' new style of air pollution measurements that provide valuable new information such as spatial and near-real time pollutant concentrations. Micro-sensors have already been utilized in different environments, but have not been formally used in a compliance monitoring context. This category of sensors, recommended recently by UNEP for developing countries[1], are very good complements to existing reference stations in cities.

Air quality monitoring in transport corridors generally requires supplementary measurements, including traffic counting and meteorological observations. Traffic counting can be easily performed using manual counters and video cameras, whereas meteorological parameters can be recorded by mobile and standard meteorological stations. A computer (laptop) is also required to download data using a data logger.

2.2.2 Mapping Software

Similar to air quality monitoring, tools for air quality mapping have been extensively investigated in the framework of this project and a dedicated manual is presented in the Chapter 6 of this report.

Interpolation techniques developed in Geographical Information System (GIS software) offers particular potential for air quality mapping, based on a combination of monitored pollution data and auxiliary variables such as population density. However, these methods do not consider the physical processes of pollutant dispersion. They are limited by the temporal resolution of the auxiliary data and monitoring results. Consequently, these methods cannot properly capture short-term concentrations with hourly or daily resolution. Moreover, these techniques cannot be used to forecast air quality and to predict the impact of future projects, such as changes in transport infrastructure.

To overcome these limitations, dispersion modelling can be used using Air Quality Models (AQMs).

[1] https://www.unenvironment.org/explore-topics/air/what-we-do/monitoring-air-quality

Air Quality Models are mathematical tools that simulate the physical and chemical processes surrounding air pollutant dispersion and atmospheric chemical reactions. They provide estimates of temporal and spatial distribution of realistic pollution levels and generate maps of pollutant concentrations using interpolation techniques. Modeling studies, in combination with air quality monitoring, are also essential and complementary tools for long- and short-term air pollution control strategies. For instance, model-measurement comparisons allow one to fill in measured concentration gaps using background concentrations. The resulting calibrated model is a unique tool that represents atmospheric dynamics and chemistry at a local scale. Thus, AQMs have become a valid instrument for air quality practitioners in many activities, such as:

- Setting emission control regulation;
- Assessing compliance of actual pollution levels;
- Predicting the impact of new infrastructure planning (new road construction, etc.) on human health;
- Selecting the best location for monitoring stations; and
- Assessing the impact of different emissions scenarios, including lifecycle management, maintenance, and modification of vehicle fleets.

Dispersion model predictions are in most cases a function of meteorology, street geometry, static data (surface roughness, elevation, etc.), traffic volumes, and emissions factors. The acquisition and pre-processing of these data is an important part of any modeling study, since the performance of a model greatly depends on the quality of the inputs. Pre-processing software is generally free and has not been considered in the procurement part of this project, which focuses mainly on dispersion modelling software (called “dispersion models”).

There are a variety of dispersion models specially developed for, or simply used, in transport corridor studies. They can be useful in air quality and traffic management, urban planning, interpretation of monitoring data, pollution forecasting, human exposure studies, etc. Although there are no clear-cut distinctions between different categories, models might be classified into groups according to their physical (e.g. reduced-scale) or mathematical principles (e.g. Gaussian or Computational Fluid Dynamics (CFDs)) as well as their level of sophistication (e.g. screening, semi-empirical, numerical). Considering the purpose of this project, the local resources in terms of skills, computational power, and the budget allocated by the Bank, preferred software is that which is easy to use and based on robust numerical approach (Gaussian method).

2.3 Procurement of the equipment

On the basis of the equipment category identified in the above section, technical specifications were elaborated on and a Request for proposal (RfP) was sent to a list of international providers. Then, an analysis of the proposals was performed by Ramboll Environ and recommendations were made and presented to the Bank. This section presents each step of this procurement process for air quality monitoring equipment and the mapping software.

2.3.1 Monitoring equipment

2.3.1.1 Technical Specifications

The technical requirements sent to the different providers are listed below and in Table 2-1:

- The monitoring station shall be a compact, integrated, protective box system, and must be able to contain several sensors;
- The sensors shall allow dynamic measurements of species such as NO_x (or NO_2), SO_2 and PM_{10}using chemical or optical technologies (expected concentration range: 0 – 300 µg/m^3);
- The system shall work autonomously using embedded batteries, allowing measurement for at least a 24-hour time period;
- In addition, and for longer periods, the power can be supplied by solar panels;
- The data must be stored by a data logger every several days and can be downloaded via a USB device;
- As an option, the data can be transmitted to a PC or a cloud system via a GPRS connection;
- A PC-based software must be provided to process the dataset and display time series;
- The equipment is adapted to African climatic conditions (especially to strong heat and humidity);
- The equipment is an “easy to use” system and can be handled by one operator;
- The calibration of the system can be done by local operators.

Table 2-1: Equipment expected from the provider for the 5 cities linked to the project

Equipment	Quantity per city	Total
NO_2 sensors	2	10
SO_2 sensors	2	10
PM_{10} sensors	2	10
Compact Air Quality stations (boxes) + batteries and data logger system	2	10
Software allowing to process the data	1	5
Tripods for stations	2	10
User guides in English and French, detailed documentation and sensor validation documents (all in PDF Format)	1	5

The equipment shall be sent by the provider to the Bank office in each city (5 packages).

2.3.1.2 Proposals Analysis

A Request for Proposal (RfP) – including Technical Specifications - has been sent to several international equipment suppliers. This document provides a technical and financial analysis of the proposals received from these suppliers. Results and the equipment/provider selected are presented in this section.

The RfP and associated technical specifications were communicated to the following international suppliers:

- AEROQUAL (New Zeland)
- CAIRPOL/Environnement SA Group (France)
- EcoLogicSense (ELS) (France)
- ECOMESURE (France)
- VAISALA (Finland)

All these suppliers have submitted a technical and a financial proposal and have been integrated in the selection process. The systems/sensors proposed by the 5 consulted suppliers are presented in the table below.

Table 2-2: System reference proposed by each supplier

Provider	Monitoring System
AEROQUAL	DustSentry
CAIRPOL	Cairnet GPRS 3 sensors + PM
EcoLogicSense (ELS)	Box ePM, eNO2, eSO2
ECOMESURE	ECOMSMART
VAISALA	AQT420

All the proposed systems meet the technical requirements, except the DustSentry system from AEROQUAL which does not integrate NO_2 and SO_2 Sensors. It is worth noting that AEROQUAL proposed another system that integrates gas measurements (AQM65), however this monitoring system cannot be considered compact (>60 kg in weight). Consequently, the AEROQUAL system was disqualified and not considered in the financial analysis.

Based on financial proposals sent by the 4 remaining suppliers, a financial analysis has been conducted. As some of providers were not able to provide optional equipment, the comparison was made without additional options. The final costs are presented in the table below.

Table 2-3: Financial proposal for 10 stations (2 per city)

	CAIRPOL	ELS	ECOMEUSRE	VAISALA
Costs in € (without taxes)	65,357	76,005	85,700	153,735

Note that all the systems can be used for 1 year without calibration. After the 1st year, sensors must be sent to the supplier for calibration purposes.

2.3.1.3 Monitoring Equipment Selected

Following a technical and financial analysis, the Cairnet Station developed by CAIRPOL has been selected for air quality monitoring in the framework of this project, especially due to the performance of the sensors embedded, the quality of the services (in French and English), and the good reputation of the company (CAIRPOL is part of the international ENVIRONNEMENT SA Group), especially in Africa.

The Cairnet system is made of a network of miniature sensors that allows real-time- measurement of traffic-related pollution. Tracked pollutants are nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and atmospheric particulate matter with a diameter less than or equal to 10µm (PM_{10}). The Cairnet station remotely communicates measurement data from the GPRS network to a relay antenna. Once the data is sent, it is collected and stored on a FTP/SFTP server. Measurement data are then sent to a remote server for visualization on the Caircloud interface. The whole system is depicted on the following figure (Figure 2-1).

Figure 2-1: Scheme of the communication system of the Cairnet Station

The Cairnet system consists of the following sensors:

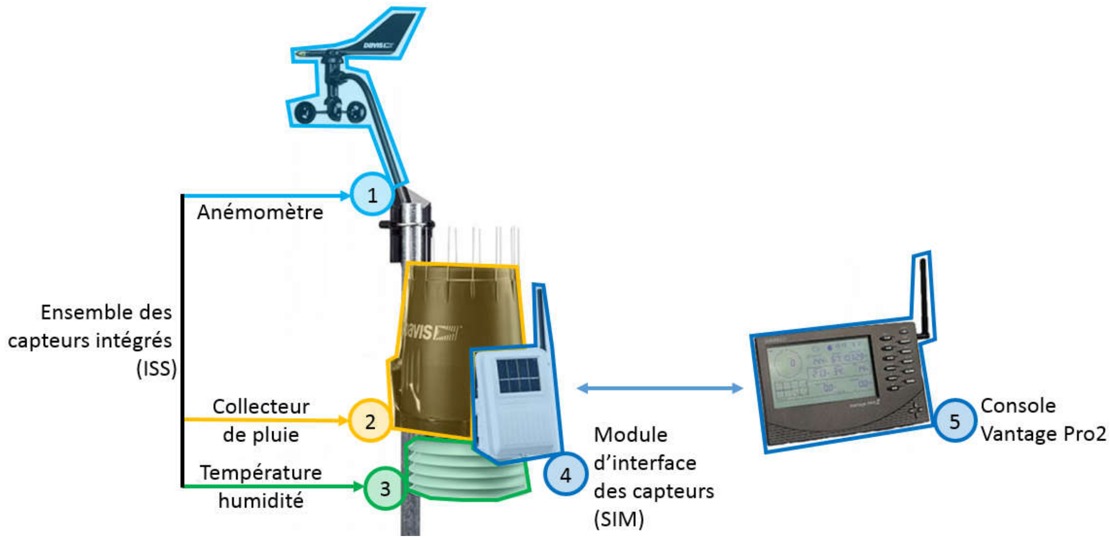
- Two Cairsens (integrated air quality measurement appliances, which measure NO_2 and SO_2),
- One optical particle counter to measure PM_{10} and $PM_{2,5}$ adjacent to two Cairsens (located at the lower part of the Cairnet).

In addition, each Cairnet station has a hardware architecture that manages and centralizes the measurement data from the sensors. This architecture is configured to send the data via the Internet to an online Caircloud results acquisition and processing interface.

The DAVIS Vantage PRO2 meteorological station has been selected to complement the air monitoring equipment. It includes a set of integrated sensors (Integrated Sensor Suite – ISS), for which the collected external meteorological parameters are transmitted to a Vantage Pro2 visual display unit. The overall system is shown in Figure 2.2 below. The version of the ISS in this guide is wireless, sun-powered, and transmits the data to the visual display unit through a low-power radio-link. It includes a temperature sensor, a rainwater collector, a hygrometer and an anemometer. The temperature and humidity sensors are located inside a passive radiation shield, in order to minimize the impact of sunrays. The anemometer measures wind speed and direction.

The data provided by the meteorological station can be analyzed on a computer via the Weatherlink software. The software communicates with the meteorological station via a data-logger on the Vantage Pro2 visual display unit.

Figure 2-2: Design of the selected weather station (Vantage Pro2)



More details about this monitoring equipment can be found in the dedicated User Guides prepared by Ramboll Environ and presented in Chapter 6 of this report.

2.3.2 Mapping Software

2.3.2.1 Technical Specifications

The main technical requirements of the software required are listed below:

- The calculation code is embedded in software which runs on Windows and has an easy-to-use interface;
- It calculates concentrations and deposition of pollutants around road intersections and over entire transport corridors (i.e. a road network);
- The averaging time may be an annual average or a shorter period (e.g. hourly time step). The software allows for the calculation of percentiles and exceedance values that are of interest;
- Calculations are based on local hourly meteorological datasets, including the following parameters: wind speed and direction, temperature, rainfall, solar radiation, and/or cloud cover. Atmospheric stability shall be considered (Pasquill or more advanced approaches);
- The system considers the local topography, including terrain elevation and street-canyon effects;
- The software contains a GIS tool that allows users to enter road network information, such as emissions, and to display and map pollutant concentrations over the domain. The software can also be linked to an external open-source GIS program;
- The system includes a simple NO_x-chemistry model for NO_2 concentrations.

The following package is expected from the provider:

- 1 multiuser licence for the African Development Bank Head Quarter, for use in all 5 cities, for up to 8 total users (1 user for 2 of the cities, 2 users for the 3 other cities);
- Installation packages ;
- User guides in English and French (PDF Format);
- Detailed documentation and validation documents (all in PDF Format).

2.3.2.2 Proposals Analysis

As for monitoring equipment, a specific RfP and associated technical specifications have been communicated to the following international suppliers:

- ARIA Technologies (France)
- CERC/NUMTECH (UK) - NUMTECH is the distributor of CERC for Africa
- Janicke Consulting (Germany)

All these suppliers have submitted a technical and a financial proposal and have been integrated in the selection process. The software proposed by the 3 consulted suppliers are presented in the table below.

Table 2-4: Software reference proposed by each supplier

Provider	Monitoring System
ARIA Technologies	ARIA Impact 1.8
CERC	ADMS Roads 4.0
Janicke Consulting	LASAT 3.3

All the proposed modeling systems meet the technical requirements, although each have technical differences.

Available international guidelines, performance analysis, and recommendations provided by reference agencies (e.g. from EU FAIRMODE, US EPA, INERIS French Institute) have been considered for the technical assessment.

Note that Janicke Consulting was not able to provide a software interface and documentation in French and English (English only).

The analysis compared the financial proposals sent by the 3 suppliers. The costs proposed are presented in the table below.

Table 2-5: Financial proposal for the Air Quality Software (8 perpetual licenses for African cities)

	ARIA	CERC/NUMTECH	Janicke Consulting
Costs in € (without taxes)	22,050	21,932	37,450

2.3.2.3 Software package Selected

Following the technical and financial analysis process, the ADMS Software developed by CERC has been selected for air quality modelling and mapping for this project.

The selected package includes :

- 1 perpetual and multiuser license for the African Development Bank Head Quarter, for use in 5 cities, by up to 8 users;
- Technical support (hot line) for 1 year;
- Installation packages ;
- User guides in English and French (PDF Format);
- Detailed documentation and validation documents (all in PDF Format).

2.3.3 Summary

According to a rigorous procurement process, 10 compact Monitoring stations (CairNet) and 8 Software licenses (ADMS-Roads) have been bought on behalf of the Bank. This equipment has been complemented by other smaller equipment, including compact meteorological stations (Davis Vantage Pro2), Laptops (DELL), video camera (GoPro), and manual counters. Details are presented in the Table below.

Table 2-6: List of eqsuipment procured and used in the framework of the project

Equipment list	Total
CairNet Stations	10
Meteo stations	5
ADMS Licenses	8
Video Cameras	5
Laptops	5
Manual Counters	20

3. EMISSIONS AND AIR QUALITY MAPPING

3.1 Introduction

This chapter presents the methodology designed for Air Quality Mapping over pilot areas representative of important transport corridors within five cities in Africa: Abidjan, Rabat, Dar Es Salam, Lusaka and Yaoundé. To assess the vehicle emission impact on the air quality within the transport corridor, four pollutants, considered to be significantly emitted by road traffic, have been selected: Nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and fine particulate matter (PM_{10} and $PM_{2.5}$).

In the first part of this chapter, the methodology –schematized in the Figure 3-1 – is presented according to the following strands:

- Traffic Network Analysis (section 3.2.2), reviewing and analyzing the network traffic and the vehicle fleet within the transport corridor,
- Emissions calculation (section 3.2.3), describing the bottom-up approach for the development of an emission inventory using the world-wide used COPERT 5 emission tool,
- Air Quality Mapping (section 0), presenting the ADMS-Roads model implemented for the production of pollution maps over the whole transport corridor domain and the calibration with measurements.

In complement to these three axes, monitoring campaigns have been conducted to fill in missing data. Monitoring campaigns are completely integrated in the methodology because they provide a very detailed with high accuracy data set but limited to small areas not representative of the entire domain of study. The key parameters monitored and recorded were pollutant concentrations under two main regimes (road traffic influence and urban background), vehicle volume & categories and meteorological parameters. Monitoring campaigns are involved in each strand of the methodology. For clarity, its description has been done separately in a dedicated section (section 3.2.1) as an umbrella for all other parts described in this chapter.

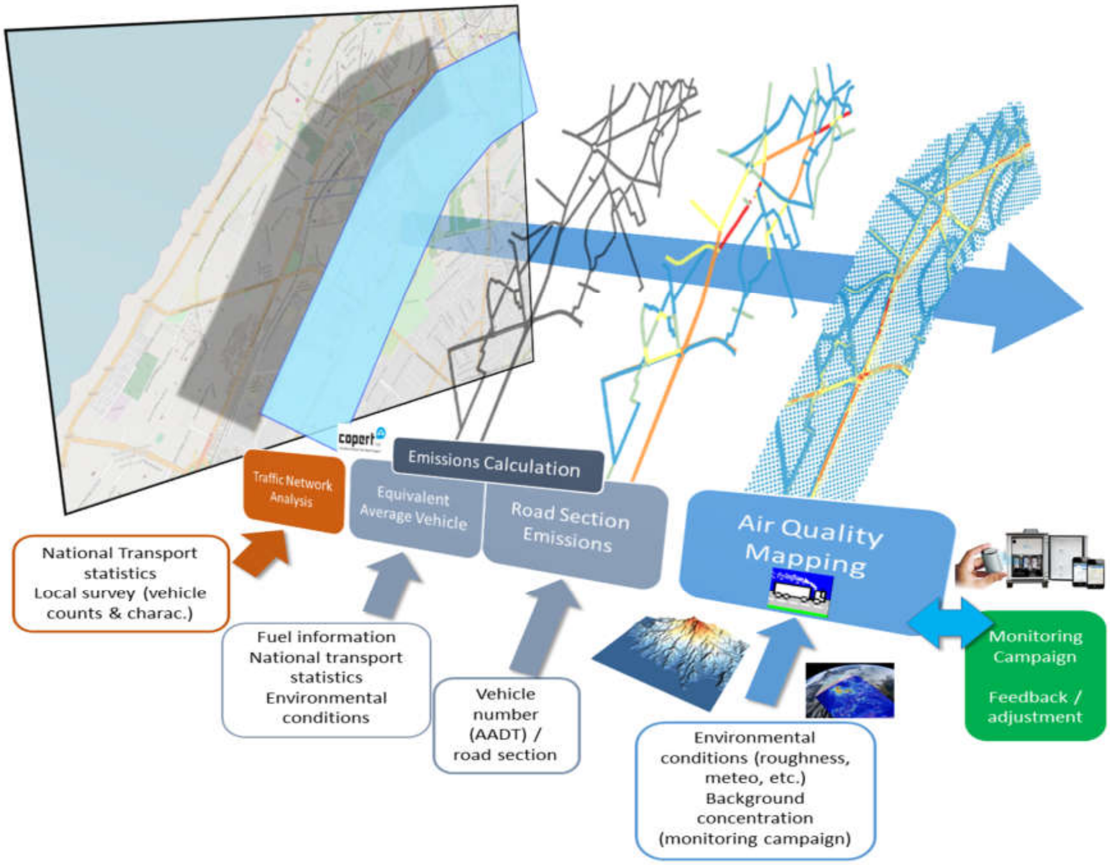
The second part of this chapter presents data collected and assumptions made for each of the five cities, as well as concentrations maps in transport corridors. Particular attention has been paid regarding the selection of the domain study in each city. This part was integrated directly in the monitoring campaign section.

The third part compiles a first set of recommendations in order to scale-up the approach at city scale.

Finally the methodology presented in this chapter relies on the following manuals already written by Ramboll for the AfDB group:

- Manual for Air Quality Monitoring in Transport Corridors. FRADBAB001-R1. September 2017,
- Data Collection Manual for Air Quality Assessment in Transport Corridors. FRADBAB002-R2. September 2017, and
- Air Quality Mapping of Road Transport Corridor: Software Manual. FRADBAB001-R3. November 2017.

Figure 3-1: Scheme of the methodology designed for emission and Air Quality Mapping over African cities.



3.2 Methodology

3.2.1 Monitoring Campaigns

3.2.1.1 Selection of the transport corridor

In order to select the most relevant pilot area, the geographic and socio-economic scopes of the project have been considered, assuming the following assessment criteria:

- A transport corridor that services a central business district or an activity center;
- An area that includes major road axis with heavy traffic;
- Vicinity of a planned or implemented transport improvement scheme; and
- Security and Safety locations for the implementation of the equipment.

3.2.1.2 Sampling plan

Aiming at assessing the contribution of the road traffic to the overall air quality within the transport corridor, a sampling campaign has been implemented over the five transport corridors defined in Abidjan, Yaoundé, Rabat, Dar Es Salam and Lusaka cities. The five monitoring campaigns were dedicated to the measurement of PM_{10}, $PM_{2.5}$, NO_2 and SO_2 concentrations with micro-sensors (Cairnet systems) presented in the chapter 2: Identification and Procurement of Cost-Effective Equipment. Note that SO_2 concentrations measurements have not been presented in this document[2].

One or two road traffic sites per city have been sampled in order to investigate the road traffic source contribution to the overall urban pollution, within the transport corridor. In addition, another sampling location was placed relatively far from the influence of road sources to quantify the urban background.

A list of meteorological parameters (wind speed and direction, temperature, humidity, pressure) was sampled via the DAVIS Vantage Pro2 weather station placed close to the road traffic pollutant samplers within an open-area without obstacle effects.

Vehicle volume samplings were performed at road traffic sites during the same period of the monitoring campaign using camera video records over short periods (15 min). In addition, manual vehicle counts implemented by four technical staff were carried out to sample road traffic as it passed the relevant road section. More specifically each investigator counted a specific vehicle class or category such as taxi, buses, motorcycles, etc.

The period of sampling is expressed in local time in each city investigated.

Table 3-1: Measurements summary during the monitoring campaign (the temporal acquisition is given in brackets)

Air Quality Pollutant Samplers	• PM_{10}/$PM_{2.5}$: 2 Cairnet Microsensor (continuous/5 min) • NO_2, SO_2: 2 Cairnet Microsensor (continuous/1 min)
Weather Station	DAVIS Vantage Pro2 station (continuous/30 min). Parameter sampled by the station are given as follow: Temperature, relative humidity, wind speed and direction, pressure and precipitations
Vehicle Number and Composition	Video camera (15 min sampling period) Manual vehicle counts per vehicle category (15 min per hour during the business hours) Note: Manual vehicle counts have been performed on major roadways (2x2 lines or 3x3 lines).

[2] Results produced by the Cairnet systems were not sufficiently robust and not validated at urban level due to instrument sensitivity under environmental without industrial influence (Cairpol, personal communication).

3.2.2 Traffic Network Analysis

3.2.2.1 Methodology description

3.2.2.1.1 Development of a simple road network analyst tool

In order to provide the sufficient road traffic volume required for the calculation of emissions, a traffic modelling tool was developed by Ramboll over all cities investigated except in Abidjan. The transport department of the BNETD[3] Institute within Abidjan has developed its own road traffic management tool that has been used in this study.

For the four other cities (Rabat, Yaoundé, Dar Es Salam and Lusaka) Ramboll developed a tool to generate vehicle activity over a specific road network reflecting the traffic flow by vehicle type within the transport corridor. The tool provides the Average Daily Traffic (ADT) volumes for specific vehicle categories (Passenger Car, Heavy Duty Truck, etc.) on each road section. These ADT volumes are then used as input data for the emission calculations described in section 3.2.3. This tool is based on a combination of both Excel and ARCGIS software tools and is fully connected with the ArcGIS Network analyst extension.

The tool developed by Ramboll is based on the main principle assuming that road traffic is generated and attracted by land use (offices, retails, etc.) and population density. The tool is designed to calculate the shortest and the fastest routes from a starting point to an end point and then generates traffic activity over road sections. The model input data includes road network datasets and information on demographic activities – population density, employment use, retail activity and any other land use types. Such parameters have been collected from national and international databases and from OpenstreetMap (OSM) satellite images that provide the physical road network and additional information such as the location of main industries, schools and other public buildings.

The main features of the tool can be summarized as follow:

- Most trips are generated by people, which is presented by population figures in the model. Also, industry, ports, railway terminals, logistic centers, etc., generate trips, especially truck and van traffic.
- Trips are attracted by jobs, commercial and other services, leisure activities, schools, etc. Many attractions can be described by their built floor area in the model. Freight traffic has its own attraction points.
- Each trip type (job related, shopping, school, …) has its own average length and typical modal share
- The longer the distance between two zones, the lesser trips are.

The assumptions made for generating road traffic activity in each transport corridor within the five cities are summarized in the Appendix 1.

3.2.2.1.2 Model calibration with traffic observations

In order to assess the ADT volumes calculated by the tool presented in the previous section, a calibration step has been performed using the road traffic observations performed during monitoring campaigns (section 3.2.1).

Road traffic observations have been done during the monitoring campaign and consist of:

- 15-min every hour during business hours of manual counts and 10 to 15 min video camera records at road traffic sites, and
- 15-min of manual counts over other road sections of the network.

[3] http://www.bnetd.ci/bnetd/index.php

The short-time period traffic observations have been converted to ADT volumes for the comparison with the tool. Some assumptions have been considered for hours without sampling (for instance during the night).

In this context, the BNETD road traffic model of Abidjan city was useful because it provides a simple methodology that derives ADT volumes using three parameters only: the Morning Traffic Peak Hour (7h-8h), the Afternoon Traffic Peak Hour (18h-19h) and the Off-Peak hours (9h-17h) parameters. The Off-Peak Hours was the only parameter used because it covers a larger period of time than the two others and was every time informed by measurements performed. A relationship was then derived from the BNETD model to convert Off-Peak Hours to ADT volumes and expressed as follow:

$$ADT = OPH \times 1.7496$$

With:

ADT = Average Daily Traffic Volume in number of vehicles

OPH = Off-Peak Hours in number of vehicles

3.2.2.2 Limitations

The methodology proposed in this project has been developed to provide a straightforward and consistent approach for each of the selected cities to estimate road traffic emissions over a small pilot area considering a small number of road axes only. This methodology, without any adjustment, cannot be deployed itself for air quality management plans or at the city scale. This is mainly due to the critical assumptions made for generating the road traffic when input parameters are not available or sparse.

The main limitations can be summarized as follow:

- The level of detail regarding the input parameters. Various information sources have been used. They mainly come from relatively recent national statistic surveys and cover larger areas than the domain of the study. In order to improve resolution of the parameters, OSM open-source databases were integrated to the data collection process. OSM has the advantage of providing a high resolution database but it suffers from data deficiency regarding building locations and descriptions,
- The model used is able to provide an overall picture of traffic over a transport corridor. However this tool is not designed to consider specific and local effects such as traffic congestion, turning movements at intersections, peak hour behavior, etc.
- The calibration of the road traffic estimations was carried out using hourly traffic observations. These observations are partially representative of a complete day (sampling during the night was rarely performed). In order to calculate ADT volumes from road traffic observations, it was assumed that each city follows the same behavior as Abidjan city in order to apply the BNETD road traffic model adjustment factor. The road traffic behavior within Abidjan could be different from that in other cities resulting in discrepancies.

3.2.3 Emissions calculation

3.2.3.1 Introduction

In contrast with Europe the vehicle fleet composition of Rabat, Yaoundé, Dar Es Salam, Lusaka and Abidjan is not known precisely making it difficult to apply the COPERT 5 methodology for the estimation of emission factors. COPERT 5 is based on a high level of detailed information about vehicle volume, technology, fuel composition and distribution (gasoline/diesel), mileage, etc.

Consequently, in order to profile a standard vehicle fleet for each city, activity data has been collected. Such data collection is not an easy task and generally cross-thematic approaches should be considered in order to provide the most statistically robust data including (i) modeling the road traffic, (ii) collection of international and local databases and (iii) in situ road traffic counts. In addition to this data collection step, a number of assumptions have been made to tackle missing information.

Emission factors generated in COPERT 5 have been applied to the major vehicle categories (Passenger Cars, Light Duty Vehicles, buses, etc.) sampled during the manual counts and expressed as Average Equivalent Vehicles (AEVs). The resulting AEV emissions provide an average emission factors specific to each vehicle category and weighted according to the vehicles distribution (engine category, age, mileage, etc.). AEV emissions have the benefit of simplifying the estimation of emission factors in order to be consistent with the limited level of detail obtained during the activity data collection.

Section 3.2.3.2 describes the data collected to generate a standard vehicle fleet for each city including fuel characteristics, distribution and vehicles volume and composition. These input data are compiled within the COPERT 5 road emission tool (section 3.2.3.3). The resulting emissions are then compiled to produce AEV emissions per vehicle category (section 3.2.3.4).

3.2.3.2 Vehicle fleet composition

3.2.3.2.1 Data Collection

Data that was collected involved parameters relating to vehicles themselves, their circulation and auxiliary variables.

Vehicle parameters:

- Vehicle category: Passenger Cars (PCs), mopeds & motorcycles, Light Duty Vehicles (LDVs), Heavy Duty Truck (HDTs), Buses and Coaches,
- Fuel type. For each vehicle category, it is necessary to know the fuel type,
- Vehicle weight and engine category (cylinder displacement). For PCs and motorcycles the engine category is generally used and expressed in cubic meter per liter. For the other vehicle categories, the vehicle weight is used ranging from <3.5t (for LDVs) and up to 50t (for HDTs),
- Emission standards, or model year that define the acceptable limits for exhaust emissions of vehicles according to the vehicle type and year of registration. The emission standards setup within the COPERT 5 model include the European standards (EURO Norms).

Vehicle circulation:

- Vehicle.kilometer travelled per vehicle category,
- Average speed on the different road type (urban, rural roads and expressways or highways).

Auxiliary variables:

- Physical and chemical characteristics of fuels,
- Climatic parameters: ambient monthly maximum and minimum temperatures, monthly mean relative humidity.

3.2.3.2.2 Assumptions

Due to the lack of accurate information, representative assumptions have been made for several parameters based on local estimations. The table below (Table 3-2) compiles the assumptions made for each parameter.

Table 3-2: Assumptions made over the five cities for missing information

Parameters	Assumptions
Vehicle category	Suppression of one specific vehicle category or merging of multiple vehicle categories has been applied when the distinction between each category of vehicles was not easy (e.g. solo and articulated HDTs). Splitting one category has been done in several cases in order to consider explicitly a significant vehicle class e.g. taxi category.
Fuel type	Assumptions have been made in order to consider gasoline and diesel only. Other fuels (such as Liquefied Petroleum Gas, LPG) have been ignored. For specific vehicle class it can be assumed that: • Mopeds and motorcycles use gasoline fuel only, • Except for PC and LDV, all other vehicle categories operate on diesel.
PCs engine power	No information was found on the engine power distribution. The European scheme was applied and adapted to the local context based on long-time (few days) digital camera observations over representative areas (structuring road sections)
Weight of Light and Heavy-Duty Vehicles	There was no information available in each city investigated. Consequently, assumptions have been made on the number of axles and the local regulation associated linking the theoretical weight to vehicle with a specific axle number.
Model year or Emission standards	In the absence of a robust statistical dataset, except for sparse technical and periodical vehicle controls, it was assumed that the model year for all vehicles is compliant with the EURO3 standard. This decision considers the recent introduction of the EURO4 norm for Passenger Cars (in 2006 in Europe), the likely weakness of vehicle maintenance and the likely use of low grade fuel.

It is important to note that emission standard adjustments were made when the distribution of vehicle age is available according to the correspondence table described below (Table 3-3).

The methodology presented here i.e. estimation of emissions resulting from AEVs, relies on the knowledge of the vehicle composition in each category. For instance, in the PC category, the portion of vehicles operating on diesel and the distribution of engine power (such as small vehicle, sedan, Sport-Utility Vehicles, etc.) must be explicitly described. The number of total vehicle number per category (PC, LDV, etc.) is not required when calculating AEVs; however, it is required in each COPERT 5 run. Consequently, arbitrary values (100,000) were considered for each vehicle category.

Table 3-3: Correspondence table between vehicle age and Emission standards. The years indicated stand for the year of vehicle first registration

Emission Standards	PCs gasoline	PCs diesel	LDVs (<3.5t) gasoline	LDVs (<3.5t) diesel	HDTs (>3.5t) diesel	Buses / Coaches	Mopeds (<50cc)	Motorcycles (> 50cc)
ECE15.04	1985	1985	1985	1985				
EURO1/I	1993	1993	1995	1995	1993	1993	1999	1999
EURO2/II	1996	1996	1998	1998	1996	1996	2002	2003
EURO3/III	2001	2001	2001	2001	2001	2001	2009	2006
EURO4/IV	2006	2006	2006	2006	2006	2006		
EURO5/V	2011	2011	2012	2012	2009	2009		
EURO6/VI	2015	2015	2015	2015	2014	2014		

3.2.3.3 COPERT 5

AEV emissions have been calculated from the emission factors available in the COPERT 5 model and for pollutants selected in this study (but are not limited to) i.e. PM_{10}, $PM_{2.5}$, SO_2 and NO_x. COPERT 5[4] is a freeware tool used world-wide to calculate air pollutant and greenhouse gas emissions from road transport. For instance, the Department for Environment Food & Rural Affairs (DEFRA) implemented COPERT in an updated Emission Factor Toolkit to help local authorities in United Kingdom. The development of COPERT is coordinated by the European Environment Agency (EEA), in the framework of the activities of the European Topic Centre for Air Pollution and Climate Change Mitigation. The European Commission's Joint Research Centre manages the scientific development of the model. COPERT has been developed for official road transport emission inventory preparation in EEA member countries. However, it is applicable to all relevant research, scientific and academic applications and for countries outside the European boundary.

The COPERT 5 methodology is part of the European Monitoring and Evaluation Program/EEA air pollutant emission inventory guidebook for the calculation of air pollutant emissions[5]. The use of a software tool to calculate road transport emissions allows for a transparent and standardized methodology, to allow consistent and comparable data collecting and emissions reporting procedures, in accordance with the requirements of international conventions and protocols and European legislation.

The COPERT 5 freeware tool estimates emissions while adjusting for specific atmospheric and traffic conditions. The software estimates all types of emissions including hot running, cold start, evaporative and non-exhaust (tyre-wear, brake wear) emissions. For the purpose of this study, COPERT will be designed to develop:

- National and city level vehicle emission inventories, and
- Emission factors as a function of traffic (Average Daily Traffic), vehicle category and vehicle speed for road-based emission calculations.

The following table (Table 3-4) compiles the main features of COPERT 5. A complete user's guide can be found at:
http://copert.emisia.com

[4] http://emisia.com/products/copert/copert-5
[5] https://www.eea.europa.eu/publications/emep-eea-guidebook-2016

Table 3-4: Main features of COPERT 5 model

Feature	Description
Emission types	• Hot emissions: Thermal stabilized engine operation • Cold start emissions: The warming-up phase • Non-Exhaust emissions: from fuel evaporation, tyre and brake wear emissions
Detailed vehicle categories	COPERT 5 contains emission factors for more than 240 individual vehicle types including: • Passenger Cars, • Light Duty Vehicles, • Heavy Duty Vehicles (including buses and coaches), • Mopeds, and Motorcycles. Emission control technologies (e.g. EURO standards) are included for the vehicle categories – additional user-defined technologies can be easily included
Pollutants	CO, NO_x, NMVOCs, CH, N_2O, NH_3, PM including PM_{10}, $PM_{2.5}$, EC, etc., CO_2, SO_2, Heavy metals (Pb, Cd, Cr, Cu, Ni, Se, Zn), PAHs, POPs, dioxins
Optional	• Lubricant consumption as a function of mileage (g/km) • Distinction between primary and end (blends) fuels • Air conditioning factor • Mileage degradation

3.2.3.4 From COPERT 5 to Equivalent Average Vehicles Emissions

The main objective of using the COPERT 5 tool is to estimate weighted average emission factors for each vehicle category (AEV). COPERT 5 provides total emissions in units of mass for a specific vehicle category (or sub-category, for instance small gasoline PCs) according to the following equation:

$$E_{VS} = EF_{VS} \times n_{VS} \times d$$

with:

E_{VS}: Vehicle sub-category total emission (kg)
EF_{VS}: Vehicle sub-category emission factor expressed as kg/veh./km
n_{VS}: Vehicle number
d: Average distance travelled by vehicles

The EF_{VS} generated by COPERT 5 are then processed in order to generate the corresponding AEV emission for the vehicle category weighted by the distribution per vehicle sub-category. An example of the AEV emissions generated is provided in the table below (Table 3-5).

Table 3-5: Example of AEV emissions resulting from the EF generated in COPERT 5

Road Type	Pollutant	Vehicle type	AEV emissions	Unit
Urban	NO_x	Passenger Car	0.044001	g/veh./km
Urban	PM_{10}	Heavy Duty Truck	0.001547	g/veh./km
Urban	$PM_{2.5}$	Bus	0.000814	g/veh./km
Highway	SO_2	Passenger Car	0.000457	g/veh./km

3.2.4 Air Quality Mapping

3.2.4.1 Description of the modeling approach (ADMS-Roads)

ADMS-Roads, a version of the Atmospheric Dispersion Modelling System (ADMS), is a PC-based model of dispersion in the atmosphere of pollutants released from road traffic and industrial sources. ADMS-Roads models emissions from line, point, area and volume sources. It is designed to allow consideration of dispersion ranging from the simplest scenarios (e.g. a single road) to more complex scenarios (e.g. multiple road traffic emission sources and industrial sources over a large area). Allowance can be made for traffic induced turbulence (in the vehicle wake) and the effects of street canyons, when modelling the dispersion of road traffic.

3.2.4.2 ADMS-Roads main features

ADMS-Roads has several distinctive features and the major features are summarized below:

- Versatile of applications including comparison with National and International Standards (WHO, guidelines, etc.),
- Advanced dispersion model in which the boundary layer structure is characterized by the height of the boundary layer and the Monin-Obukhov length, a length scale dependent on the friction velocity and the heat at the surface,
- A range of explicit source types – 150 road sources (each with up to 50 vertices, for a total of over 7,000 road links) and 35 industrial sources,
- Integrated basic and advanced street canyon models,
- An integrated model for dispersion of emissions from road tunnels,
- An integrated model for urban canopy flow field effects,
- The modeling of chemical reactions involving NO, NO_2 and Ozone, and generation of sulfate particles from SO_2,
- A meteorological processor that calculates the boundary layer parameters from a variety of input data: e.g. wind speed, day, time and cloud coverage, or wind speed, surface heat flux and boundary layer height: Meteorological data may be raw, hourly values or statistically analyzed,
- A non-Gaussian vertical profile of concentration in convective conditions, which improves accuracy by allowing for the skewed nature of turbulence within the atmospheric boundary layer that can lead to high surface concentrations near the sources,
- The realistic calculation of flow and dispersion over complex terrain.

3.2.4.3 Model parameters over all cities investigated and particles resuspension

The following table (Table 3-6) compiles assumptions made to setup the ADMS-Road model over each city.

Table 3-6: Modelling Parameters

Meteorology	Weather station (Vantage Pro 2) placed in front of the Cairnet system The Cloud Coverage parameter has been obtained from the dataset of the closest International Airport weather station
Surface Roughness on the domain (m)	0.8
Minimum Monin-Obukhov Length	30
Pollutants	NO_2, SO_2, PM_{10}, $PM_{2.5}$
Chemistry	NO_x-NO_2 correlation (Derwent-Middletown, 1996)[6]
Emission sources	Road traffic over roadways inside the transport corridor
Road characteristics	For all road sections: • Road width = 10m • Canyon height = 0m No building effect
Background	Concentrations measured during the monitoring campaign at the background site
Grid Calculation	The domain covers the entire transport corridor area. Refining gridding close to the emission sources

3.2.4.4 Particles resuspension

In addition to the modelling parameters described in the table above, the resuspension of particulate matter from paved road surfaces has been considered as well. In general terms, resuspended particulate emissions from paved roads originate from, and result in the depletion of, the loose material present on the surface (i.e. the surface loading). In turn, that surface loading is continuously replenished by other sources such as spillage of material and track-out from lateral unpaved roads or segment, etc. The methodology comes from the US EPA (2011)[7] and available at:

https://www3.epa.gov/ttn/chief/ap42/ch13/index.html

The US EPA methodology uses a formulation in order to derive the resulting emissions from resuspension. This formulation includes vehicle weight and speed, number of wet days, etc. One of the key parameters is the silt loading parameter that represents the quantity of silt/sand on roads surface. Values of 0.1 g/m^2 have been chosen for Yaoundé, Lusaka and Dar Es Salaam, 0.4 g/m^2 for Abidjan due to sand presence observed along the roads of the studied corridors. Note that these values are within the range of Ubiquitous default values proposed by the US EPA for paved roads (ranging from 0.03 to 0.6 g/m^2). Resuspension has been setup for PM_{10} pollutant only.

[6] Derwent, R.G and Midldletown, D.R, 1996: An empirical function for the ratio NO2:NOx. Clean Air, 26, 57-60.
[7] AP 42, fifth Edition, Volume I. Chapter 13: Miscellaneous Sources. Section 13.2.2 Paved roads.

3.3 Emissions and Air Quality Mapping in the five selected cities

This section presents data collection, emission calculations and air quality mapping results over the five cities investigated: Abidjan (3.3.1), Rabat (3.3.2), Yaoundé (3.3.3), Lusaka (3.3.4) and Dar Es Salaam (3.3.5). For each city, the following Items are considered:

- Selection of the transport corridor and the pilot area within each city is chosen according to short- and medium-term length infrastructure projects;
- Monitoring campaign results and description;
- Assumptions and data collection for the emission calculations, and
- air quality mapping of pollutant concentrations.

Important Note: All results presented in this section correspond to a short time period (limited number of days) and cover a relatively small area within a city. These results cannot be considered as representative of annual concentrations in the city of interest.

3.3.1 Abidjan

3.3.1.1 Selection of the pilot areas

Two transport corridors have been considered for the city of Abidjan:

- Axis Adjamé-Yopougon, as it is the major East-West axis and because of concern for the Yopougon Area Network Project (YoANP), which includes construction of the 5th bridge.
- Abidjan-N'Dotré, as it is a major North-South transport corridor, and is of concern for the project "Extension voie N'Dotré" according to the SDUGA (Master Plan).

3.3.1.2 Monitoring campaign

3.3.1.2.1 Sampling locations

The Monitoring Campaign has been performed during the period from the 3rd, May 2017 (12:00) to the 5th, May 2017 (18:00). As described in the previous section, two transport corridors have been selected. The figure below (Figure 3-2) presents the sampling locations. The two Road Traffic sites can be described as follow:

- Yopougon site (investigated from the 3rd, May 2017 at 8:00 to the 4th, May 2017 at 19:00). The sampling site is adjacent of the North Highway (Autoroute du Nord), a 3x3 lines that services the northwest part of Abidjan. The sampling site was located close to the first pedestrian bridge (5°21'37.08"N; 4°4'25.50"O). The instruments have been installed at the terrace of a Settee shop, at a distance of approximately 5 m from the road side. The vertical distance above the highway level is 4 m; and
- N'Dotré site (investigated from 4nd, May 2017 at 14:00 to 5th, May 2017 at 20:00). Samplers have been placed 250 m at the north of the N'Dotré main crossroad with the T170 road (5°26'45.39"N; 4°4'11.16"O). This road mainly services the north Abidjan suburb up to the Abobo Highway. Instruments have been installed at the rooftop of a bakery (6 m above ground level) at a horizontal distance of 15 m from the roadside.

For each site a weather station has been placed near the air pollutant samplers. In addition to these two Road Traffic sites, another site has been investigated at the Félix Houphouët Boigny University (Cocody district, 5°20'41.03"N; 3°59'18.38"O) in order to sample the urban background pollution (Figure 3-3).

Figure 3-2: Map of the pilot areas (red boxes) showing both Yopoungon and N'Dotré sites

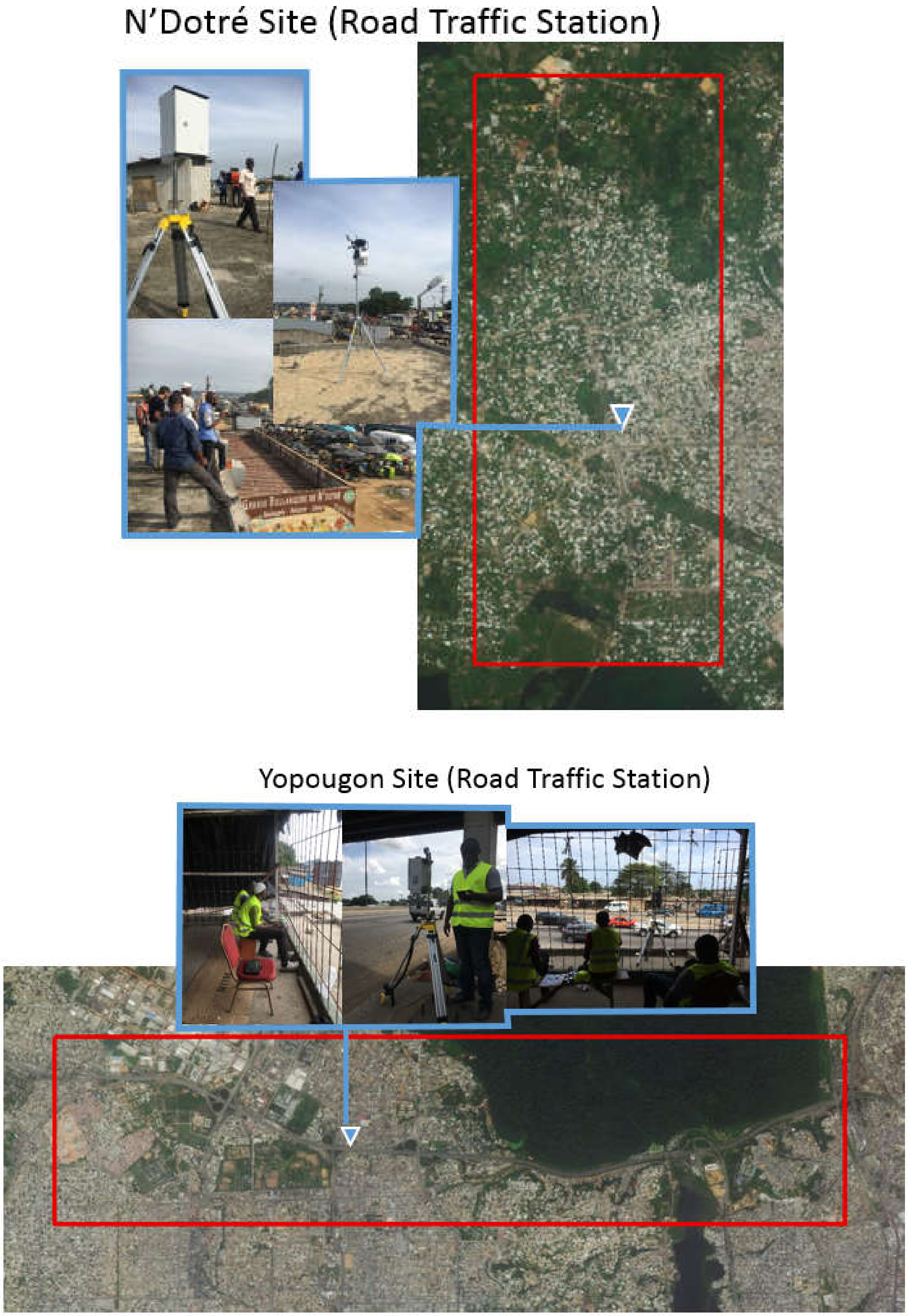
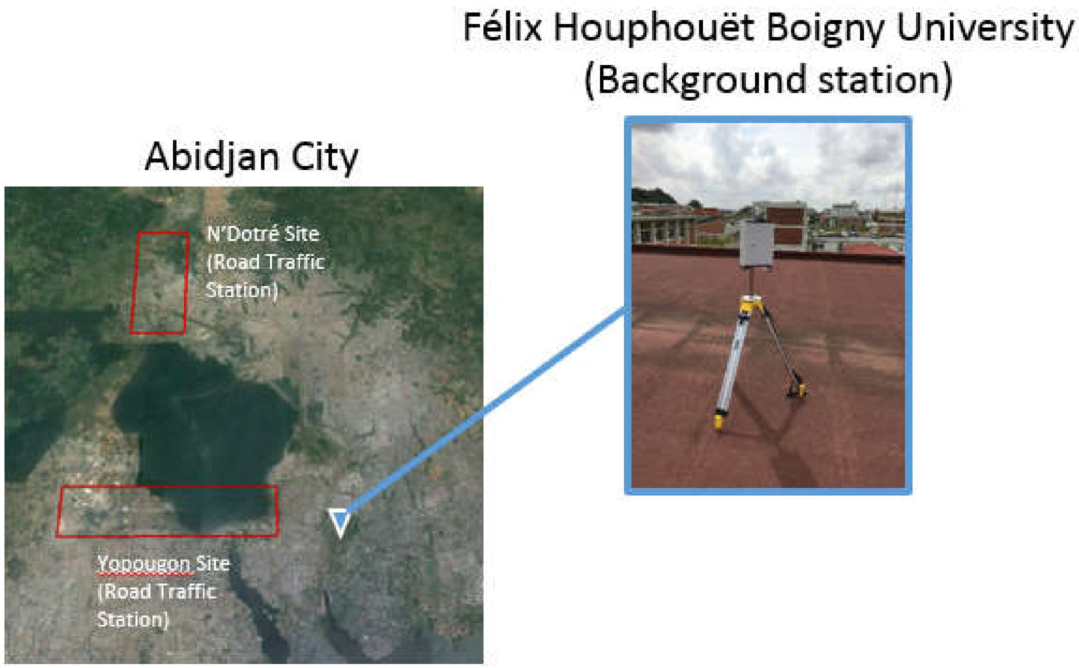


Figure 3-3: Location of the background sampling site at the FHB University (Cocody)

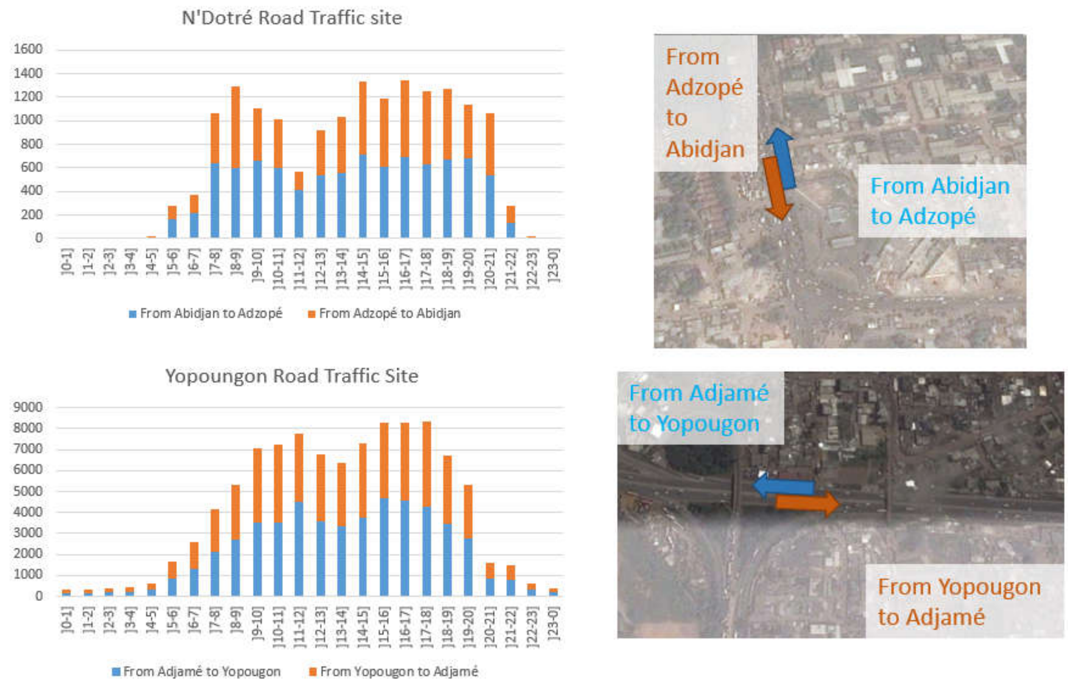


3.3.1.2.2 Monitoring campaign results

Average hourly traffic volumes, derived from manual vehicle counts and dataset from the BNETD road traffic model are presented in the figure below (Figure 3-4). Daily road traffic patterns have been sampled at both Road Traffic sites (N'Dotré and Yopougon).

The Figure 3-4 shows that the total number of vehicles travelling on the North Highway at the Yopougon site is about 5 times more important than at the N'Dotré site.

Figure 3-4: Hourly traffic at the Road Traffic Station. Locations and directions (with corresponding colors) are indicated on the left pane (Abidjan)



The distribution of vehicles per category sampled at both Yopougon and N'Dotré sites are provided in the table below (Table 3-7). Overall, the results show an equivalent distribution of traffic per category of vehicles at both sites with a slightly lower relative contribution of Taxis and higher Passenger Cars contribution at the N'Dotré site.

Table 3-7: Road traffic distribution (%) and Average Daily traffic estimated (ADT) from measurements in Abidjan city

Site Locations	Passenger Cars	Taxis	2-wheels (Motorcycle)	Light duty Vehicles (<15t)	Trucks (>15t)	Coaches / Buses	Special Vehicles (construction machinery,	ADT
Yopougon	50.9	18,1	3.5	18.6	6.7	2.2	0.0	96,292
N'Dotré	53.3	13.6	10.5	13.9	7.2	1.5	0.1	16,490

Figure 3-5 shows the concentrations of NO_2, PM_{10} and $PM_{2.5}$ sampled during the monitoring campaign using the Cairnet system instruments at both road traffic sites (Yopougon and N'Dotré) and at the background site (Cocody district).

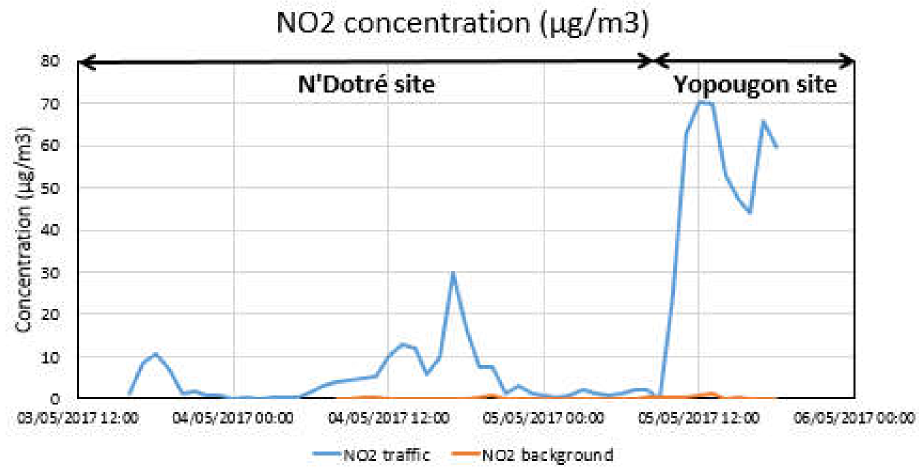
The NO_2 concentrations measured at road monitoring sites are significantly greater than at the background site (with maximum hourly levels reaching 70 µg/m^3 at the Yopougon site), reflecting the impact of road pollution. This road traffic influence is confirmed by the different levels of pollution at both Road Traffic sites. Concentration levels are also much higher at Yopougon (due to dense road traffic: 96,292 total number of vehicles) than at N'Dotré (with less road traffic: 16,490 total number of vehicles).

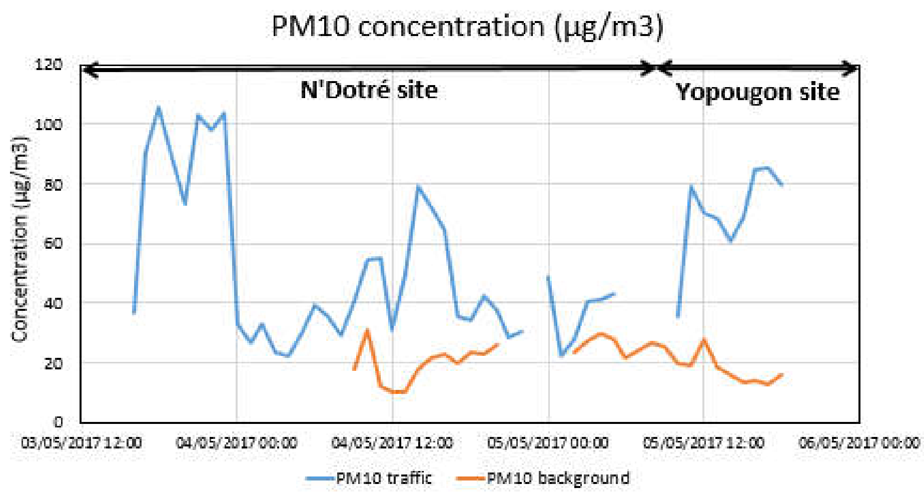
For PM_{10} and $PM_{2.5}$ pollutants, high concentration levels have been measured at the N'Dotré site (up to 100 µg/m^3). These high concentrations can be explained by:

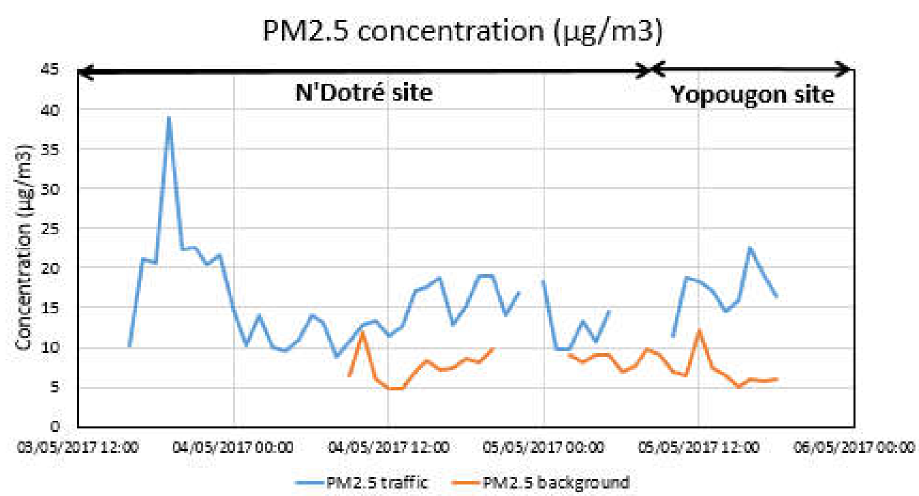
- Meteorological parameters: rainfall and generally high relative humidity (over 90% humidity) exceed the limitations of the Cairnet systems as indicated by the developer of the system, Cairpol institute (personal communication);
- Large particle resuspension from lateral unpaved roads; and
- Short electricity blackout periods (from 20 minutes to 1 hour during the night) which making the necessity to use auxiliary power unit at the bakery shop.

At the Yopougon site, concentration levels stayed high with an average concentration of 51 µg/m^3 and 15 µg/m^3 for PM_{10} and $PM_{2.5}$ respectively. PM_{10} concentrations are higher than the shortest time (24-hours mean) WHO standards (50 µg/m^3). The $PM_{2.5}$ WHO standard (25 µg/m^3 in annual average) was not exceeded during the period of sampling.

Figure 3-5: Ambient Air PM_{10}, $PM_{2.5}$ and NO_2 concentrations at the Yopougon, N'Dotré and Félix Houphouët Boigny University (background concentrations) sites

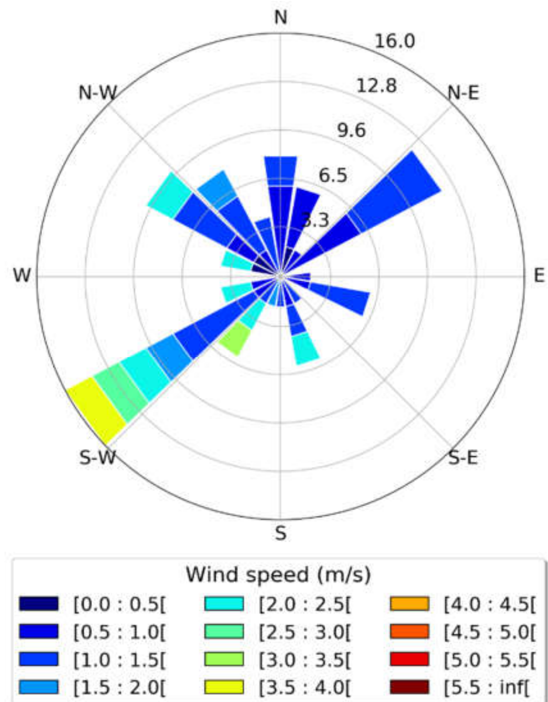






In addition to the concentrations measured at the two road traffic sites, a DAVIS weather station was placed close to the instruments. The wind rose presented in Figure 3-6 shows that there was no clear prevailing wind direction during the monitoring campaign due to low wind speeds (mostly between 1 and 2 m/s). However, the wind rose shows that 16% of wind directions came from the south-west sector. Temperatures varied between 23.8 to 31.7°C with an average of 27.4°C. Relative humidity during the night between the first two days of measurement was relatively high in N'Dotré (85%), with some rainfalls (3 mm/6 hours).

Figure 3-6: Wind rose derived from observation performed during the monitoring campaign



3.3.1.3 Calculation of emissions

Assumptions made to generate a vehicle fleet at the Lusaka transport corridor are summarized in the Table 3-8. Average Equivalent Vehicles (AEV) emissions obtained from all these assumptions and calculated after the COPERT 5 step are summarized in the Appendix 2.

Table 3-8: Assumptions for the construction of vehicle fleet at Abidjan city and Average Equivalent Vehicles (AEVs)

Parameter	Assumption
Population of the selected vehicle categories	The number of vehicles per category has been derived from the distribution obtained from measurements carried out during the monitoring campaign. As indicated within the methodology section, arbitrary values could have been setup without any influence on results. Bus category has been split between Gbaka vehicles (small buses) and SOTRA buses (standard buses: 15t -18t). A specific treatment, using the video camera records, has been applied to split over three sub-categories of Passenger Cars, PCs (small, medium and SUV). The resulting distribution is given in the Table 3-9. Taxi class has been assimilated to diesel Toyota Corolla (model year: 2000) only. This assumption has been made according to observations and Ramboll expert judgment.

Parameter	Assumption
Fuel type	Gasoline and diesel vehicles ratios have been derived from the vehicle registration office SONATT[8] database.
Fuel composition	The fuel composition has been defined according to the default value within COPERT 5 model. Sulfur-content has been setup to 2,000 ppm (mass) for diesel according to the CCAC[9] (Climate & Clean Air Coalition) document. Without any information relative to the gasoline composition, the sulfur-content was considered to be the same as for diesel (i.e. 2,000 ppm).
Engine rating	The engine rating chosen for PCs category has been derived from the analysis of video camera records (Table 3-9; Table 3-10). Without any information on the distribution between gasoline and diesel vehicles, the same distribution has been applied to both vehicle types.
Weight	The HDTs distribution according to the vehicle weight has been derived from axle number observations via the analysis of video camera records during the monitoring campaign. The formula that came from the regulation 14/2005/CM/UEMOA[10] linking the number of axles to the vehicle weight has been applied (Table 3-10). Gbakas has been assimilated to small buses (<15t) and SOTRA as 15t to 18t buses.
Emission Standards	The EURO 3 standard has been used for the PCs category. For the Taxi class the EURO 2 standard has been considered. Regarding buses and HDTs categories the EURO 1/I standard has been applied according to the vehicle age.
Vehicle Lifetime	Vehicle lifetimes has been calculated according to the emission calculation methodology (section 3.2.3).
Average Speed	Average speeds on highways, rural roads and urban area were based on the Ramboll expert judgement: • Urban road: 25 km/h • Rural road: 60 km/h • Highway: 80 km/h.

The next two tables compile the vehicle distribution among the categories provided in the methodology section. These results have been derived from the analysis of the video camera records taken during the monitoring campaign.

Table 3-9: Vehicles distribution – PCs category (Abidjan)

	Passenger Cars Sub Category		
	Small	**Medium**	**SUV**
Distribution [%]	3.3	38.1	58.1

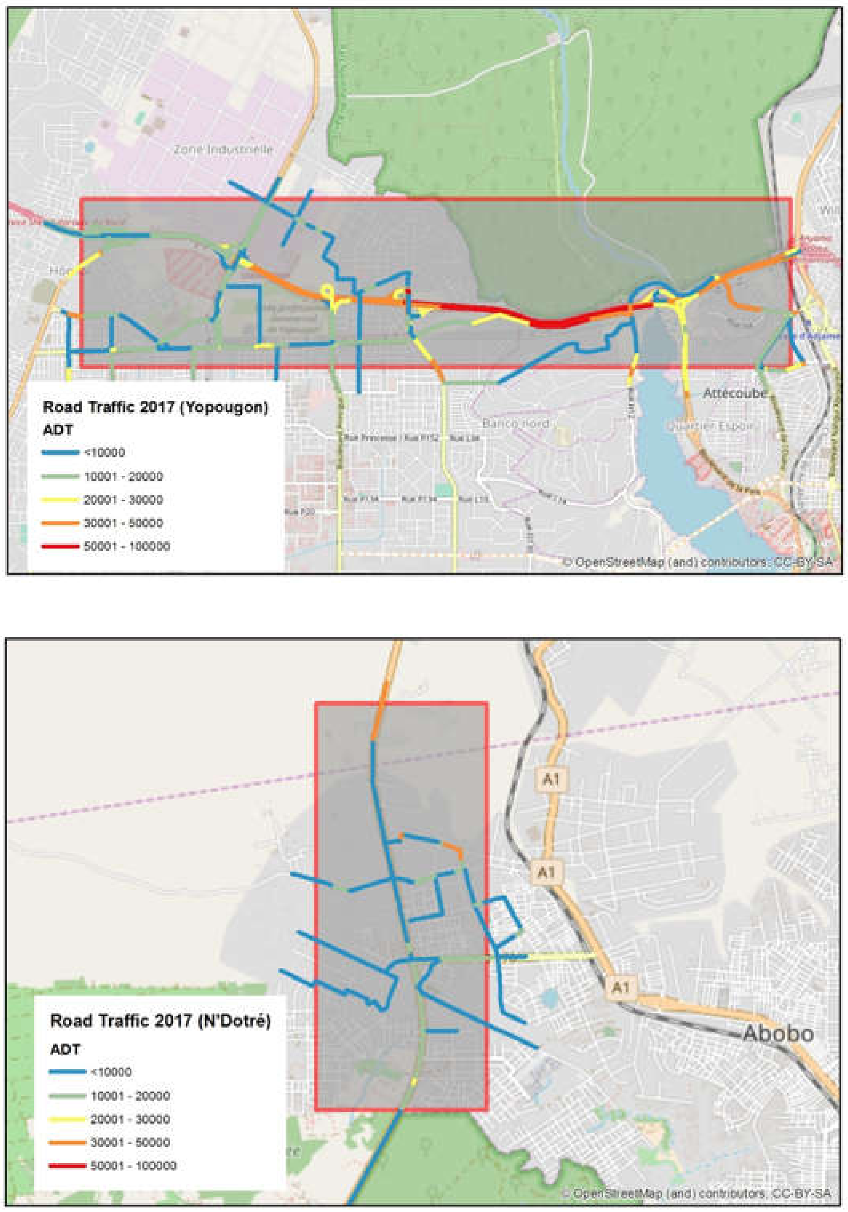
Table 3-10: Vehicles distribution - HDTs category (Abidjan)

	HDT, axles #				
	2	**3**	**4**	**5**	**6**
Distribution [%]	45.6	23.7	5.9	17.2	7.7

[8] http://www.transports.gouv.ci/
[9] Cleaning up the global on-road diesel fleet a global strategy to introduce low-sulfur fuels and cleaner diesel vehicles, 2016, 79 p.
[10] http://news.abidjan.net/h/600628.html

The emissions from the AEVs have been calculated according to the assumptions listed in the tables ab Table 3-11: ove (from Table 3-8 to Table 3-10). The BNETD road traffic model that produces Average Daily Traffic (ADT) volumes and the vehicles distribution per category (Table 3-7) have been used to spread emissions over each road section within both transport corridors. The ADT volumes calculated using the BNETD model is presented in the Figure 3-7, corresponding to the 2017-year estimation, and show that, overall, the road traffic is more important over the Yopougon transport corridor than within the pilot area of N'Dotré.

Figure 3-7: ADT volumes in Yopougon and N'Dotré corridors



The following figures (Figure 3-8; Figure 3-9) show the air emissions of NO_x, PM_{10} and $PM_{2.5}$ due to the road traffic within both Yopougon and N'Dotré transport corridors. Emissions have been calculated according to the methodology described in the section 3.2.3.

Figure 3-8: Air emissions of NO_x, SO_2, PM_{10} and $PM_{2.5}$ over the Yopougon pilot area (defined by the dark red box)

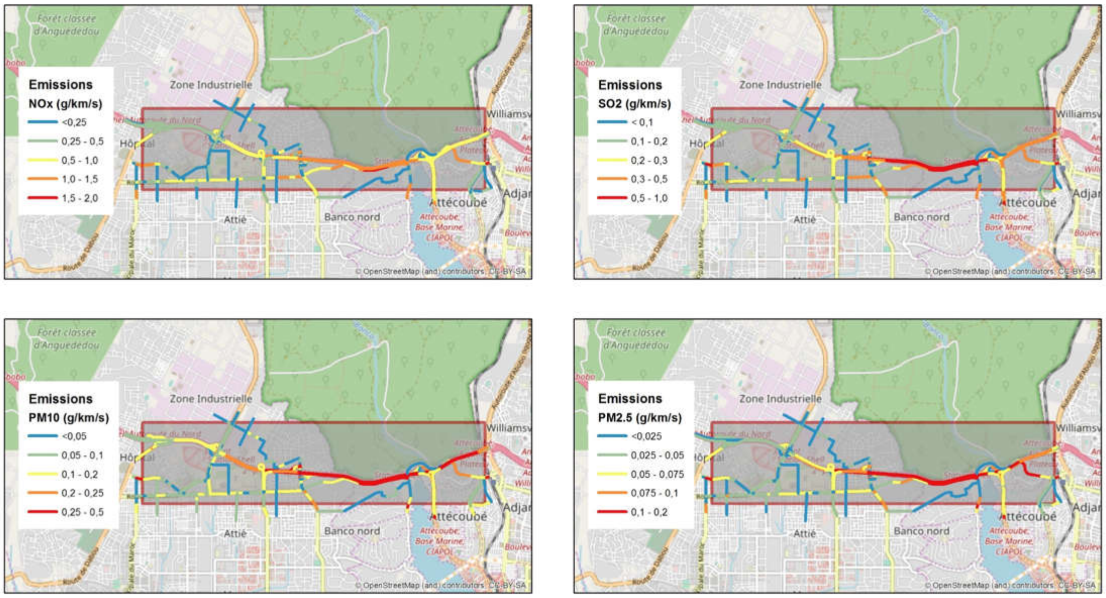
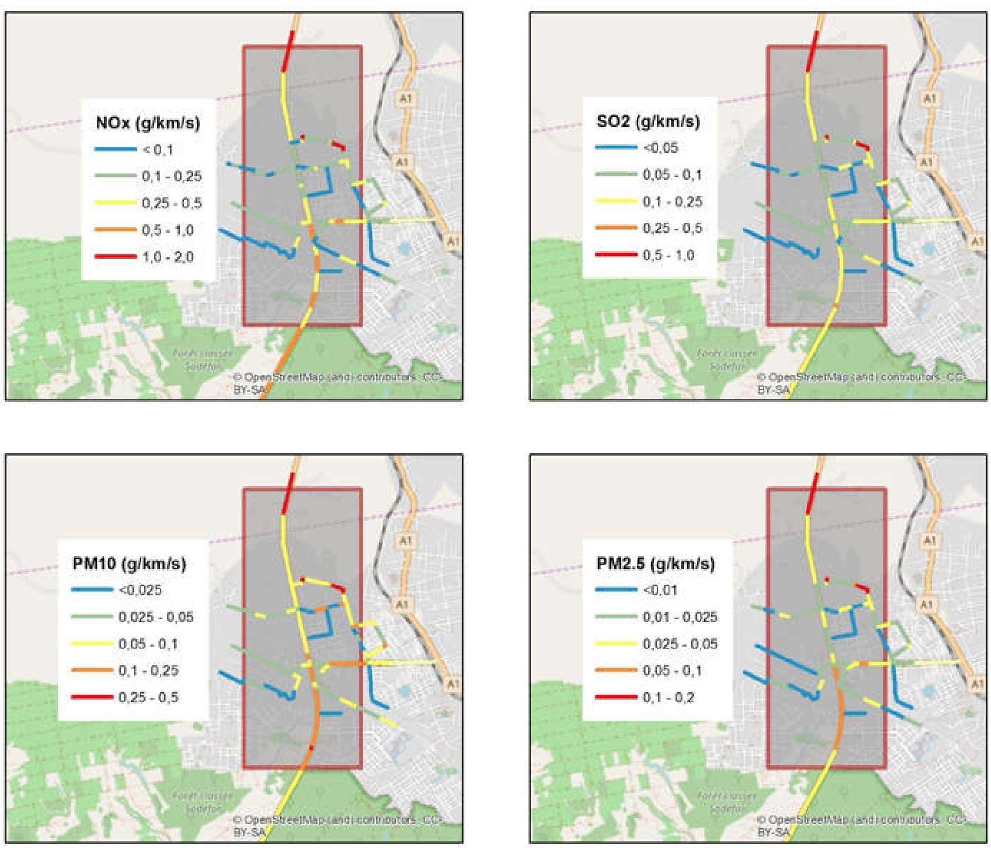


Figure 3-9: Air emissions of NO_x, SO_2, PM_{10} and $PM_{2.5}$ over the N'Dotré pilot area (defined by the dark red box)



3.3.1.4 Air Quality mapping

3.3.1.4.1 Meteorological parameters and time period

Meteorological parameters have been extracted from the DAVIS weather station, except for the cloud coverage, which has been extracted from the Abidjan Felix Houphouet Boigny International Airport (Table 3-12).

The time period has been chosen in order to cover the entire duration of the monitoring campaign i.e. from the 3rd, May 2017 (12:00) to the 5th, May 2017 (18:00).

Table 3-12: Abidjan Felix Houphouet Boigny International Airport – Weather station

Site Identification (WMO)	65578
Latitude	5°15'40.99"N
Longitude	3°55'34.66"O
Elevation	6.4 m

3.3.1.4.2 Particulate Matter (PM) resuspension and background concentrations

Particulate matter resuspension has been considered for PM_{10} only. The value calculated is 0.7136 g/veh./km at the N'Dotré site and 0.4934 g/veh./km at the Yopougon site. These values are different in order to reflect as possible the specific regime of resuspension over N'Dotré, due to unpaved lateral roadways and parks.

Background concentrations have been derived from measurements performed at the background site during the measurement campaign. For the purpose of this study, background concentration represents an integrated and averaged value of the urban pollution far from the road traffic influence.

Background concentrations obtained for each pollutant are summarized as follow:

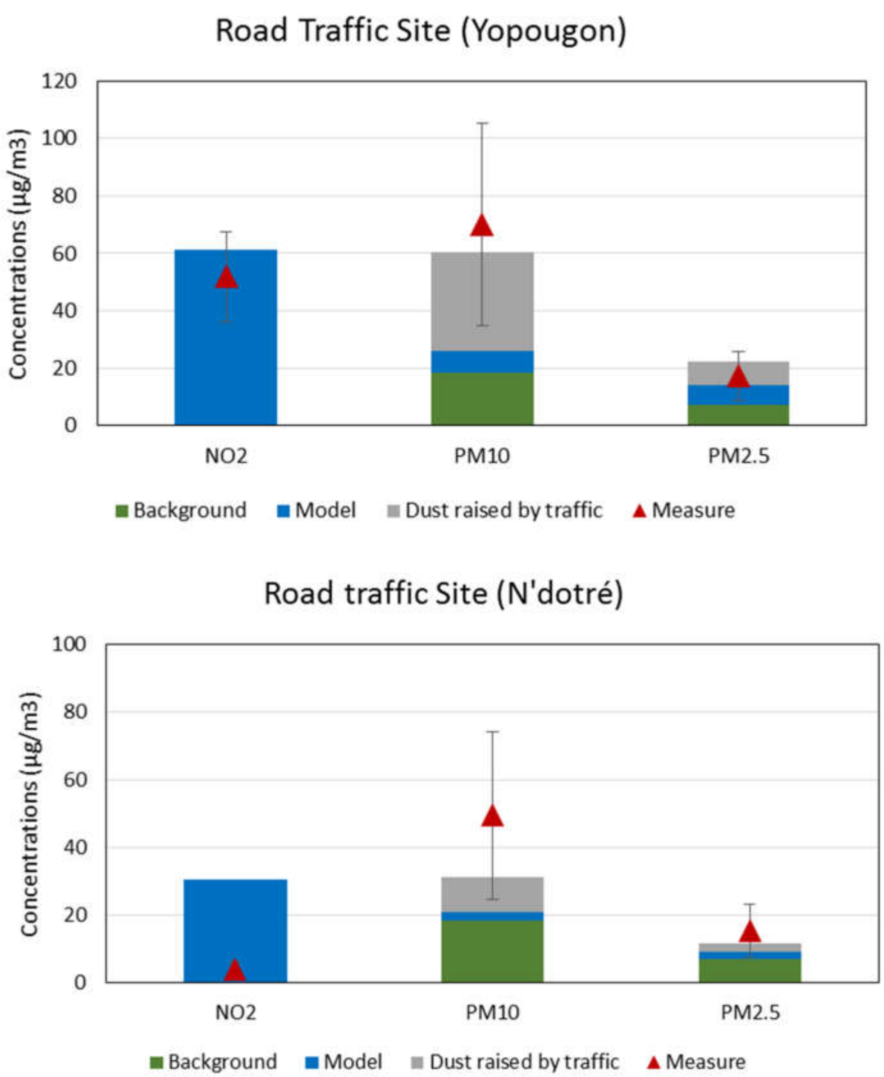
- NO_2= <5 µg/m^3,
- PM_{10} = 18.5 µg/m^3,
- $PM_{2.5}$ = 7.2 µg/m^3.

3.3.1.4.3 Concentrations calculated over Yopougon and N'Dotré pilot areas

Figure 3-10 shows concentrations calculated by ADMS-Roads and observed at the Road Traffic Sites. The green bar represents the background level and blue bar represents the road traffic contribution at Both Yopougon and N'Dotré sites. The red markers correspond to measurement values for the same time period and the black vertical lines represent the uncertainties associated to the measurement (50% for indicative measurement). This figure indicates that results from ADMS-Roads, considering both background concentrations and PM_{10} resuspension, reproduce correctly the concentration levels of particulate matter. An underestimation of PM_{10} concentration is still observed at the N'Dotré station but still within the measurement uncertainties range. Concerning PM, especially PM_{10}, contributions of both background level and dust raised by the traffic can be considered as significant compared to exhaust emissions.

The ADMS-Roads model gives a good estimation of the NO_2 concentrations measured at the Yopougon site. However, it clearly overestimates the levels observed at the N'Dotré site.

Figure 3-10: Concentrations measured and calculated with ADMS-Roads model at the Road Traffic Sites (Yopougon and N'Dotré). Model contribution in the graph corresponds to exhaust emissions



3.3.1.4.4 Mapping of concentrations calculated over the transport corridor

The following figures (Figure 3-11 and Figure 3-12) show the total concentration (including background, road traffic contribution and particulate matters resuspension) maps for NO_2, SO_2, PM_{10} and $PM_{2.5}$ over both transport corridors. As expected, the major structuring axes of the corridor are impacted by high levels of pollution within both pilot areas. The Yopougon site appears to be impacted much more in term of pollutant levels than at the N'Dotré site, due to higher traffic.

For PM pollutants, exceedances of the WHO annual average guideline values (20 and 10 µg/m^3 for PM_{10} and $PM_{2.5}$ respectively) flagged by the blue arrows on the color scale, are observed in most parts of the Yopougon and N'Dotré pilot areas, with an increase of concentration levels close to dense road traffic areas. These hourly levels of pollutant can reach more than 70 and 40 µg/m^3 for PM_{10} and $PM_{2.5}$ respectively.

NO_2 concentrations calculated using the ADMS-Roads model are relatively low (5 to 10 µg/m^3) far from roads. Concentration levels become more important near the structuring roadways with exceedances of the WHO guideline (40 µg/m^3 in annual average) identified. These concentrations exceed 70 µg/m^3 close to the North Highway at the Yopougon site.

For SO_2, the concentrations calculated by the ADMS-Roads model follow the same pattern discussed above for NO_2 pollutant. Level of SO_2 remains quite low (2 – 4 µg/m^3) far from roads but becomes more important near the main roadways (up to 50 µg/m^3).

Figure 3-11: Map concentrations of pollutants (NO_2, SO_2, PM_{10} and $PM_{2.5}$) within the N'Dotré transport corridor. Note that WHO guidelines (blue arrows) are based on annual average except for SO_2 (daily average only)

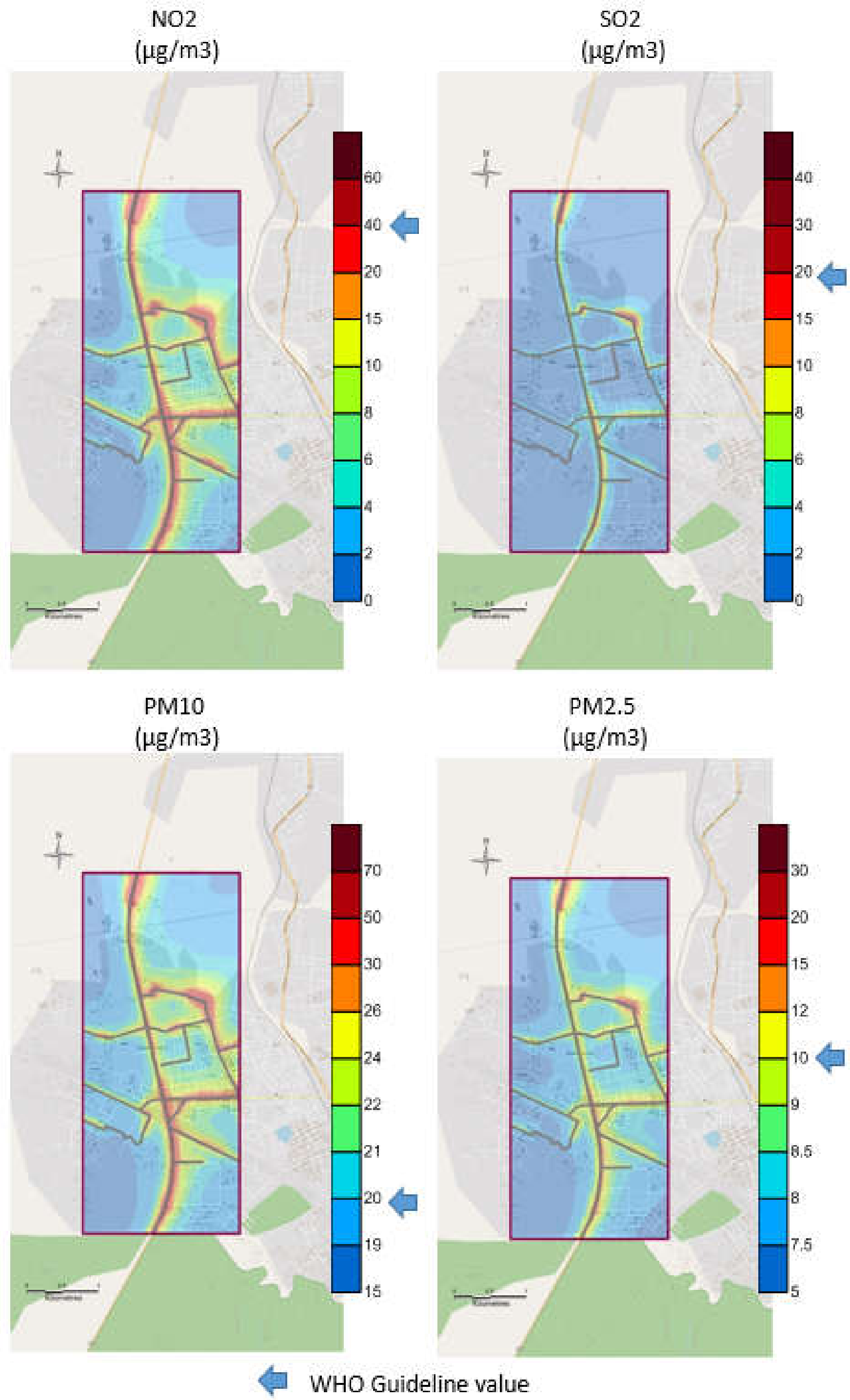
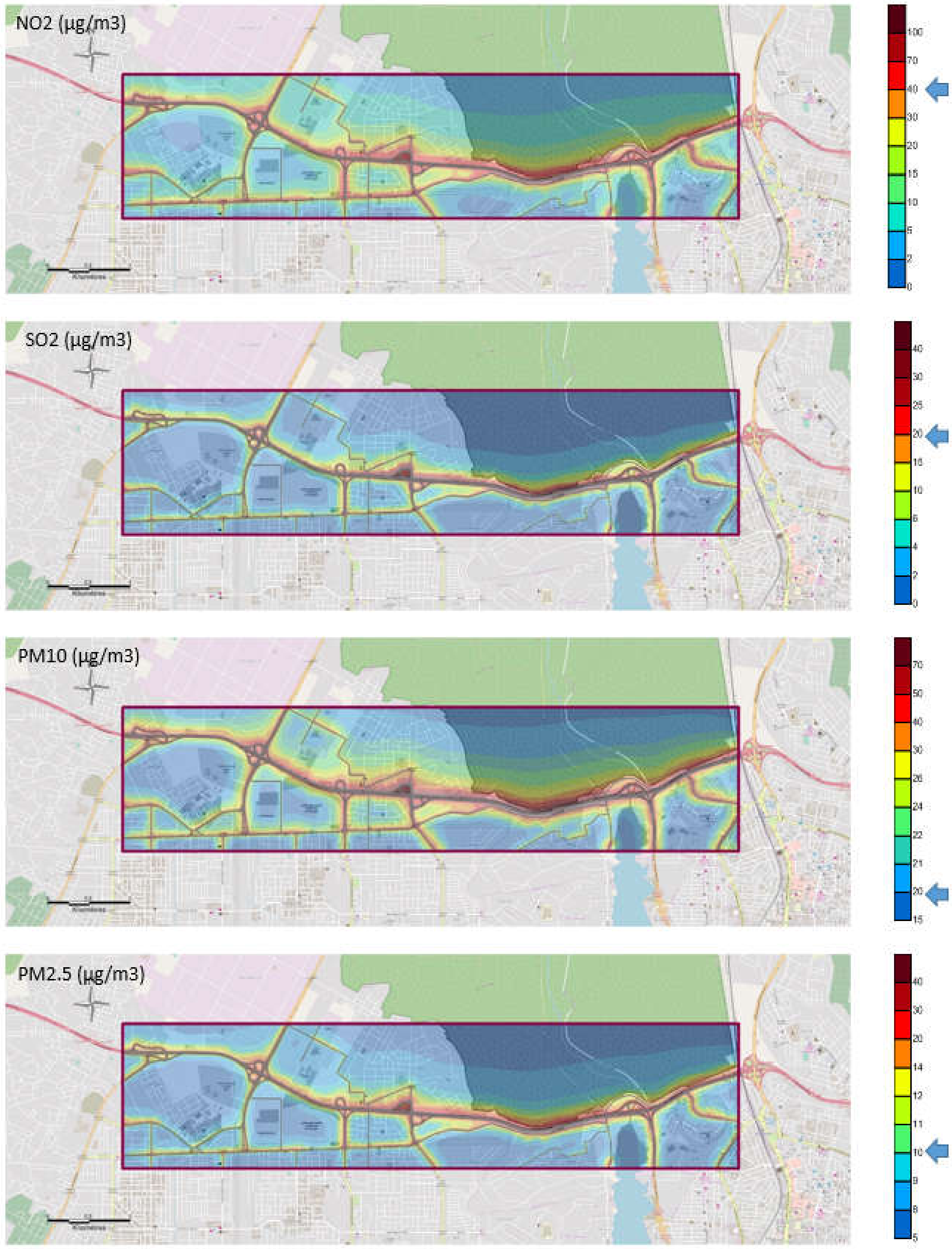


Figure 3-12: Map concentrations of pollutants (NO_2, SO_2, PM_{10} and $PM_{2.5}$) within the Yopougon transport corridor. Note that WHO guidelines (blue arrows) are based on annual average except for SO_2 (daily average only)



3.3.2 Rabat

3.3.2.1 Selection of the pilot area

Within the district of Rabat-Salé, there is a growing realization that there are valuable benefits to using the existing roadway facilities to their full potential rather than expanding capacity in a traditional way. Recently, Rabat stakeholders have looked for cost-effective transportation solutions to mitigate the growing of congestion and increasing funding gaps. To this aim urban development projects has been started in 2014 under the regional program: “Rabat, ville lumière, capitale marocaine de la culture” to improve and reinforce road infrastructures. This program includes for instance the project of the redevelopment of the Rabat Agdal train station, of the Hassan II avenue and of roads running along the tram structures. In this context the pilot area has been defined along the Hassan II avenue.

3.3.2.2 Monitoring campaign

3.3.2.2.1 Sampling locations

Aiming at assessing the contribution of the road traffic to the overall air quality within the transport corridor, the sampling campaign was implemented during the period from the 31, May 2017 to the 2nd, June 2017. In addition, a calibration campaign has also been conducted to perform a comparison of the instrument data generated by the two Cairnet compact installed side-by-side with reference methods (i.e. NO_2 and SO_2 analyzers and gravimetric method device for particulate matter) and passive sampler devices (for NO_2 and SO_2 only). Two passive sampler devices were used for each pollutant to replicate the measurement. Another passive sampler device was placed and considered as a blank measurement[11]. The following table (Table 3-13) summarizes the sampling periods and the measured parameters. The Figure 3-13 shows the locations of sites investigated during both campaigns.

Table 3-13: Measurements summary during the monitoring and the calibration campaigns (the temporal resolution is given in brackets)

Monitoring Campaign	
Sampling Period and Locations	From the 31/05/2017 to the 2/06/2017 Locations: • Agdal Riad District (33°58’46’’N;6°52’28’’W) • Regional center of investment (33°58'37.64"N; 6°52'35.43"W)
Air Quality Pollutant Samplers	• PM_{10}/$PM_{2.5}$: 2 Cairnet Microsensor (continuous/5 min) • NO_2, SO_2: 2 Cairnet Microsensor (continuous/1 min)
Weather Station	DAVIS Vantage Pro2 station (continuous/30 min). Parameter sampled by the station are given as follow: Temperature, relative humidity, wind speed and direction, pressure and precipitations
Vehicle Number and Composition	Video camera (15 min sampling period) Manual counts per vehicle category (15 min per hour during the business hours) Note: Manual vehicle counts have been performed on major roadways (2x2 lines or 3x3 lines).

[11] Blanck measurements are usually conducted in order to assess both potential contamination during transport of sampling and residual concentration of pollutant on sampling supports

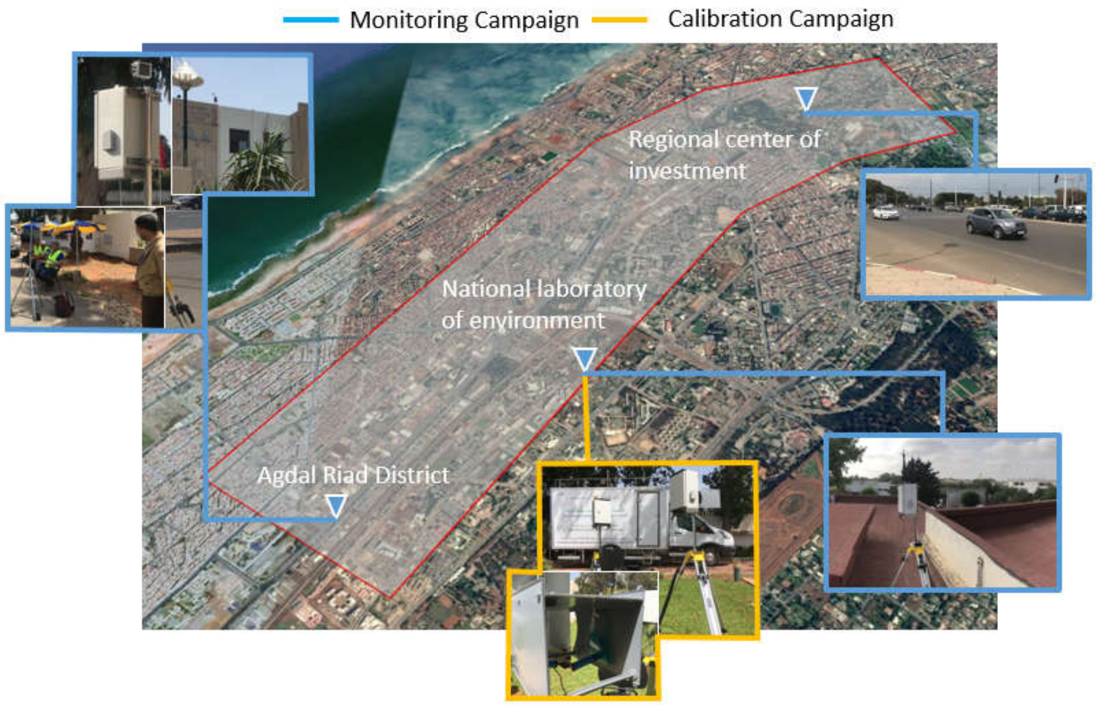
Calibration Campaign	
Sampling Period and Locations	From the 20/07/2017 to the 25/07/2017 Location: • National Laboratory of Environment (33°59'17.08"N; 6°51'40.35"W)
Air Quality Samplers	• PM_{10}/$PM_{2.5}$: 2 Cairnet stations (continuous/5 min) 1 Gravimetric Method (1 sample per day) • NO_2, SO_2: 2 Cairnet stations (continuous/1 min) 2 Analysers (continuous/15 min) 3 Passive sampler devices (integrated): 2 replicates and 1 blank measurement

During the Monitoring Campaign, road traffic sampling was carried out at two different sites in front of the Hassan II Avenue, located within the Agdal Riad District and regional center of investment (Figure 3-13). The samplers have been installed at ground level on their own tripod (1.5 m). The horizontal distances from the instrument to the roadside were approximately 15 m and 5 m for the Agdal Riad District and Regional center of investment locations respectively. The sampler located at National laboratory of environment site was used to measure the urban background concentrations. The sampler was placed on the rooftop of the administrative building. The horizontal distance from the closest roadway[12] was 50 m, while the height above the ground level was 10 m.

During the Calibration Campaign, only the National Laboratory of Environment was investigated. The Cairnet device initially placed at the rooftop of the building during the Monitoring campaign was located within the garden of the site at ground level in front of the administrative building and close to the Air Quality Mobile Laboratory (AQML). The AQML is a mobile shelter dedicated to Air Quality measurements using the most common international reference methods. AQML is the property of the National Laboratory of Environment. In front of this shelter, the passive sampler devices (PSDs) have been placed.

[12] The roadway indicated is with little traffic and considered as part of the secondary road network of Rabat linking the university to the Al Fassi Avenue.

Figure 3-13: Map of the study area showing the three monitoring sites during the two campaigns performed (calibration and monitoring campaigns). The boundaries of the transport corridor is delimited by the red box



During the calibration campaign, pollutants were measured continuously by the Cairnet stations and were compared to measurements performed by the reference equipment placed within the AQML. This equipment can be described as follows:

- An automatic sequential particulate matter sampler (PM162M from Environment SA). This additional sampling heads meet the EN 12341 (PM_{10}) and EN 14907 ($PM_{2.5}$) standards, and operated at a flow-rate of 1 m^3/h, with a collection time of 24h per sample. Samples were collected on PTFE membranes filters with a supporting ring (Φ 47 mm, pore size 2 µm);
- Two analysers for SO_2 and NO_2 (AF22M and AC32M respectively from environment SA).

In complement, three passive sampling devices (PSDs), Radiello® type, were used during this calibration campaign. The PSDs used here consist of a small cylindrical tube with a metal grid (stainless steel coated with TEA, TriEthylAmine) trapping SO_2 and NO_2. PSDs are an integrated measurement which means that the sampled mass of pollutants is representative of the entire sampling period.

3.3.2.2.2 Calibration Campaign results

As indicated in the preamble of this section, the Calibration Campaign was dedicated to the validation of the concentrations sampled by the Cairnet instruments performed during the monitoring campaign[13]. Particular attention was paid to investigate both road traffic conditions and urban background in order to cover a large range of concentration values. To this aim a SUV-vehicle from the National Laboratory of Environment has been punctually moved close to the instruments during two periods of 30 minutes to sample pollutant concentrations resulting from vehicle exhaust system within a distance of 3 m.

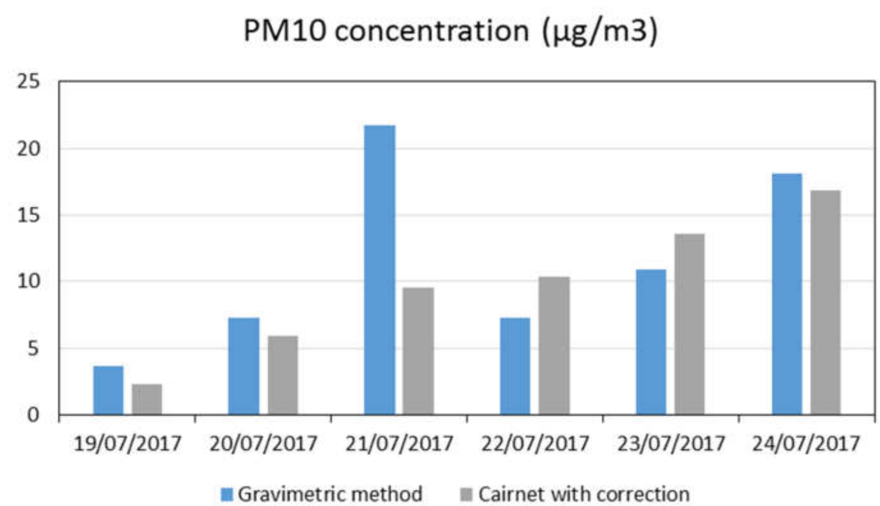
[13] In this second campaign the two Cairnet systems have been used independently. However, in order to facilitate the analysis, results were presented in this report as the average between the two instruments. These Cairnet instruments have been compared each other and PM_{10} concentrations showed a good correlation coefficient at hourly resolution (r^2 = 0.78).

Concentrations measured by the Cairnet was compared against the three other sampling methodologies (analyzers, gravimetric method and passive sampler devices). Correction factors have been then calculated and applied when necessary. The figure below (Figure 3-14) shows the concentrations of PM_{10} measured by the gravimetric method (1 sample per day) and the Cairnet system with correction factor. Note that concentrations measured by the Cairnet system were – in average - more important than concentrations obtained by the gravimetric method, due to high humidity during night time. Consequently, and according to recommendations from the Cairnet provider, a linear correction factor has been applied to the Cairnet system to fit as much as possible with the gravimetric method measurements. This linear correction factor is given by the following formula:

$$PM_{10\ (corrected)} = 0.77 \times PM_{10\ (without\ correction)} - 13.72$$

The resulting corrected concentrations of PM_{10} are indicated in grey in the Figure 3-14, showing a quite good correlation in average.

Figure 3-14: Concentrations of PM_{10} measured using a gravimetric method (blue bars), and using the Cairnet system (grey bars)



The table below (Table 3-14) shows the concentration of SO_2 and NO_2 measured by the analyzers, the Cairnet systems and the integrated measurement given by the passive sampler devices. The passive sampler results are presented as the average between the two replicates minus the concentrations measured on the blank measurement sample.

This comparison shows that the level of SO_2 is low (<1 µg/m^3) as expected without any industrial pollution and relatively low fuel sulfur-content used in Morocco. The Cairnet station was not able to measure these very low concentrations, due to higher detection thresholds mostly applied within industrial environment. Regarding the NO_2 pollutant, concentrations are extremely close, even for low concentrations. Consequently, no correction factors were applied to the concentration sampled by the Cairnet systems.

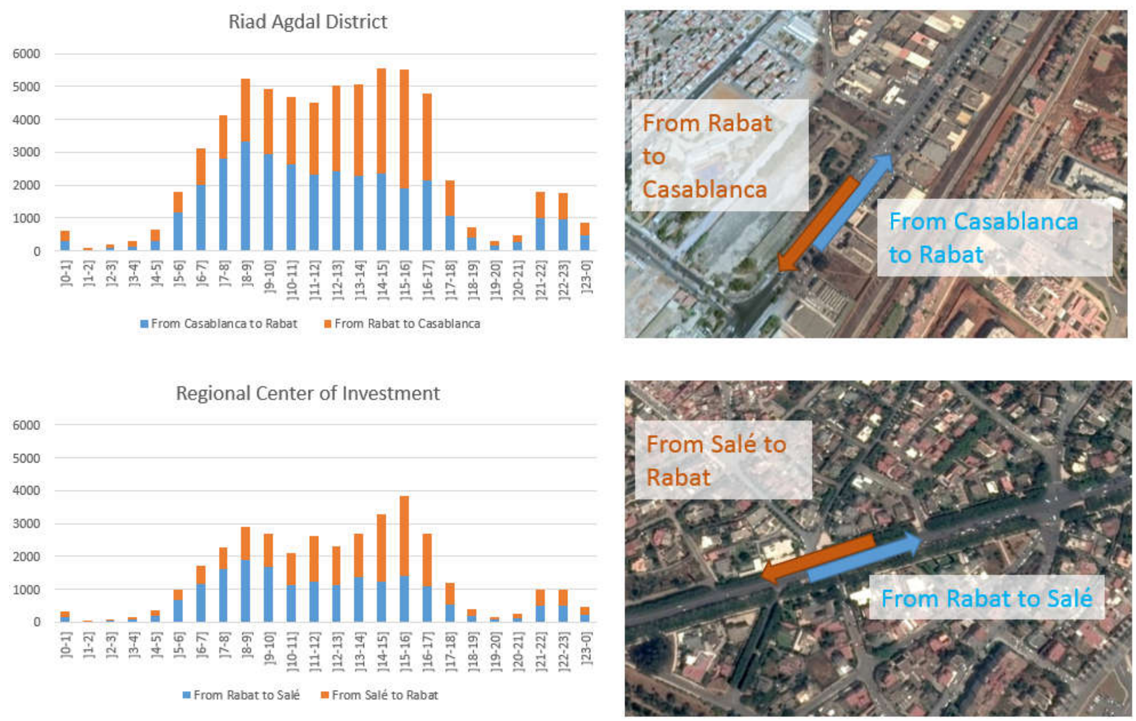
Table 3-14: Concentrations of SO_2 and NO_2 measured during the calibration campaign

Pollutant	Air Quality Mobile Laboratory (µg/m^3)	Passive Sampler Devices (µg/m^3)	Cairnet system (µg/m^3)
SO_2	0.6	0.3	-
NO_2	14.9	15.8	16.3

3.3.2.2.3 Monitoring campaign results

Results of the manual vehicle counts performed during this campaign (31 May – 2nd June, 2017) are summarized in the Figure 3-15 showing the vehicles number per hour passing on both directions of the road (hourly average during the period, detailed manual vehicle counts are available in Appendix 3). As presented in the methodology section, these time series are derived using both manual vehicle count samplings and completed by the road traffic model implemented by Ramboll. The Figure 3-15 shows that the total number of vehicles at the Riad Agdal District site is 1.5 times more important than the volume observed at the Regional Center of Investment site. The number of vehicles travelling on the Hassan II Avenue (Riad Agdal District) is mainly impacted by the road traffic flow coming from and to the Expressway, A3, and the National Road, N1. The Regional Center of Investment site is less impacted by such traffic because it is located within the dense road network of Rabat downtown. The important vehicles volume that flows from the Hassan II Avenue are then spread over multiple roads and consequently tends to decrease the total number of vehicles on each road.

Figure 3-15: Hourly traffic at the Road Traffic Stations. Locations and directions (with corresponding colors) are indicated on the left pane (Rabat)



For each site location the daily temporal profile is not representative of a typical workday generally found in Rabat. The vehicle traffic sampled here shows a strong vehicle traffic period between 8h and 16h and a singularity between 21h and noon. The monitoring campaign was performed during the Ramadan Religious Feast Event that implied mostly extended and modified opening times of shops, workdays[14] and drastically daily rhythm changes. These changes have been considered for calculated Average Daily Traffic (ADT) volumes.

The distribution of vehicles per category sampled at both Riad Agdal District and Regional Center of Investment sites are provided in the table below (Table 3-15). Overall, the results show an equivalent distribution of traffic per category of vehicles at both sites with a slightly lower relative contribution of buses and trucks at the Regional Center of Investment site. Surprisingly taxi category show a quite low relative contribution at both sites.

[14] During the Ramadan Period the typical workday is a continuous period of work (without lunchtime break) starting from 9h and ending at 15h.

Table 3-15: Vehicle distribution (%) and total Average Daily traffic (ADT) volumes estimated from measurements within the pilot area

Site Locations	Passenger Cars	Taxis	2-wheels (Motorcycle)	Light duty Vehicles (<15t)	Trucks (>15t)	Coaches / Buses	Special Vehicles (construction machinery,	ADT
Riad Agdal District	79.0	7.6	4.6	5.2	2.2	1.4	0.0	64,307
Regional Center of Investment	79.1	9.6	6.7	3.2	0.5	0.8	0.0	35,632

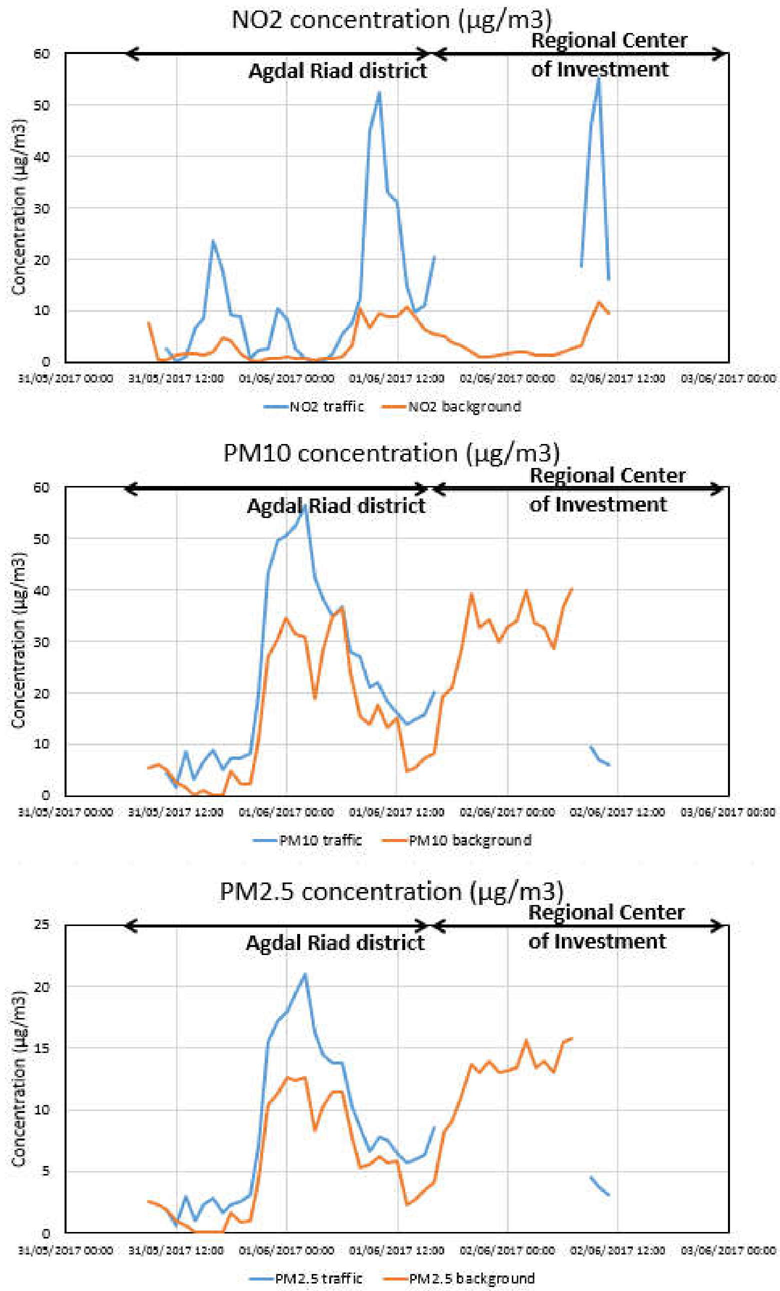
Figure 3-16 shows the concentrations of NO_2, PM_{10} and $PM_{2.5}$ sampled during the monitoring campaign using the Cairnet stations at both road traffic sites (Riad Agdal District and Regional Center of Investment) and background sites (within the area of the National Laboratory of Environment). PM_{10} and $PM_{2.5}$ were corrected according to the results obtained during the calibration campaign (see the previous section for more details).

NO_2 concentration levels are generally higher on both road traffic monitoring sites than on the background site reflecting the impact of road pollution. There are three major hourly concentration peaks identified on the Road Traffic sites which are significantly low against the WHO international hourly standard[15] (i.e. 200 µg/m^3): the 31, May 2017: 23.6 µg/m^3; the 1st, June 2017: 52.3 µg/m^3; and the 2nd, June 2017: 55.2 µg/m^3. The occurrence of these peaks is correlated to hourly episodes with high number of vehicles travelling during the campaign. In addition, another high hourly concentration was observed the 31, June 2017 around 23h (10.5 µg/m^3). This concentration peak observed during the night can be explained by the particular circumstance of the Ramadan event showing a high activity at this time.

For PM_{10} and $PM_{2.5}$ pollutants, both road traffic and background stations show the same behavior i.e. low concentrations the first day until midnight and relatively high concentrations until the next day at midday. PM_{10} and $PM_{2.5}$ hourly concentrations measured at both Road Traffic sites varied from 5 to 56 µg/m^3 and 3 to 31 µg/m^3 respectively and can exceed the shortest time (24-hours average) WHO standards, i.e. 50 µg/m^3 and 25 µg/m^3 for PM_{10} and $PM_{2.5}$ respectively. These high concentrations measured at all sites (background and road traffic stations) and their occurrence during the night show that pollution could be due to other sources instead of road traffic (dusts, sea salts, etc.). In addition, temperature (22.5°C on average) and relative humidity (80% on average) measured by the instruments during the night can exceeds the limitations of the Cairnet systems as mentioned by the equipment developer.

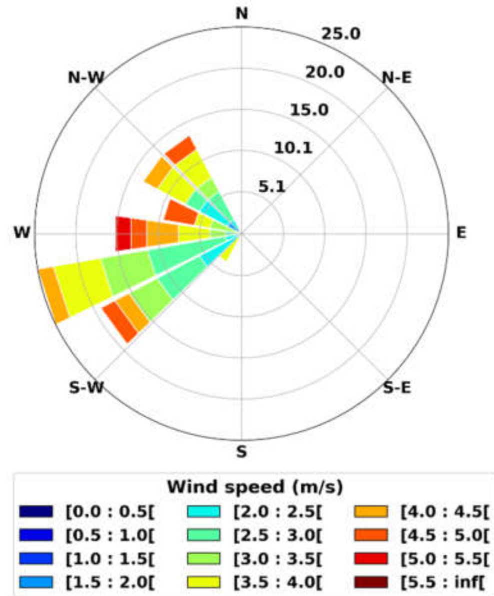
[15] Air quality guidelines. Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide (2006). World Health Organisation.

Figure 3-16: Ambient Air PM_{10}, $PM_{2.5}$ and NO_2 concentrations at the Hassan II Avenue (Riad Agdal district), at the Regional Center of Investment and at the background sites



In addition to the concentrations measured at the two Road Traffic sites, a DAVIS weather station was placed close to the instruments. The resulting wind rose is presented in the following figure (Figure 3-17) for the 3-days period and shows that prevailing winds mainly came from the western sector. The wind speeds were low to moderate and ranging mainly from 2 m/s to 5 m/s. Temperatures were stables and ranging from 20.2 to 24.4°C with an average of 22.1°C. Relative humidity was relatively high due to the coastal influence and varied from 61 to 85%.

Figure 3-17: Wind rose derived from the weather station (DAVIS Vantage Pro2) during the monitoring campaign (Rabat)



3.3.2.3 Calculation of emissions

Assumptions made to generate a vehicle fleet over Rabat is summarized in Table 3-16. Average Equivalent Vehicle (AEV) emissions obtained from all these assumptions and calculated after the COPERT 5 step are summarized in the Appendix 2, for each vehicle category.

Table 3-16: Assumptions for the construction of vehicle fleet at Rabat city and Average Equivalent Vehicles (AEVs)

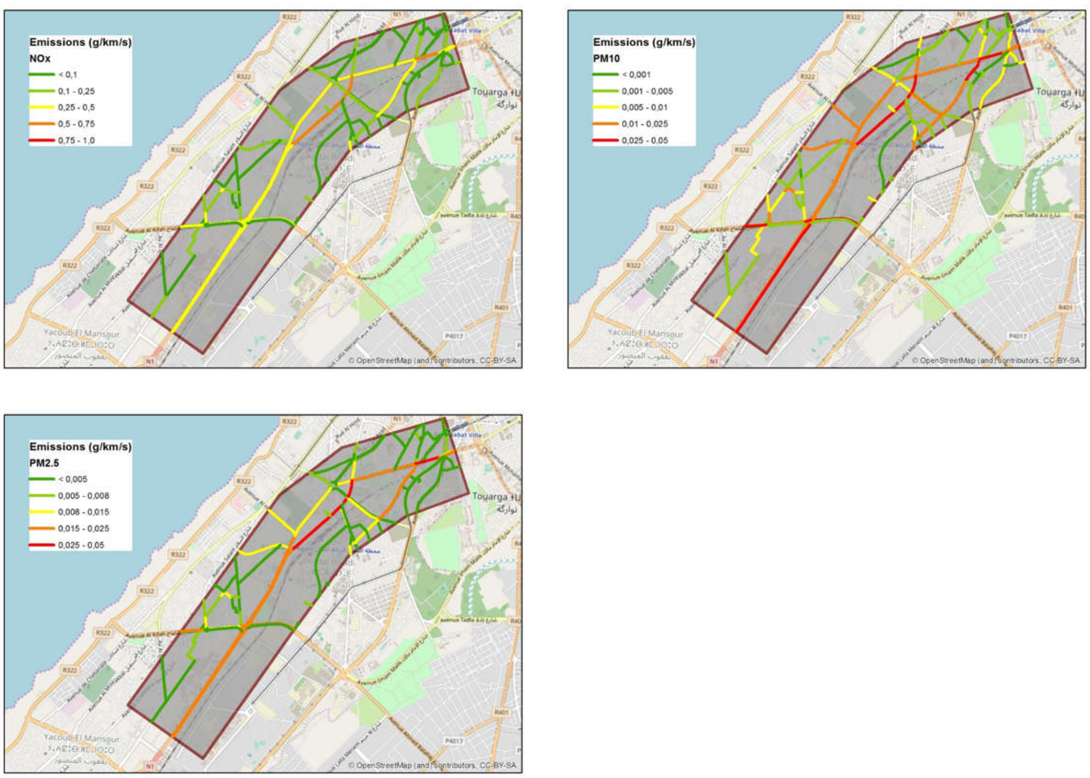
Parameter	Assumption
Population of the selected vehicle categories	The number of vehicles in each category has been derived from DTRSR [16] database. As indicated within the methodology section, arbitrary values could have been setup within any influence on results.
Fuel type	Gasoline and diesel PC vehicles ratio have been collected from the DTRSR database i.e. 66% of diesel vehicles. Motorcycle class has been considered to operate with petrol only. LDVs, Buses and HDTs have been considered as diesel vehicle only.
Fuel composition	The fuel composition has been defined according to the default value within COPERT 5 model. Sulfur-content has not been considered specifically for this study because of the low sulfur-content according to the CCAC [17] (Climate & Clean Air Coalition) document (>15 – 50 ppm).
Engine rating	The engine rating chosen came from Numtech assumptions[15].
Weight	The Light duty vehicle weight has been derived from the DTRSR database (<7.5t).

[16] DTSTR : Direction du Transport routier et de la Sécurité Routière. http://www.equipement.gov.ma/routier/Organisation/Pages/Missions-DTRSR.aspx
[17] Cleaning up the global on-road diesel fleet a global strategy to introduce low-sulfur fuels and cleaner diesel vehicles, 2016, 79 p.

Parameter	Assumption
Emission Standards	Based on assumptions retained for the regional emission inventory completed by the Environment Ministry, the EURO 3/III standard has been chosen for all vehicles for emission calculation (section 3.2.3)[18].
Vehicle Lifetime	Vehicle lifetimes has been calculated according to the emission calculation methodology (section 3.2.3).
Average Speed	Average speeds on highways, rural roads and urban area were based on the Ramboll expert judgement: • Urban road: 25 km/h • Rural road: 60 km/h • Highway: 80 km/h

The following figure (Figure 3-18) shows the air emissions of NO_x, PM_{10} and $PM_{2.5}$ due to the road traffic within the transport corridor. Emissions have been calculated according to the methodology described in the section 3.2.3. Emissions mainly distributed close to the main road axes within the transport corridor (i.e. on the Hassan II Avenue).

Figure 3-18: Air emissions of NO_x, PM_{10} and $PM_{2.5}$ over the transport corridor - Rabat (defined by the dark red box)



[18] Étude pour la mise en place de systèmes de modélisation de la dispersion des polluants atmosphériques, Numtech. Study performed for the DPR.

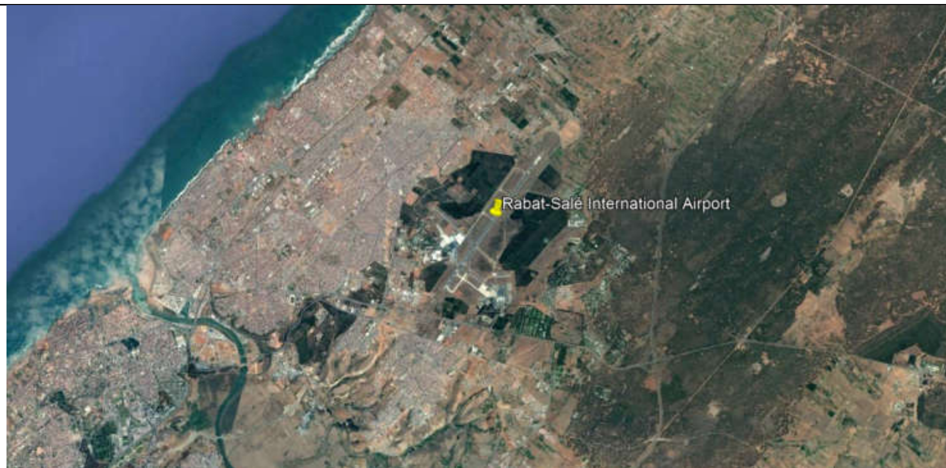
3.3.2.4 Air quality mapping

3.3.2.4.1 Meteorological parameters and time period

Meteorological parameters have been extracted from the DAVIS weather station, except for the cloud coverage, which has been extracted from the Rabat-Salé international airport (Table 3-12).

The time period has been chosen in order to cover the entire duration of the monitoring campaign i.e. between the 31, May 2017 (10:00 am) to the 2nd of June (12:00 am).

Table 3-17: Rabat-Salé International Airport – Weather station



Site Identification (WMO)	60135
Latitude	34.051467
Longitude	-6.751519
Elevation	84.12 m

3.3.2.4.2 Particulate Matter (PM) resuspension and background concentrations

According to the good state of the road network in Rabat, no dust resuspension has been considered for this model calculation.

Background concentrations have been derived from measurements performed at the National Laboratory of Environment during the measurement campaign. For this study, background concentration represents an integrated and averaged value of the urban pollution far from the road traffic influence.

Background concentrations obtained for each pollutant are summarized as follow:

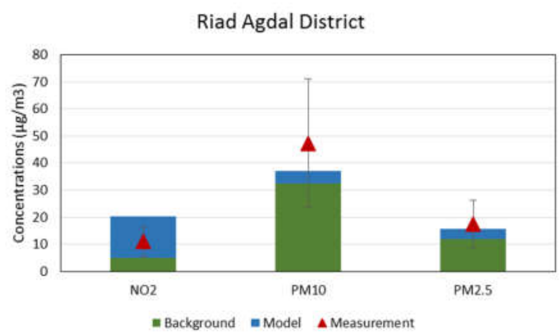
- NO_2= 5.0 µg/m^3,
- PM_{10} = 24.9 µg/m^3,
- $PM_{2.5}$ = 10.4 µg/m^3.

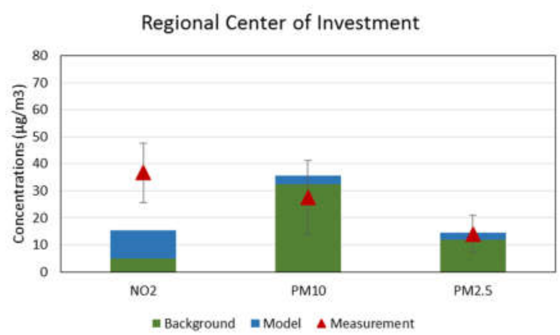
3.3.2.4.3 Concentrations calculated over the two road traffic sites

Figure 3-19 shows concentrations calculated by ADMS-Roads model and observed at both road traffic sites (Riad Agdal District and Regional Center of Investment). The green bar represents background level and blue bar represents road traffic contribution at both Road Traffic sites (Riad Agdal District and Regional Center of Investment). The red markers correspond to measurements for the same time period and the black vertical lines represent the uncertainties associated to the measurement (50% for indicative measurement). This figure indicates, considering the background concentrations estimated, that ADMS-Roads reproduces correctly the concentration levels observed at these two sites except for NO_2 pollutant at the Regional Center of Investment site. The road traffic contribution to the particulate matter is low compared to the background (about 12% and 20% for PM_{10} and $PM_{2.5}$ pollutants respectively).

NO_2 concentrations at the Riad Agdal District site are also correctly represented by the ADMS-Road model and show a road traffic contribution to the total NO_2 concentrations about 75%. Concentrations of NO_2 calculated at the Regional Center of Investment site are underestimated by a factor 2 comparing to the observed concentrations. This large underestimation can be explained by the low number of concentration observations (4 hours) retrieved at this site and cannot be representative of the entire environmental conditions occurring during the sampling of road traffic at this location.

Figure 3-19: Concentrations cumulated measured and calculated with ADMS-Road model (Rabat). Model contribution in the graph corresponds to exhaust emissions



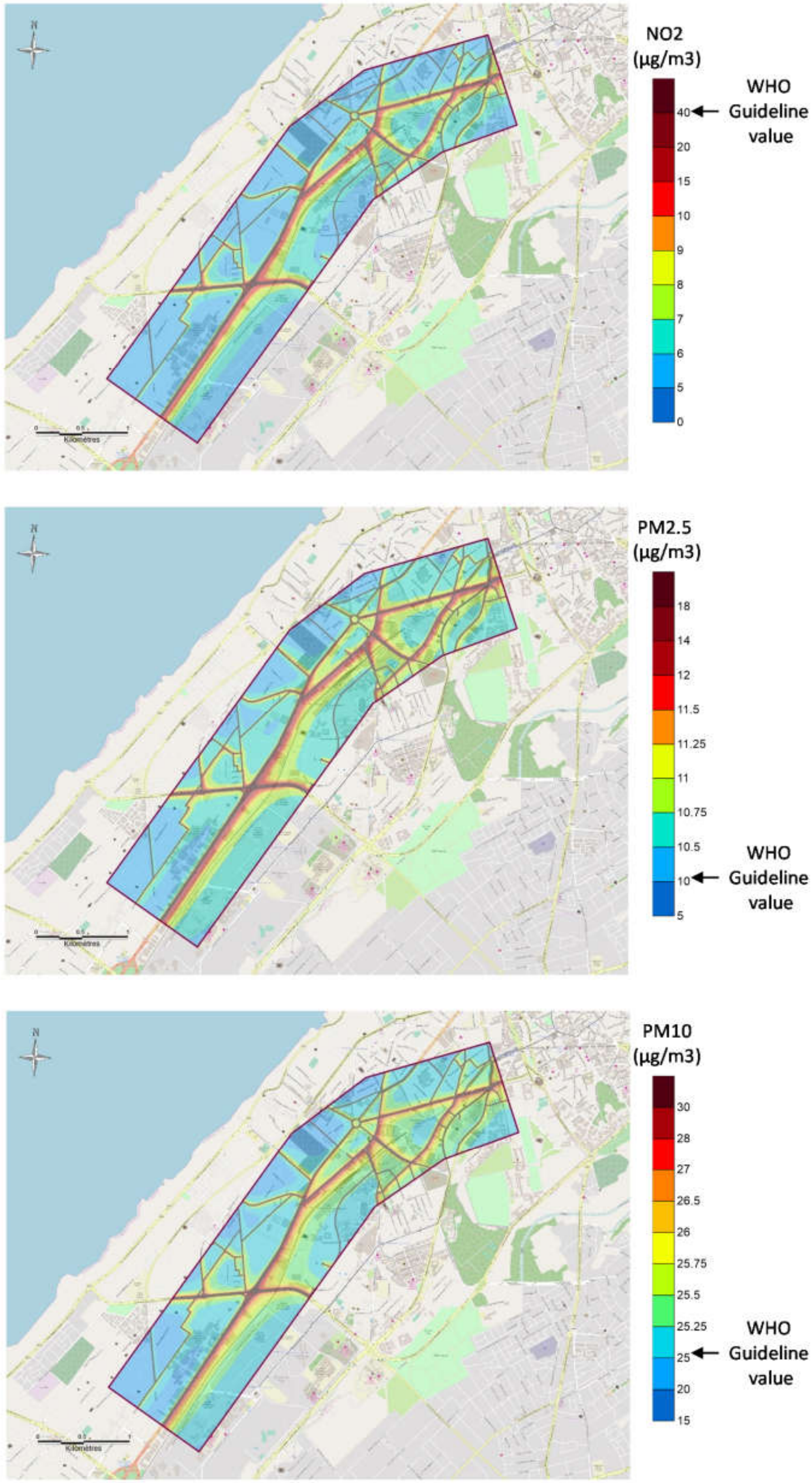


3.3.2.4.4 Mapping of concentrations calculated over the transport corridor

The figure below (Figure 3-20) shows the total concentration (background and road traffic contribution) maps for NO_2, PM_{10} and $PM_{2.5}$ over the transport corridor. **Due to the low sulfur content, SO_2 pollutant has not been considered in this study as referred in the Table 3-16.**

The major structuring road axes (e.g. Hassan II Avenue) within the transport corridor are characterized by high levels of pollution. For PM pollutants, exceedances of the WHO annual average guideline values (20 and 10 µg/m^3 for PM_{10} and $PM_{2.5}$ respectively) flagged by the blue arrow on the color scale, are observed mostly close to these structuring roadways. The WHO guideline values for both PM_{10} and $PM_{2.5}$ are exceeded in most locations within the transport corridor. These concentrations cannot be explained by road traffic sources only which account for 10 to 20% of the total concentrations calculated as discussed in the previous section. The main contributor to the total concentrations is the background level that express the contribution of all other local sources (industrial for instance) and long-range transported pollution (such as Saharan dusts or sea salts). For NO_2 pollutant, concentrations didn't exceed the guideline but the maximum located near the Hassan II Avenue lies with this guideline).

Figure 3-20: Map concentrations of pollutants (NO_2, PM_{10} and $PM_{2.5}$) within the transport corridor in Rabat city. Note that WHO guidelines (blue arrows) are based on annual average



3.3.3 Yaoundé

3.3.3.1 Selection of the pilot area

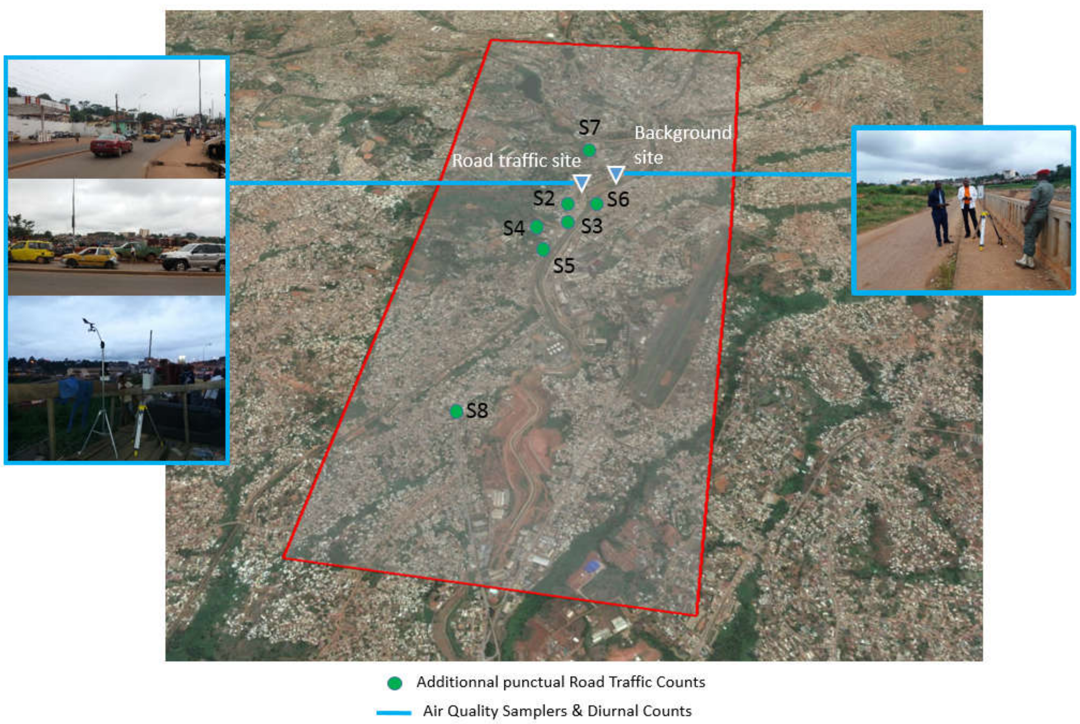
The transport corridor has been selected according the development of the Atangana Avenue scheduled within the few next months in the downtown part of Yaoundé. This project is part of the development of the future expressway from the Nsimalen-Yaoudé International Airport to the downtown of Yaoundé. The project has already started close to the International Airport.

3.3.3.2 Monitoring campaign

3.3.3.2.1 Sampling locations

The Monitoring Campaign has been performed during the period from the 1st, August 2017 (2:00 pm) to the 4th, August 2017 (12:00 am). Road traffic sampling was carried out at one site in front of the roadside of Charles Atangana Avenue, located at 03°50.9770'N; 11°30.9100'E (Figure 3-21). The Cairnet station has been installed at 1.5 m above ground level on its own tripod. Near the Cairnet system, the weather station has been placed as well. The horizontal distances from the instruments to the roadside were 25 m. The background concentrations have been sampled on the bridge located at 03°51.0018'N; 11°31.0023'E close to the Charles Atangana Avenue; relatively far from the road traffic influence.

Figure 3-21: Map of the pilot area (delimited by red box) showing the two monitoring sites. The green symbols represent the additional traffic counts



7 supplementary sites (S2 to S8 markers indicated on the Figure 3-21) have been investigated to sample road traffic volumes including vehicles category samplings. Measurements were performed during 1 to 2 hours each site. The table below (Table 3-18) compiles the geographic coordinates for each site.

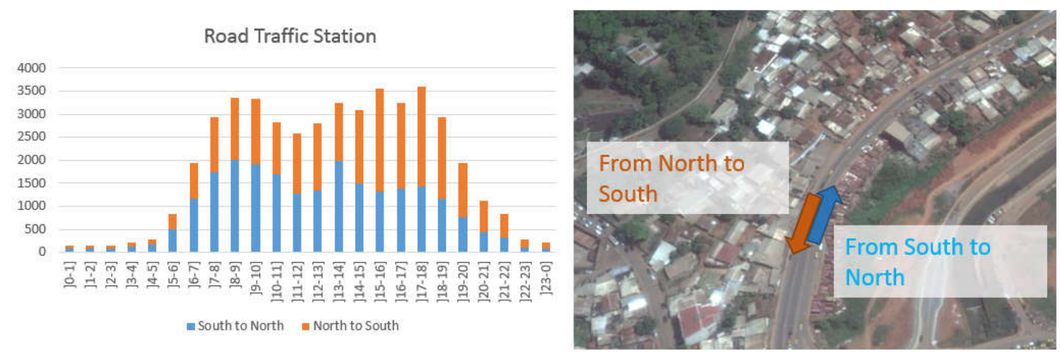
Table 3-18: Additional sampling locations dedicated to vehicle volume counts

Site	Location
S2	3°50,9189'N; 11°30,9848'E
S3	3°50,7443'N; 11°30,8557'E
S4	3°50,7238'N; 11°30,7443'E
S5	3°50,6245'N; 11°30,8045'E
S6	3°50,9063'N; 11°30,8497'E
S7	3°51,2062'N; 11°30,8987'E
S8	3°49,5182'N; 11°30,4776'E

3.3.3.2.2 Monitoring Campaign results

Result of the manual counts are summarized in the figure below (Figure 3-22) showing the vehicles number per hour passing on both directions of the road (detailed manual vehicle counts are available in Appendix 3). As presented in the methodology section these time series are derived using both manual vehicle count samplings and assumptions regarding the hours with missing data completed by the Abidjan traffic model. The total number of vehicles estimated is 45,525 vehicles per day.

Figure 3-22: Hourly traffic on the Charles Atangana Avenue near the Cairnet station. Locations and directions (with corresponding colors) are indicated on the left pane (Yaoundé)



The distribution of vehicles per category sampled at the Road Traffic site is presented in the Table below (Table 3-19). Results show that Passenger cars (PCs) and Taxis were the most important categories in term of relative contribution.

Table 3-19: Road traffic distribution (%) and Average Daily traffic estimated (ADT) from measurements in Yaoundé city.

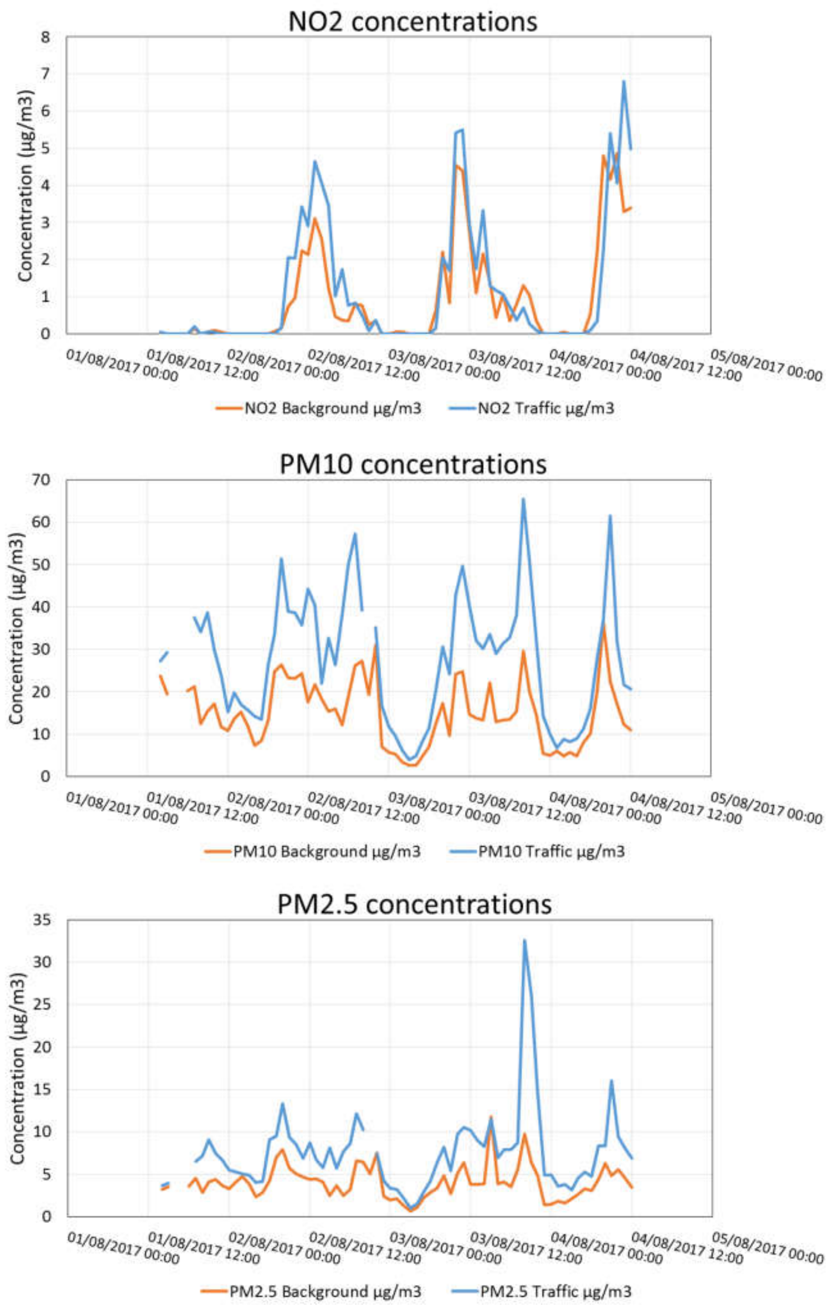
Site Locations	Passenger Cars	Taxis	2-wheels (Motorcycle)	Light duty Vehicles (<15t)	Trucks (>15t)	Coaches / Buses	Special Vehicles (construction machinery,	ADT
Road Traffic Station	46.4	41.1	6.5	3.5	2.3	0.2	0	45,525

Figure 3-23 shows the concentrations of NO_2, PM_{10} and $PM_{2.5}$ sampled during the monitoring campaign at the Road traffic site. It was not possible to treat the SO_2 measurements due to inconsistent results and detection limit of the sampler.

NO_2 concentrations measured were low at both sites (with maximum hourly levels reaching 8 µg/m^3). Concentration levels of NO_2 were more important during the day and more specifically during business hours with concentration peaks at midday. Concentrations of NO_2 were slightly greater at the Road traffic site than at the background site, reflecting the relative small impact of road pollution on total NO_2 concentrations. The distance to the road and the location of the weather station associated to the main prevailing wind directions (Figure 3-24) can explain the low values (below 10 µg/m^3) of NO_2 concentration levels at the Road Traffic site.

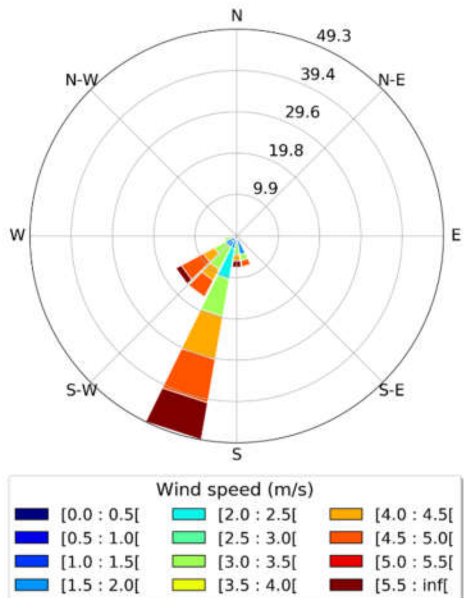
For PM_{10} and $PM_{2.5}$ pollutants, both road traffic and background Cairnet systems show the same behavior i.e. low concentrations during the night and high level of pollution during the day (between 7h to 22h). The concentration levels varied from 5 to 68 µg/m^3 and 2 to 33 µg/m^3 for PM_{10} and $PM_{2.5}$. These values can exceed the shortest integration time (24-hours mean) WHO standards, 50 µg/m^3 and 25 µg/m^3 for PM_{10} and $PM_{2.5}$ respectively.

Figure 3-23: Ambient Air NO_2, PM_{10} and $PM_{2.5}$ concentrations at the Road Traffic and at the Background sites (Yaoundé)



In addition to the concentrations measured at the road traffic site, a DAVIS weather station was placed close to the Cairnet instrument. The wind rose presented in the Figure 3-24 shows that prevailing winds mainly came from the south-western sector. The wind speeds were low to moderate ranging from 2 m/s to 5 m/s. Temperatures were stables ranging from 20.3 to 27.1°C with an average value of 22.3°C. Relative humidity varied from 69 to 75%.

Figure 3-24: Wind rose derived from the weather station (DAVIS Vantage Pro2) during the monitoring campaign from 1st, August 2017 (2:00 pm) to the 4th, August 2017 (12:00 am) (Yaoundé)



3.3.3.3 Calculation of emissions

Assumptions made to generate a vehicle fleet at the Yaoundé transport corridor is summarized in the Table 3-20. AEV emissions obtained from all these assumptions and calculated after the COPERT 5 step are summarized in the Appendix 2.

Table 3-20: Assumptions for the construction of vehicle fleet at Yaoundé city and Average Equivalent Vehicles (AEVs)

Parameter	Assumption
Population of the selected vehicle categories	The number of vehicles per each category has been derived from the distribution obtained from measurements carried out during the monitoring campaign (Table 3-19). As indicated within the methodology section, arbitrary values could have been setup without any influence on results. A specific treatment, using the video camera records, has been done to split over three sub-category of Passenger Cars (small, medium and SUV). The resulting distribution is given in the Table 3-21.
Fuel type	Due to absence of robust information regarding the fuel type used within each vehicle category, gasoline and diesel ratio have been supposed to be 50% (for PCs and Taxis). LDVs and HDTs are assumed to operate with diesel, motorcycles operated with gasoline only.

Parameter	Assumption
Fuel composition	The fuel composition has been defined according to the default value within COPERT 5 model. Sulfur-content has been setup to 2,000 ppm (mass) for diesel according to the CCAC[19] (Climate & Clean Air Coalition) document. Without any information relative to the gasoline composition, and according to a conservative approach, the sulfur-content was considered to be the same as for diesel (i.e. 2,000 ppm).
Engine rating	The engine rating chosen for PCs category has been derived from the analysis of video camera records (Table 3-21; Table 3-22). Without any information of the distribution between gasoline and diesel vehicles, the same distribution has been applied to both vehicle types.
Weight	The LDVs weight has been derived from the video camera records (< 7.5 t). The composition of HDTs and buses is reported in the Table 3-22
Emission standards	The EURO 3/III standard has been defined for all vehicles according to the methodology of the emission calculation (section 3.2.3).
Vehicle Lifetime	Vehicle lifetimes has been calculated according to the emission calculation methodology (section 3.2.3).
Average Speed	Average speeds on highways, rural roads and urban area were based on the Ramboll expert judgement: • Urban road: 25 km/h • Rural road: 60 km/h • Highway: 100 km/h.

The next two tables compile the vehicles distribution among the categories provided in the methodology section. These results have been derived from the analysis of the video camera records taken during the monitoring campaign.

Table 3-21: Vehicles distribution – PCs category (Yaoundé)

	Passenger Cars Sub-Categories		
	Small	**Medium**	**SUV**
Distribution [%]	11.49	48.84	39.66

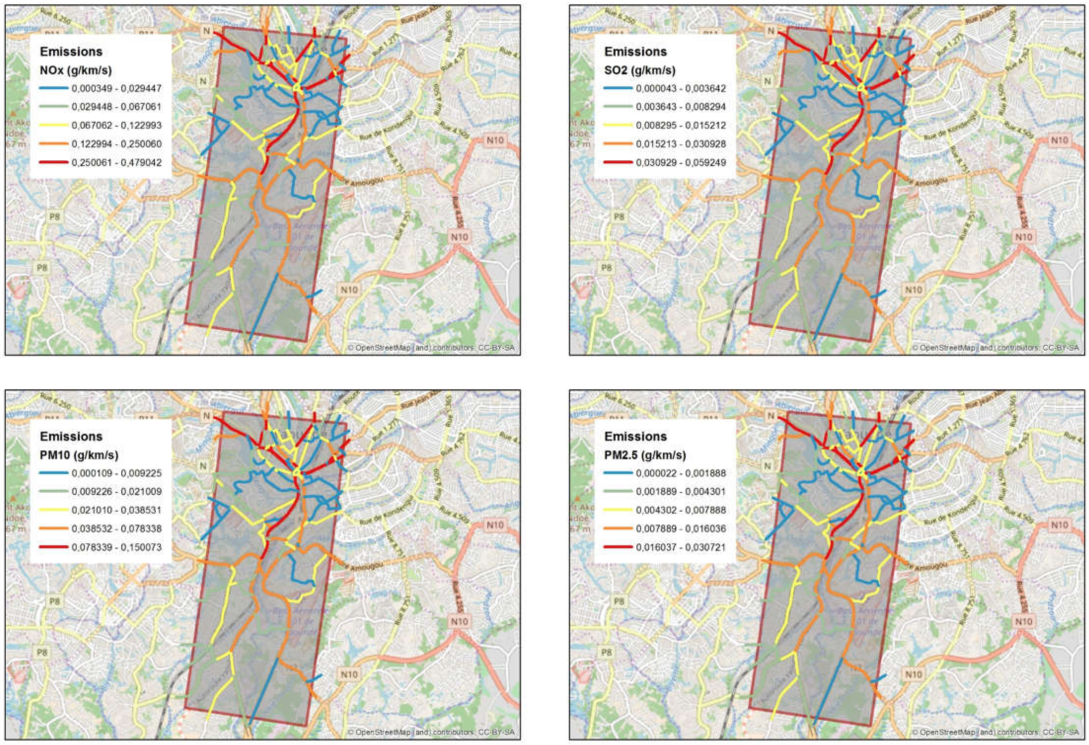
Table 3-22: Vehicles distribution - HDTs and bus categories (Yaoundé)

	HDTs, axles #				Bus Weight	
	2	**3**	**4**	**5**	**<15t**	**>15t**
Distribution [%]	65.7	28.4	1.5	4.5	64.3	35.7

The figure below (Figure 3-25) shows the air emissions of NO_x, SO_2 and PM_{10} and $PM_{2.5}$ due to the road traffic within the transport corridor. Emissions have been calculated according to the methodology described in the section 3.2.3.

[19] Cleaning up the global on-road diesel fleet a global strategy to introduce low-sulfur fuels and cleaner diesel vehicles, 2016, 79 p.

Figure 3-25: Air emissions for NO_x, SO_2, PM_{10} and $PM_{2.5}$ (Yaoundé)



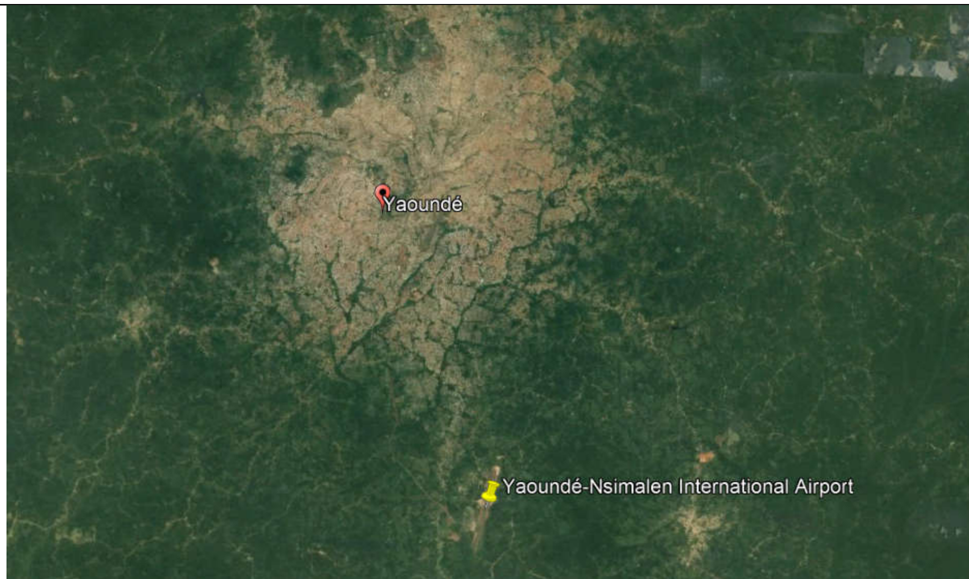
3.3.3.4 Air Quality Mapping

3.3.3.4.1 Meteorological parameters and time period

Meteorological parameters have been extracted from the DAVIS weather station, except for the cloud coverage, which has been extracted from the Yaoundé-Nsilamen international airport (Table 3-19).

The time period has been chosen in order to cover the entire duration of the campaign i.e. between the 2nd, August 2017 at 14:00 to the 4th August at 12:00.

Table 3-23: Yaoundé-Nsimalen International Airport – Weather station



Site Identification (WMO)	64950
Latitude	3°43'21.20"N
Longitude	11°33'11.77"E
Elevation	694.33 m

3.3.3.4.2 Particulate Matter (PM) resuspension and background concentrations

Particle resuspension has been considered for PM_{10} only. The value calculated is 0.14 g/veh./km.

Background concentrations have been derived from measurements performed at the Background site during the Monitoring Campaign. For the purpose of this study, background concentration represents an integrated and averaged value of the urban pollution far from the road traffic influence.

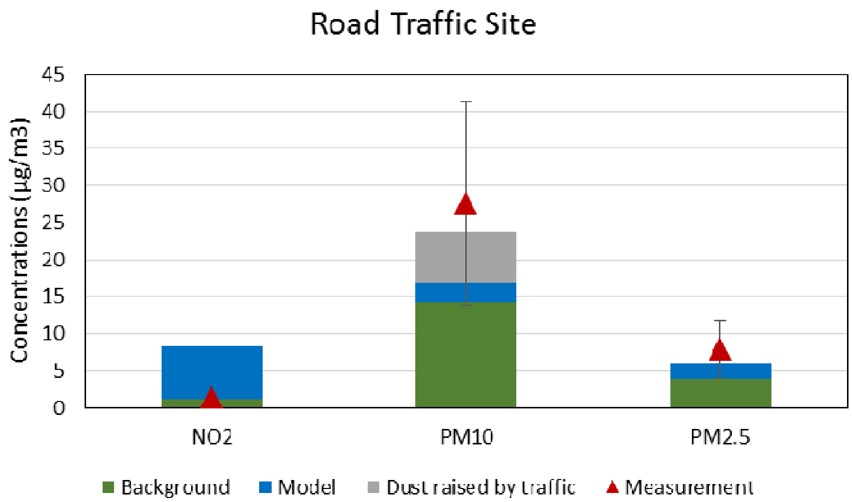
Background concentrations obtained for each pollutant are summarized as follow:

- NO_2= 1.2 µg/m^3,
- PM_{10} = 14.3 µg/m^3,
- $PM_{2.5}$ = 4.0 µg/m^3.

3.3.3.4.3 Concentrations calculated over the road traffic station

Figure 3-26 shows concentrations calculated by the ADMS-Roads model and observed at the Road Traffic site. The green bar represents background levels and blue bar represents road traffic contribution over Road Traffic site. The red markers correspond to measurements performed at the same time period and the black vertical lines represent the uncertainties associated to the measurement (50% for indicative measurement). This figure indicates, considering both background concentrations estimated and PM_{10} resuspension, that ADMS-Road model reproduces correctly the concentration levels of particulate matter. However, the ADMS-Roads model clearly overestimates the NO_2 concentrations measured: the average measured value is about 1.7 µg/m^3 and the model calculates a road traffic contribution equal to about 7 µg/m^3.

Figure 3-26: Concentrations cumulated measured and calculated with ADMS-Road model over the Road Traffic Site at Yaoundé city. Model contribution in the graph corresponds to exhaust emissions



3.3.3.4.4 Mapping of concentrations calculated over the transport corridor

The figure below (Figure 3-27) shows the total concentration (background, road traffic contribution and the particulate matter resuspension) maps for NO_2, SO_2, PM_{10} and $PM_{2.5}$ over the transport corridor.

The major structuring axes of the corridor were the most impacted roads by high levels of pollution i.e.:

- The Charles Atangana Avenue that crosses the corridor from the south to the north;
- The National road, N3, crossing the domain from the west to the east; and
- The National road, N1, partially captured within the pilot area located in the north part of the domain.

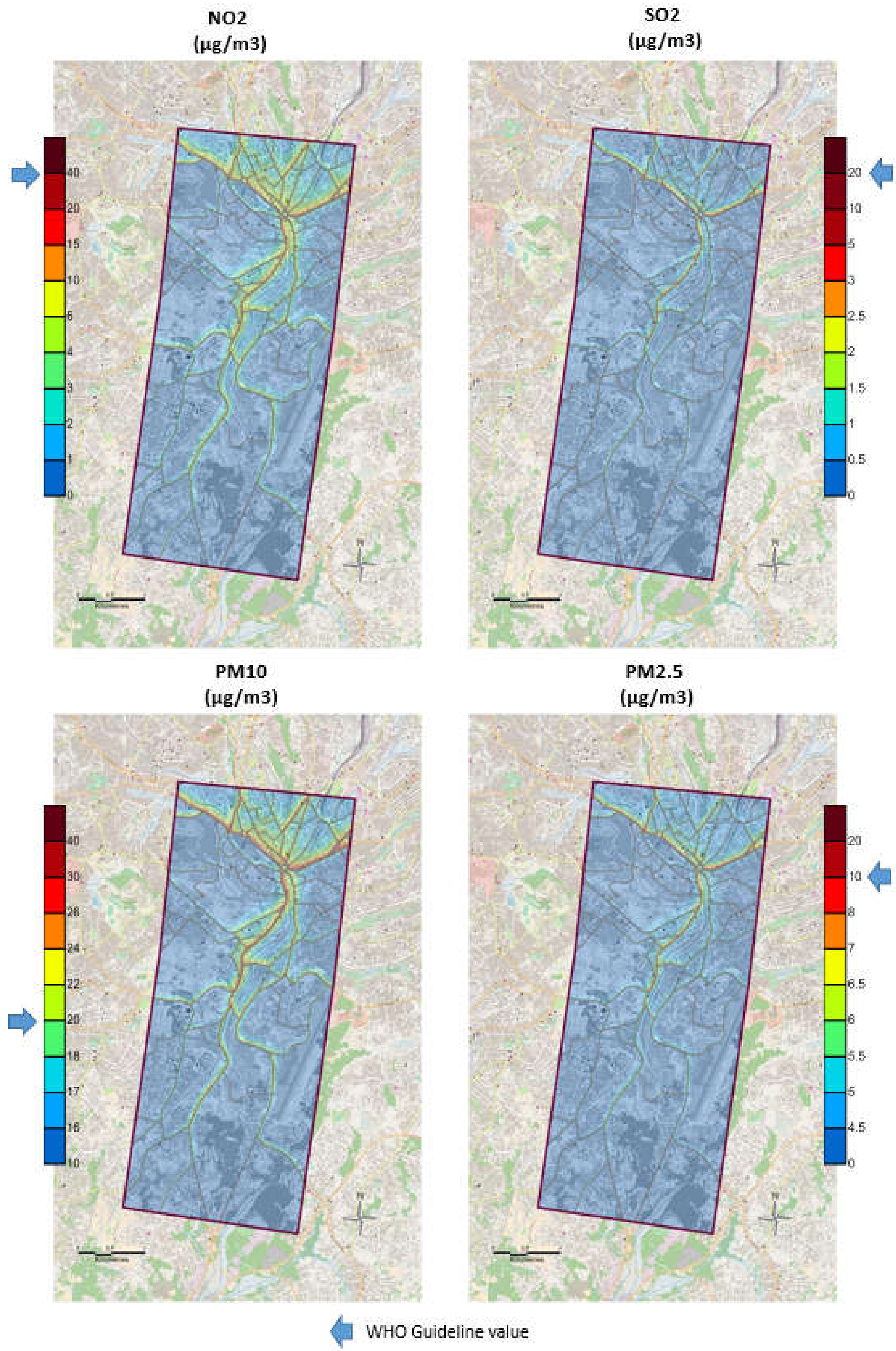
During the period, the parallel National road, N2, appears to be less impacted.

For PM pollutants, exceedances of the WHO annual average guideline values (20 and 10 µg/m^3 for PM_{10} and $PM_{2.5}$ respectively) flagged by the blue arrow on the color scale, are observed mostly in the north part of the corridor particularly close to the dense road network linking the N1, N2 and N3 national roads. The contribution of the exhaust emissions of vehicle travelling is relatively low (around 10% for PM_{10}). The main contributor of the total PM_{10} concentration is the background (60%) followed by the dust resuspension (30%).

For NO_2, the concentrations calculated by ADMS-Roads model are much lower than the WHO guideline. The maximum NO_2 concentration is about 20 µg/m^3 that is two times lower than the WHO guideline.

For SO_2, the concentrations calculated by ADMS-Roads model are much lower than the WHO guideline. The maximum SO_2 concentration is about 5 µg/m^3 that is four times lower than the WHO guideline.

Figure 3-27: Concentration maps of pollutants (NO_2, SO_2, PM_{10} and $PM_{2.5}$) within the transport corridor in Yaoundé city. Note that WHO guidelines (blue arrows) are based on annual average except for SO_2 (daily average only)



3.3.4 Lusaka

3.3.4.1 Selection of the pilot area

The localization of the transport corridor has been done regarding the construction of the future (within the 2020 year) by-pass outlying street linking the Great North Road to the Mumbwa Road. This project is described in the "Lusaka city comprehensive Master Plan" document[20]. This is the western part of the sampling pilot area dedicated to the vehicle counts and air pollution samplings over the major surrounding road.

3.3.4.2 Monitoring Campaign

3.3.4.2.1 Sampling locations

The Monitoring Campaign has been performed during the period from the 23, May 2017 (8:00 am) to the 25, May 2017 (9:00 pm). Road traffic sampling was carried out at one site in front of the Lumumba Road, located at 28°16.0187'S; 15°23.9369'E (Figure 3-28). The Cairnet station has been installed on the rooftop of a shelter (3.5 m above ground level). In front of the Cairnet system, the weather station has been placed. The horizontal distances from the instruments to the roadside were 15 m. The urban background concentration has been sampled on the Zambia Environmental Management Agency[21] (ZEMA) site located at 15°25.1111'S; 28°18.1087'E, relatively far from the traffic of the Church Road. The instrument has been placed at 1.5 m above ground level.

Figure 3-28: Map of the pilot area showing the two monitoring sites during the monitoring campaign performed (Road traffic site, Lumumba and background site, ZEMA). The boundaries of the transport corridor is delimited by the red box. The green symbols represent the additional counts of vehicle volumes performed (Lusaka)

8 supplementary sites (represented by the green markers in the Figure 3-28) have been investigated to sample road traffic volumes including vehicles category samplings. Measurements were performed during 1 to 3 hours each site. The table below (Table 3-24) compiles the geographic coordinates for each site.

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[20] The Study on comprehensive Urban Development Plan for the City of Lusaka in the Republic of Zambia. Final Report. 2009

[21] www.zema.org.zm

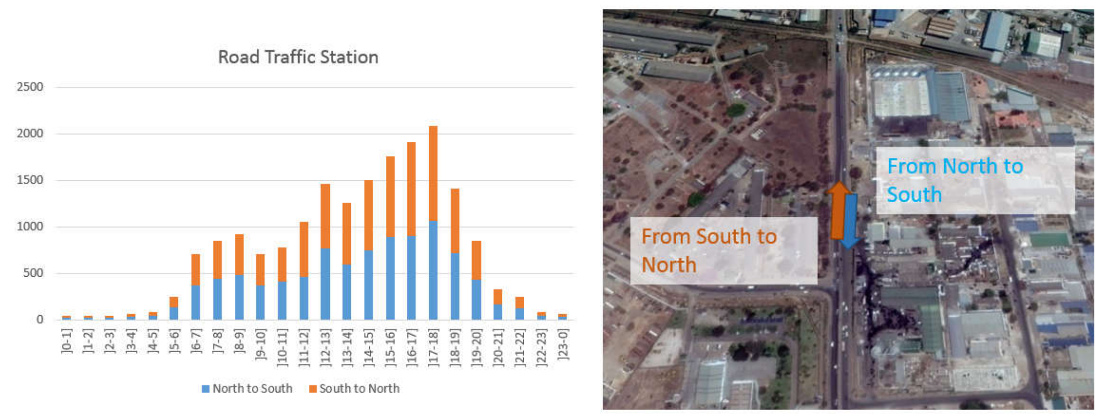
Table 3-24: Additional sampling location dedicated to the short-term vehicle volume and category counts (Lusaka)

Site	Location
Mungwi Road	15°23,9613'E; 28°15,7838'S
Great North Road	15°24,0169'E; 28°16,7392' S
North Road Exit	15°22,3694'E; 28°16,5719' S
Great North Road II	15°23,0770'E; 28°16,8054'S
Katima Road	15°23,4478'E; 28°16,9242' S
Makishi Road	15°23,8721'E; 28°17,0145'S
Cairo Road	15°24,7608'E; 28°16,8518'S
Freedom Way	15°24,7729'E; 28°16,8493'S

3.3.4.2.2 Monitoring Campaign results

Result of the manual vehicle counts are summarized in the figure below (Figure 3-29) showing the vehicles number per hour passing on both directions of the road (detailed manual vehicle counts are available in Appendix 3). As presented in the methodology section these time series are derived using both manual vehicle count samplings and assumptions regarding hours without information (especially during night) deduced from the Abidjan road traffic model (BNETD) and local surveys. The total number of vehicles travelling on the Lumumba Road has been estimated to be 18,237 vehicles per day.

Figure 3-29: Hourly traffic at the Road Traffic Station. Locations and directions (with corresponding colors) are indicated on the left pane (Lusaka)



The distribution of vehicles per category sampled at the Road Traffic site is provided in the table below (Table 3-25). Results show that Passenger Cars category is the most important category in term of relative contribution to the total number of vehicles (55.8%). The Road Traffic site displays a different vehicle distribution behavior when comparing to the other transport corridors investigated in other cities. The Taxi category contribution is low (4.6%) and the LDV class contribution is high (22.4%).

Table 3-25: Road traffic distribution (%) and Average Daily traffic estimated (ADT) from measurements done at the Road Traffic Station site (Lusaka)

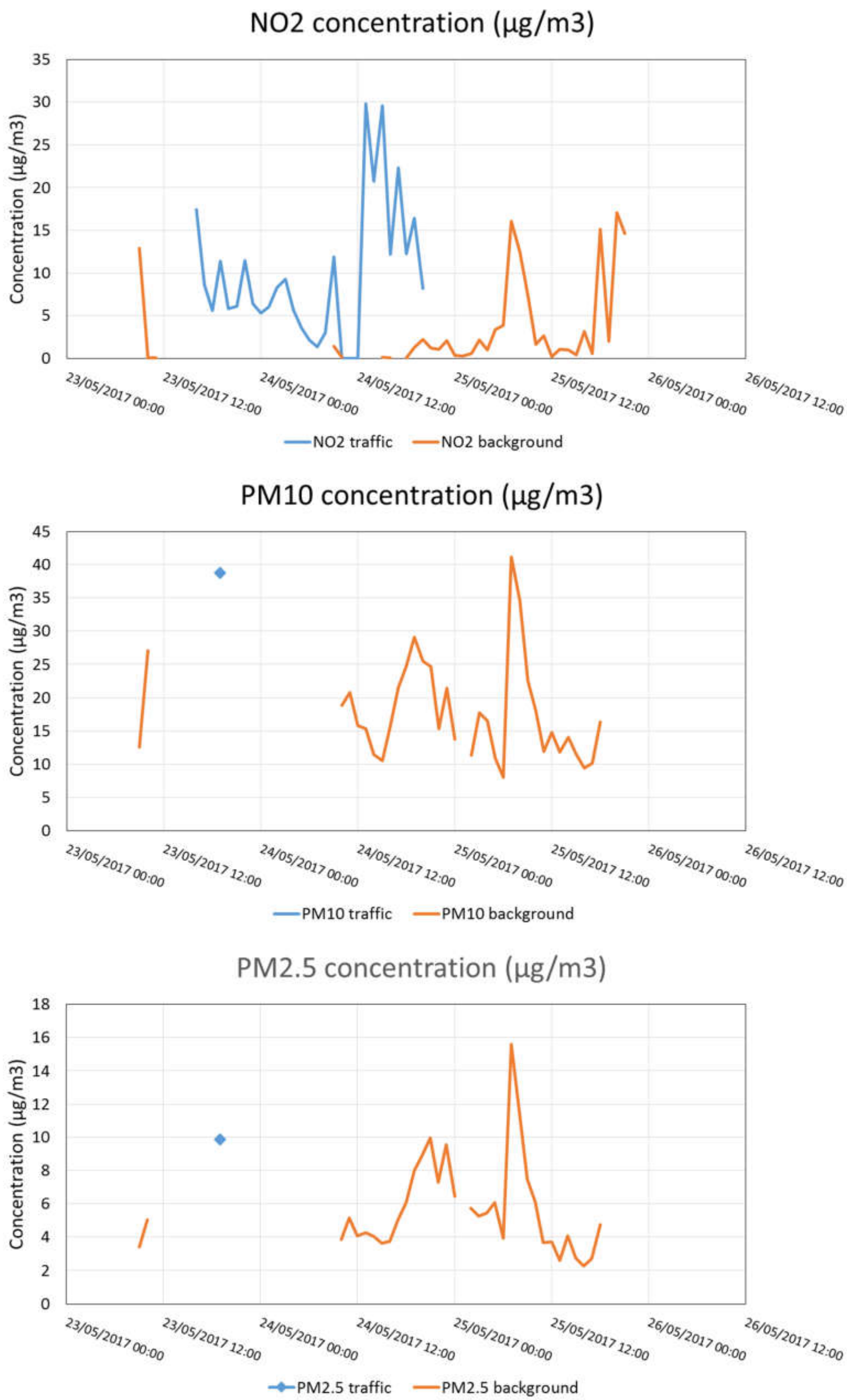
Site Locations	Passenger Cars	Taxis	2-wheels (Motorcycle)	Light duty Vehicles (<15t)	Trucks (>15t)	Coaches / Buses	Special Vehicles (construction machinery,	ADT
Road Traffic Station	55.8	4.6	0.5	22.4	15.8	0.8	0	18,237

Figure 3-30 shows the concentrations of NO_2, PM_{10} and $PM_{2.5}$ sampled during the monitoring campaign at the Road traffic site (in blue) and at the ZEMA site (background pollution, in orange). PM data are limited for the Road Traffic site due to data transmission issues with the Cairnet GSM system.

NO_2 hourly concentrations measured at the Road Traffic site ranged between 5 to 30 µg/m^3 with maximum levels identified during the afternoon reflecting the impact of the road pollution (due to high number of vehicles travelling). The background concentrations were relatively low (between 1 and 15 µg/m^3).

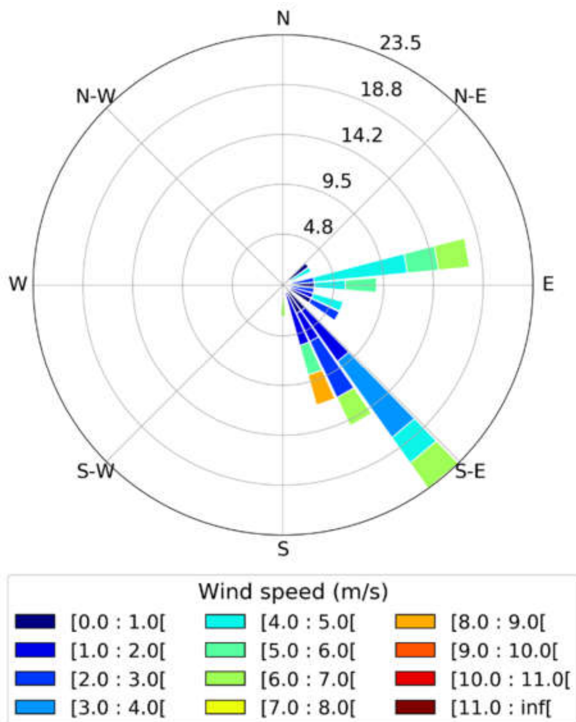
For PM_{10} and $PM_{2.5}$ at the ZEMA site, the averaged concentrations during the period of measurement are moderate (17.69 and 5.75 µg/m^3 in average for PM_{10} and $PM_{2.5}$ respectively), without clear distinction between day and night.

Figure 3-30: Ambient Air PM_{10}, $PM_{2.5}$ and NO_2 concentrations at the Road Traffic Station and at the ZEMA site for background concentrations (Lusaka)



The wind rose resulting from the sampled winds at the DAVIS weather station is provided in the Figure 3-31. Wind speeds were in most cases moderate. 44% of wind speeds were comprised between 2 and 5 m/s. The prevailing winds came from the south-eastern sector. Temperatures were stables and ranging from16.8 to 27.1°C with an average value about 22.5°C. Relative humidity varied from 40 to 60%.

Figure 3-31: Wind rose derived from the weather station (DAVIS Vantage Pro2) during the monitoring campaign (Lusaka)



3.3.4.3 Calculation of emissions

Assumptions made to generate a vehicle fleet at the Lusaka transport corridor are summarized in the Table 3-20. Average Equivalent Vehicles (AEV) emissions obtained from all these assumptions and calculated after the COPERT 5 step are summarized in the Appendix 2.

Table 3-26: Assumptions for the construction of vehicle fleet at Lusaka city and Average Equivalent Vehicles (AEVs)

Parameter	Assumption
Population of the selected vehicle categories	The number of vehicles per category has been fixed to 100,000 vehicles. A specific treatment, using the video camera records, has been applied to split Passenger Cars, PCs, over three sub-categories (small, medium and SUV). The resulting distribution is given in the Table 3-27. Articulated and solo- Heavy Duty Trucks (HDTs) have been merged together because no sufficient information was found to distinguish properly these two classes. No coach has been identified during the analysis of camera video records. The class was not considered.

Parameter	Assumption
Fuel type	Due to absence of robust information regarding the fuel type used within each vehicle category, gasoline and diesel ratio have been supposed to be 50% (for PCs and Taxis). LDVs and HFTs are assumed to operate with diesel, motorcycles operated with gasoline only.
Fuel composition	The fuel composition has been defined according to the default value within COPERT 5 model. Sulfur-content has been setup to 2,000 ppm (mass) for diesel according to the CCAC[22] (Climate & Clean Air Coalition) document. Without any information relative to the gasoline composition, the sulfur-content was considered to be the same as for diesel (i.e. 2,000 ppm).
Engine rating	The engine rating chosen for PCs category has been derived from the analysis of video camera records (Table 3-27; Table 3-28). Without any information on the distribution between gasoline and diesel vehicles, the same distribution has been applied to both vehicle types.
Weight	The vehicles distribution for HDTs and Buses according to the vehicle weight has been derived from video camera records analysis. The weight of HDTs has been calculated from the number of vehicle axles according to the Eat African Regulations[23].Two bus categories have been observed the light buses (<15t) and the standards buses (>18 t). The Table 3-28 indicates the HDTs and Bus category distributions.
Emission standards	Without any information of the vehicle age distribution a conservative approach has been considered assuming the EURO 2/II standard for all vehicle categories.
Vehicle Lifetime	Vehicle lifetimes has been calculated according to the emission calculation methodology (section 3.2.3).
Average Speed	Average speeds on highways, rural roads and urban area were based on the Ramboll expert judgement: • Urban road: 25 km/h • Rural road: 60 km/h • Highway: 80 km/h

The next two tables compile the vehicle distribution among the categories provided in the methodology section. These results have been derived from the analysis of the video camera records taken during the monitoring campaign.

Table 3-27: Vehicles distribution – PCs category (Lusaka)

	Passenger Cars Sub-Categories		
	Small	**Medium**	**SUV**
Distribution [%]	13.5	32.4	54.1

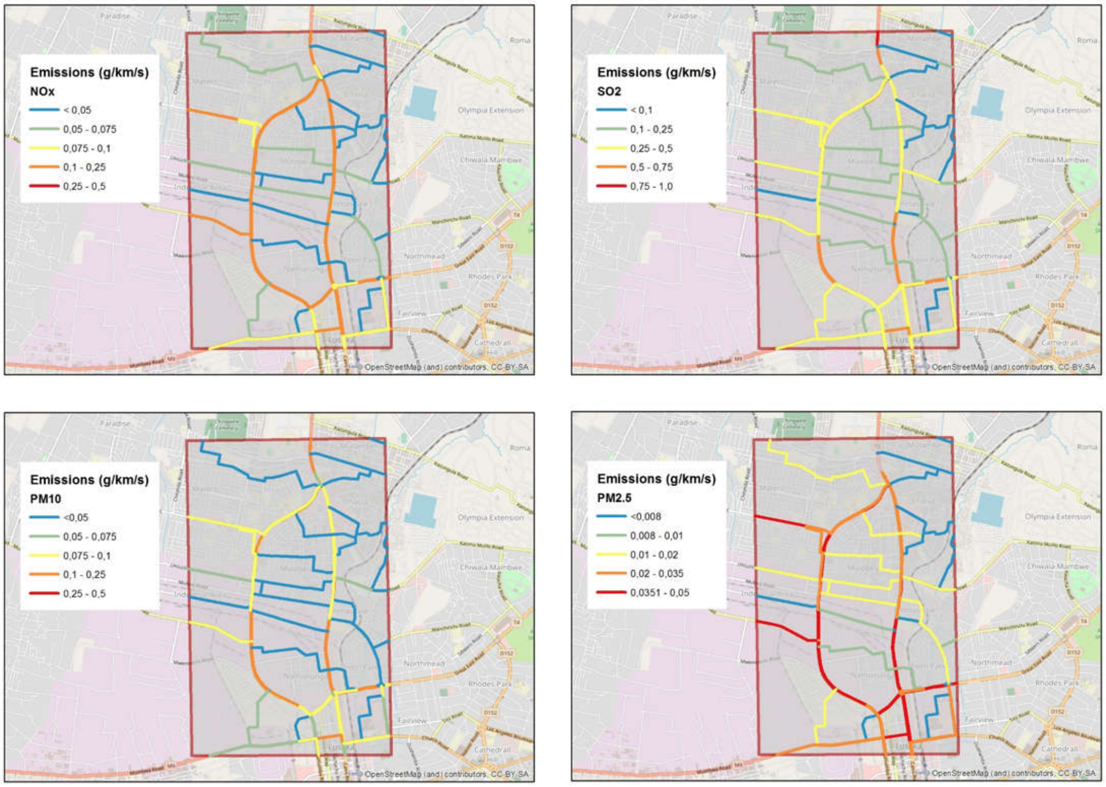
Table 3-28: Vehicles distribution - HDTs and buses categories (Lusaka)

	HDTs, axles #				Buses Weight	
	2	**3**	**4**	**5**	**<15t**	**>15t**
Distribution [%]	46.4	8.0	0.8	44.8	78.9	21.1

[22] Cleaning up the global on-road diesel fleet a global strategy to introduce low-sulfur fuels and cleaner diesel vehicles, 2016, 79 p.
[23] http://www.eaotransport.com/axleloadrules.php

The following figure (Figure 3-32) shows the air emissions of NO_x, SO_2, PM_{10} and $PM_{2.5}$ due to the road traffic within the transport corridor.

Figure 3-32: Air emissions of NO_x, SO_2, PM_{10} and $PM_{2.5}$ over the transport corridor – Lusaka (defined by the dark red box)



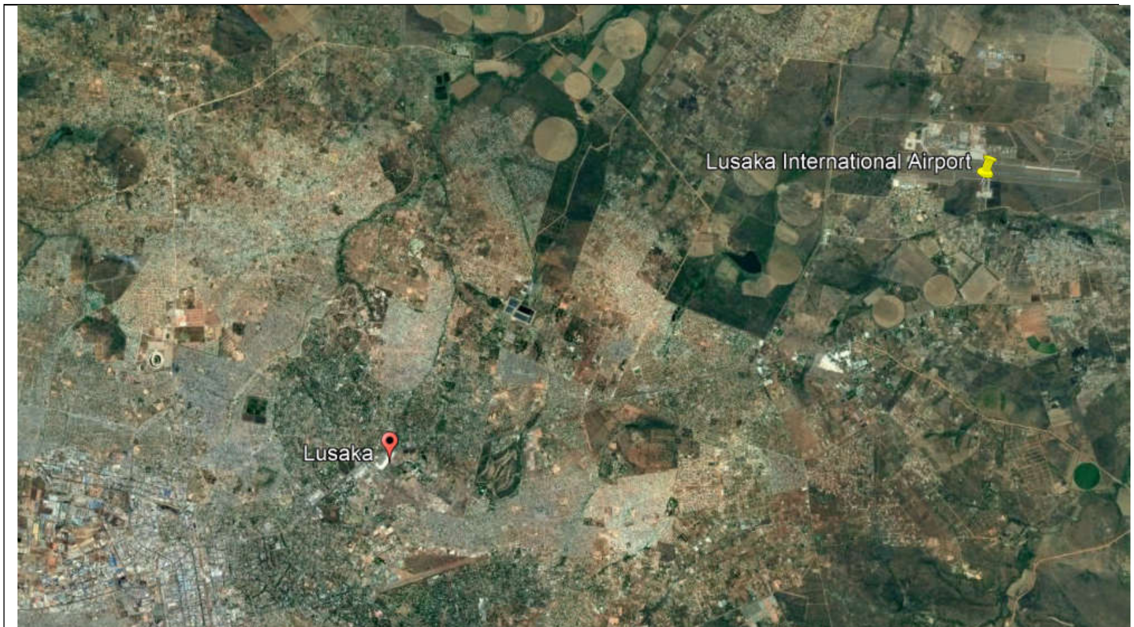
3.3.4.4 Air Quality Mapping

3.3.4.4.1 Meteorological parameters and time period

Meteorological parameters have been extracted from the DAVIS weather station, except for the cloud coverage, which has been extracted from the Lusaka international airport (Table 3-29).

The time period has been chosen in order to cover the entire duration of the campaign i.e. between the 23, May 2017 at 8:00 to the 25 May at 19:00.

Table 3-29: Lusaka International Airport – Weather station



Site Identification (WMO)	67665
Latitude	15°19'60.00"S
Longitude	28°26'60.00"E
Elevation	1,151.83 m

3.3.4.4.2 Particulate Matter (PM) resuspension and background concentration

Particle resuspension has been considered for PM_{10} only. The value calculated is 0.14 g/veh./km.

Background concentrations have been derived from measurements performed at background site during the measurement campaign. For the purpose of this study, background concentration represents an integrated and averaged value of the urban pollution far from the road traffic influence.

Background concentrations obtained for each pollutant are summarized as follow:

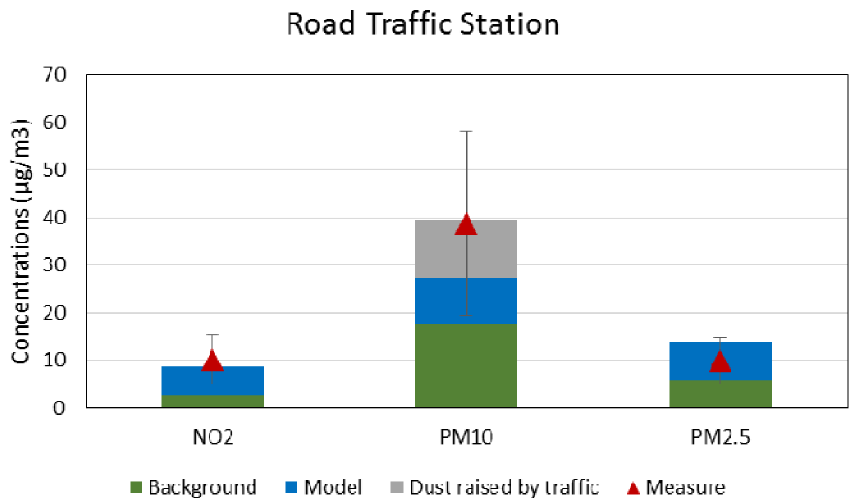
- NO_2= 2.67 µg/m^3,
- PM_{10} = 17.69 µg/m^3,
- $PM_{2.5}$ = 5.75 µg/m^3.

3.3.4.4.3 Concentrations calculated over the road traffic station

Figure 3-33 shows concentrations calculated by ADMS-Roads model and observed at the Road Traffic site. The green bar represents background level and blue bar represents road traffic contribution over Road Traffic site. The red markers correspond to measurements for the same time period and the black vertical lines represent the uncertainties associated to the measurement (50% for indicative measurement). Note that concentration of SO_2 is not reported in this figure due to measurement Issues during the campaign. This figure indicates, considering both background concentrations estimated and PM_{10} resuspension, that ADMS-Roads model reproduces correctly the concentration levels of all pollutants.

The Road Traffic contribution (exhaust emissions) on particulate matter is relatively low compared to the background contribution and of the same order of magnitude as the dust resuspension contribution. The Road Traffic contribution is much more important for the NO_2 pollutant (about 70%).

Figure 3-33: Concentrations cumulated measured and calculated with ADMS-Road model at the Road Traffic site within Lusaka. Model contribution in the graph corresponds to exhaust emissions



3.3.4.4.4 Mapping of concentrations calculated over the transport corridor

The figure below (Figure 3-34) shows the total concentration (background, road traffic contribution and the particulate matters resuspension) maps for NO_2, SO_2, PM_{10} and $PM_{2.5}$ over the transport corridor.

As expected, the major structuring axes of the corridor are impacted by the highest levels of pollution i.e.:

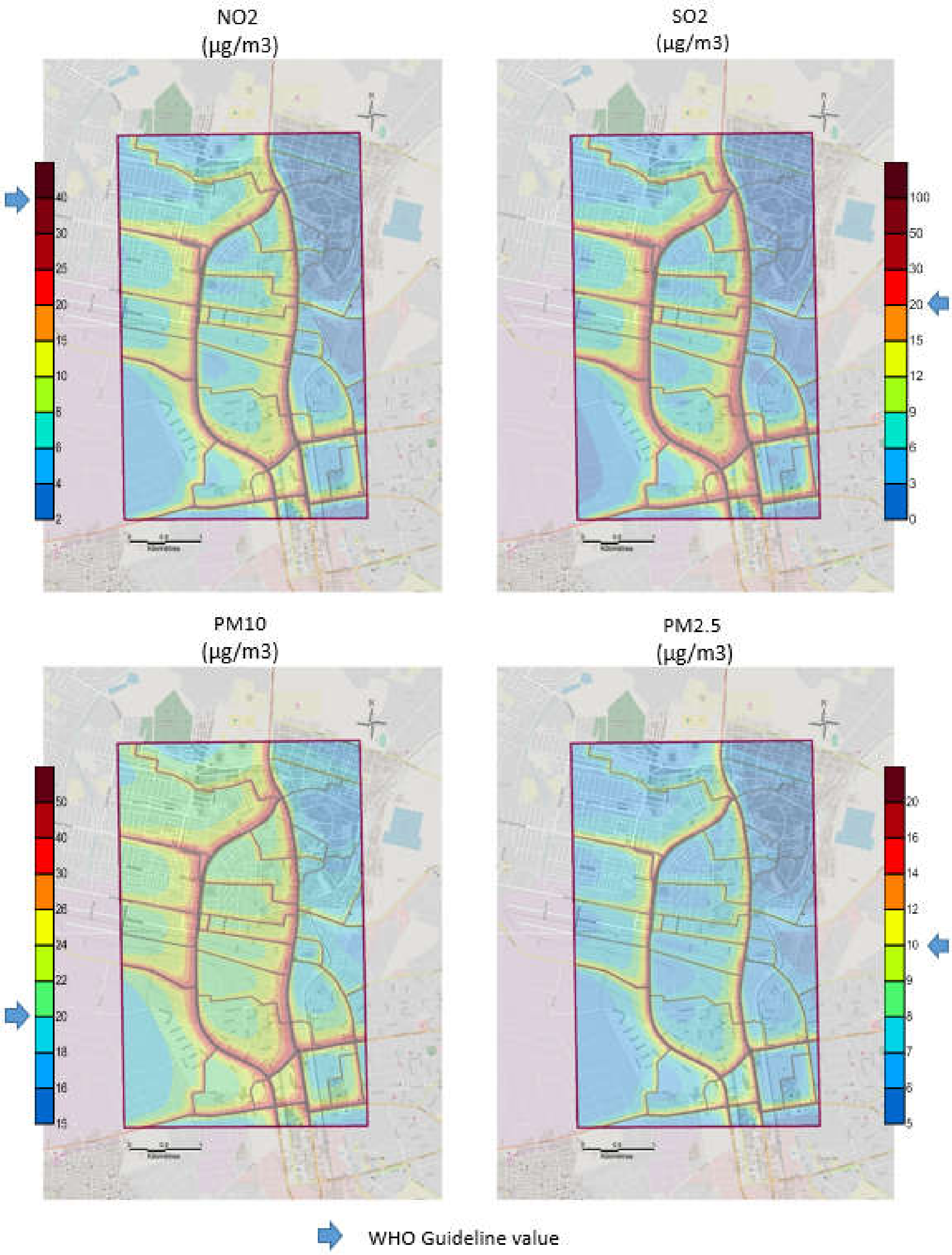
- The Great North Road that crosses the entire domain from the south to the north;
- The Lumumba Road (the parallel road to the Great North Road); and
- Some major axes that cross the domain from the east to the west (Kalambo Road, Great East Road, Mungwi Road and Commonwealth Road).

For PM pollutants, exceedances of the WHO annual average guideline values (20 and 10 µg/m^3 for PM_{10} and $PM_{2.5}$ respectively) flagged by the black arrow on the color scale, are obtained mostly close to the structuring roads.

For NO_2, the concentrations calculated using the ADMS-Roads model are lower than the WHO guideline. The maximum NO_2 concentration is about 30 µg/m^3.

For SO_2, high levels of pollution have been calculated around structuring roads with maximum concentration about 80 µg/m^3. Many exceedances of the daily WHO guideline (20 µg/m^3) were identified and impacted a large part of the domain study.

Figure 3-34: Concentration maps of pollutants (NO_2, SO_2, PM_{10} and $PM_{2.5}$) within the transport corridor in Lusaka city. Note that WHO guidelines (blue arrows) are based on annual average except for SO_2 (daily average only)



3.3.5 Dar es Salaam

3.3.5.1 Selection of the pilot area

The selection of the transport corridor has been done regarding the future infrastructure developments in the medium to long-term within Dar Es Salaam downtown. The corridor transport has been selected because the main structuring roadway is part of the development of the second bus line within the FBT (Fast Bus transport) network. The rehabilitation project will consider to construction of two additional bus lines at the middle of the road in a similar manner of what was already done over Morogoro road at the North part of the Dar Es Salaam city.

3.3.5.2 Monitoring Campaign

3.3.5.2.1 Sampling locations

The Monitoring Campaign has been performed during the period from the 30, May 2017 (17:00) to the 1st, June 2017 (17:00). Road traffic sampling was carried out at one site near the roadside of the Kilwa Road, located at 06°50.9890’S; 39°16.9198’E (Figure 3-35). The Cairnet sampler has been installed at ground level (1.5 m above ground level). In front of the Cairnet system, the DAVIS weather station has been placed. The horizontal distances from the instruments to the roadside were 20 m. The background concentration has been sampled at the TANROADS[24] site (06°46.6706'S; 39°15.8837'E). Instrument has been placed at the rooftop of the administrative building (i.e. 8 m above ground level).

[24] Ministry of Works, Transport and Communications, more information at http://www.tanroads.go.tz/regional-offices

Figure 3-35: Map of the pilot area (red box) showing the two monitoring sites (in blue) and the additional traffic counting sites (in green)

6 supplementary sites (represented by the green markers in the Figure 3-35) have also been investigated to sample road traffic volumes per vehicles category. Measurements were performed during 1 to 2 hours each site. The table below (Table 3-30) compiles the geographic coordinates for each sampling site.

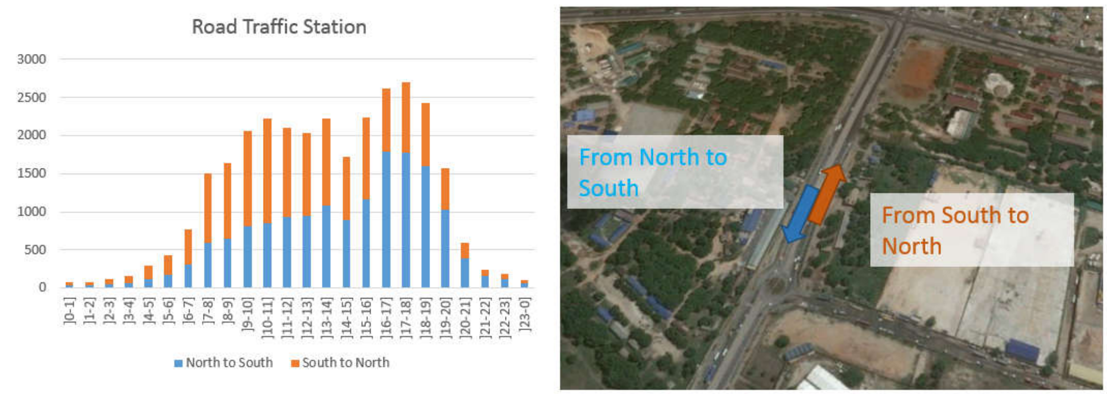
Table 3-30: Additional sampling location dedicated to the short-term vehicle volumes and category counts (Dar Es Salaam)

Site	Location
Kilwa road II	39°16,9198'S; 6°50,9890'E
Nelson Mandela Road	39°16,4600'S; 6°51,4451'E
Nelson Mandela Road II	39°16,8809'S; 6°51,4810'E
Nelson Mandela Road III	39°17,5038'S; 6°50,8597'E
Kurasini Road	39°16,9289'S; 6°51,2388'E
Changombe Road	39°16,7391'S; 6°51,0701'E

3.3.5.2.2 Monitoring Campaign results

Results of the manual vehicle counts have been used (with Ramboll traffic model data) to build the hourly traffic data presented in the figure below (Figure 3-36) for both directions of the road (detailed manual vehicle counts are available in Appendix 3). The total number of vehicles travelling over the Lumumba Road has been estimated to be 31,135 vehicles per day.

Figure 3-36: Hourly traffic on the Road Traffic Station. Locations and directions (with corresponding colors) are indicated in the left pane (Dar Es Salaam)



The distribution of vehicles per category sampled at the Road Traffic site is provided in the table below (Table 3-31). Results show that Passenger Cars (PCs) is the most important category (41.6%) in term of relative contribution to the total number of vehicles per day. The Taxi category contribution is relatively low (13.3%). The motorcycle category contribution is relatively important (21.0%) when comparing to relative contribution of motorcycle category sampled at the 4 others cities.

Table 3-31: Road traffic distribution (%) and Average Daily traffic estimated (ADT) from measurements done at the Road Traffic Station site (Dar Es Salaam)

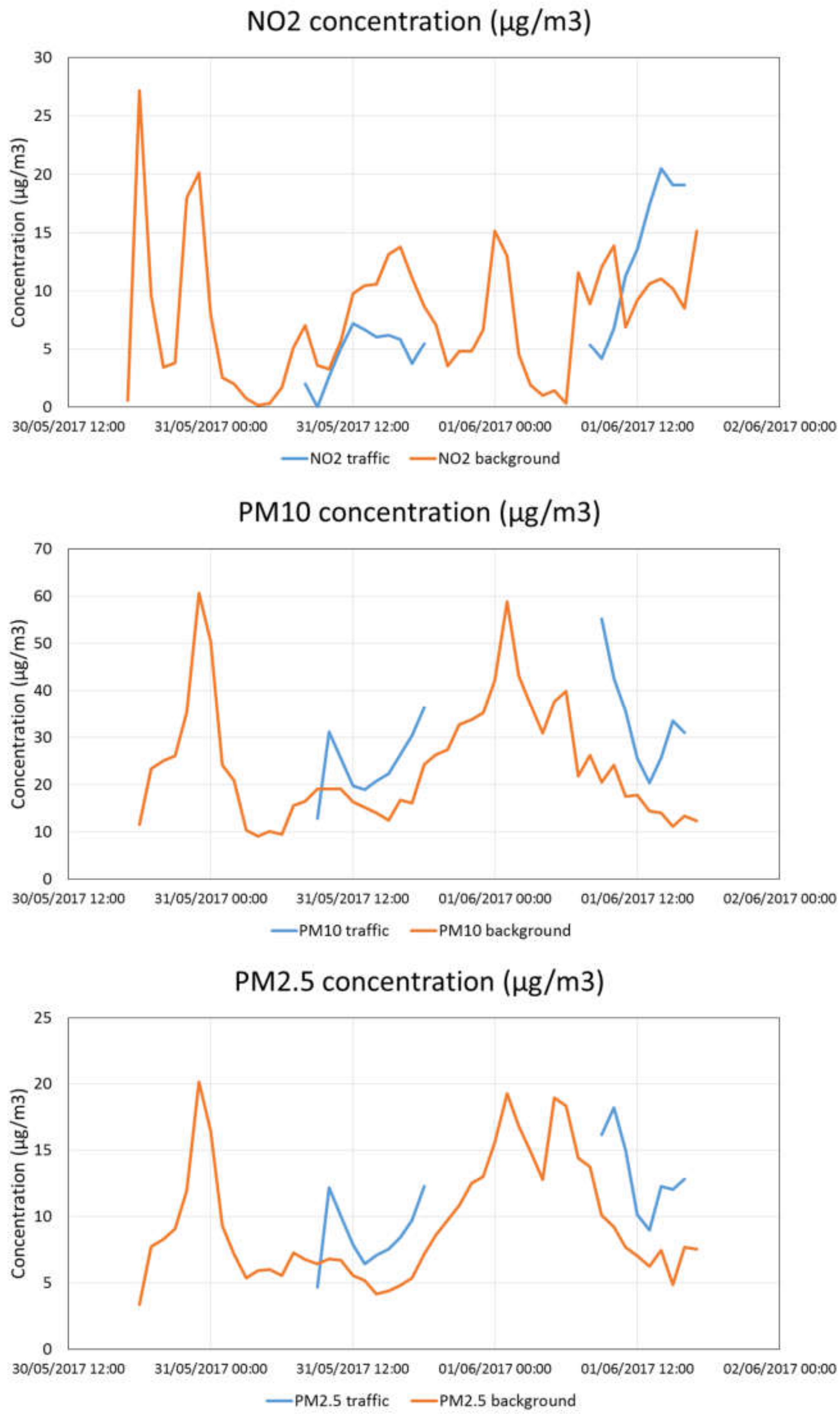
Site Locations	**Passenger Cars**	**Taxis**	**2-wheels (Motorcycle)**	**Light duty Vehicles (<15t)**	**Trucks (>15t)**	**Coaches / Buses**	**Special Vehicles (construction machinery,**	**ADT**
Road Traffic Station	41.6	13.3	21.0	2.5	5.5	16.0	0	31,135

Figure 3-37 shows the concentrations of NO_2, PM_{10} and $PM_{2.5}$ sampled during the monitoring campaign at the Road traffic site (in blue) and at the background site (in orange). The data transmission from the Cairnet system was partially disturbed due to low GSM coverage in particular during the night and at the location of the Road Traffic site.

NO_2 hourly concentrations measured at the Road Traffic site varied between 0 and 20 µg/m^3 with maximum levels identified during the afternoon. The background concentrations are quite similar to the pollutant levels observed at the Road Traffic site without any clear daily behavior. The concentrations at midnight can reach the maximum level measured i.e. 20 µg/m^3 with lower concentrations during the day (from 5 to 10 µg/m^3).

For PM_{10} and $PM_{2.5}$ pollutants, the daily behavior at both sites implemented is the same with an average concentration during the day approximately equal to 35 µg/m^3 and higher concentration levels during the night up to 60 µg/m^3 for the maximum concentrations.

Figure 3-37: Ambient Air PM_{10}, $PM_{2.5}$ and NO_2 concentrations at the Road Traffic site and at the TANROADS site for background concentrations (Dar Es Salaam)



A technical issue –that has since been rectified - regarding the DAVIS weather station during the campaign has hindered the measurements of meteorological parameters. For the needs of the air quality modelling using ADMS-Roads model the meteorological data from the Dar Es Salaam international Airport have been used to calculate all meteorological parameters.

3.3.5.3 Calculation of emissions

Assumptions made to calculate vehicle emissions at the Dar Es Salaam transport corridor are summarized in the Table 3-32. Emissions of the Average Equivalent Vehicles (AEVs) obtained from all these assumptions and calculated after the COPERT 5 step are summarized in the Appendix 3.2.

Table 3-32: Assumptions for the construction of vehicle fleet at Dar Es Salaam city and Average Equivalent Vehicles (AEVs)

Parameter	Assumption
Population of the selected vehicle categories	The number of vehicles per category has been fixed to 100,000 vehicles. Articulated and solo- Heavy Duty Trucks (HDT) have been merged together because no sufficient information was found to distinguish properly these two classes of vehicles. A specific treatment, using the video camera records, has been applied to split Passenger Cars (PCS) over three sub-categories (small, medium and SUV). The resulting distribution is given in the Table 3-33. No coach has been identified during the analysis of video camera records. This class was not considered.
Fuel type	Without any information regarding the fuel type used within each vehicle category, gasoline and diesel ratios have been supposed to be 50% (for PCs and Taxis). HDV, Trucks are assumed to operate with diesel, motorcycles operated with gasoline only.
Fuel composition	The fuel composition has been defined according to the default value within COPERT 5 model. Sulfur-content has not considered specifically for this study because of the low sulfur-content according to the CCAC[25] (Climate & Clean Air Coalition) document (>15 – 50 ppm).
Engine rating	The engine rating chosen for PCs category has been derived from the analysis of video camera records (Table 3-33; Table 3-34). Without any information on the distribution between gasoline and diesel vehicles, the same distribution has been applied for both vehicle types.
Weight	The vehicles distribution for HDT and Buses according to the vehicles weight has been derived from video camera records analysis. The weight of HDT has been calculated from the number of vehicle axles according to the Eat African Regulations[26].Two bus categories have been observed, the light buses (<15t) and the standards buses (>18t). The Table 3-34 indicates the HDT and Bus category distributions.
Emission Standards	According to the vehicles distribution by age presented by the UNEP[27] in 2011[28], the middle age of 55% vehicles is 15 years. It has been assumed that all vehicles (without fuel or vehicle category distinction) operate are compliant with the EURO 2/II standard.

[25] Cleaning up the global on-road diesel fleet a global strategy to introduce low-sulfur fuels and cleaner diesel vehicles, 2016, 79 p.
[26] http://www.eaotransport.com/axleloadrules.php
[27] United Nations Environment Programme
[28] UNEP, Division of Technology, Industry and Economics, Transport Environment & Development in Africa, Jane Akumu - Programme Officer, Transport Unit National Workshop on Investments for People and Mobility11 October 20111

Parameter	Assumption
Vehicle Lifetime	Vehicle lifetimes has been calculated according to the emission calculation methodology (section 3.2.3).
Average Speed	Average speeds on highways, rural roads and urban area were based on the Ramboll expert judgement: • Urban road: 25 km/h • Rural road: 60 km/h • Highway: 80 km/h

The next two tables compile the vehicle distribution among the categories provided in the methodology section. These results have been derived from the analysis of the video camera records taken during the monitoring campaign.

Table 3-33: Vehicles distribution – PCs category (Dar Es Salaam)

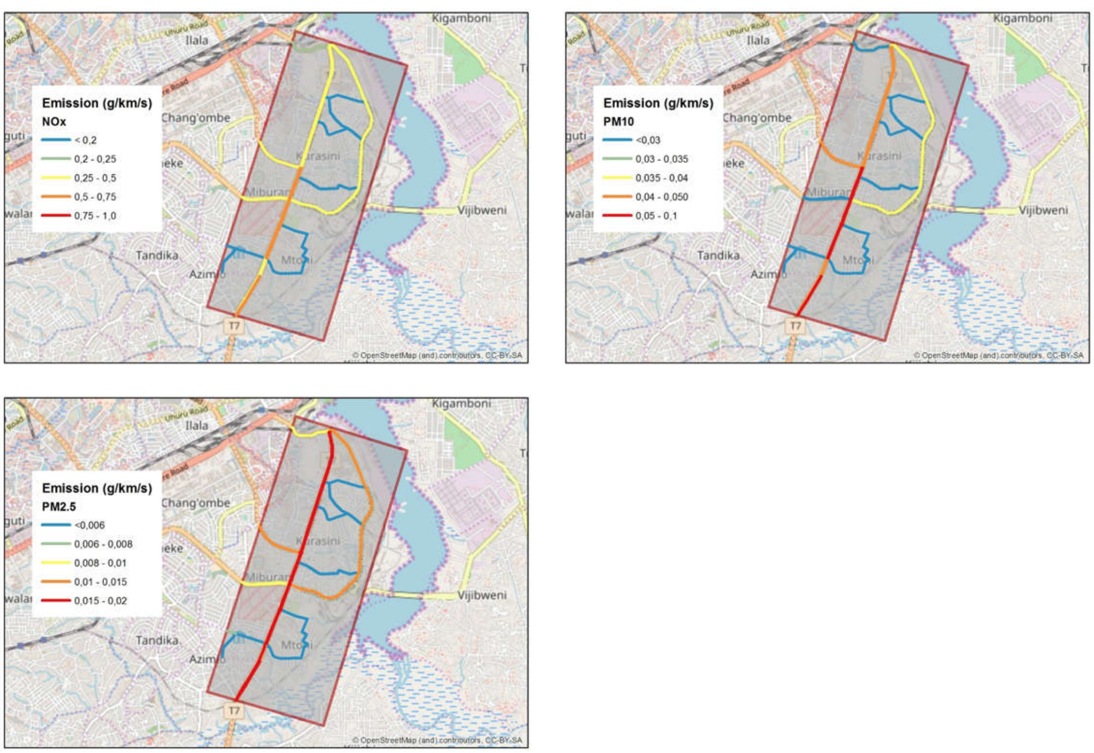
	Passenger Cars Sub-Categories		
	Small	**Medium**	**SUV**
Distribution [%]	14.8	41.5	43.7

Table 3-34: Vehicles distribution - HDTs and buses categories (Dar Es Salaam)

	HDTs, axles #				Buses Weight	
	2	**3**	**4**	**5**	**<15t**	**>15t**
Distribution [%]	34.8	8.7	8.7	47.8	67.7	32.3

The figure below (Figure 3-38) shows the air emissions of NO_x, PM_{10} and $PM_{2.5}$ due to the road traffic within the transport corridor.

Figure 3-38: Air emissions of NO_x, PM_{10} and $PM_{2.5}$ over the transport corridor – Dar Es Salaam (defined by the dark red box)

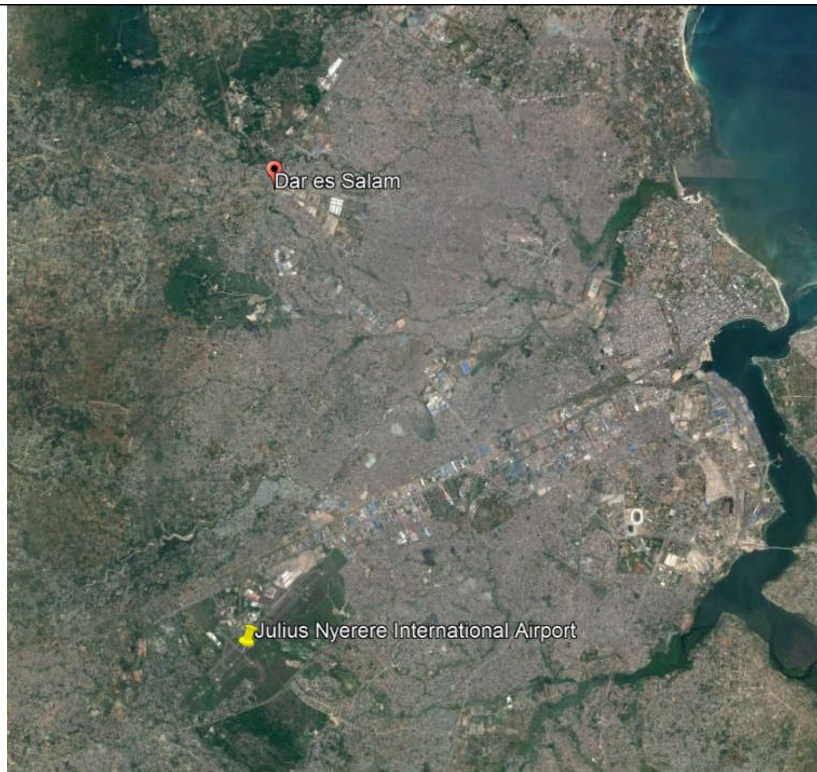


3.3.5.4 Air Quality Mapping

3.3.5.4.1 Meteorological parameters and time period

As indicated in the monitoring section, the meteorological parameters have been retrieved from the Julius Nyerere International Airport only (Table 3-35).

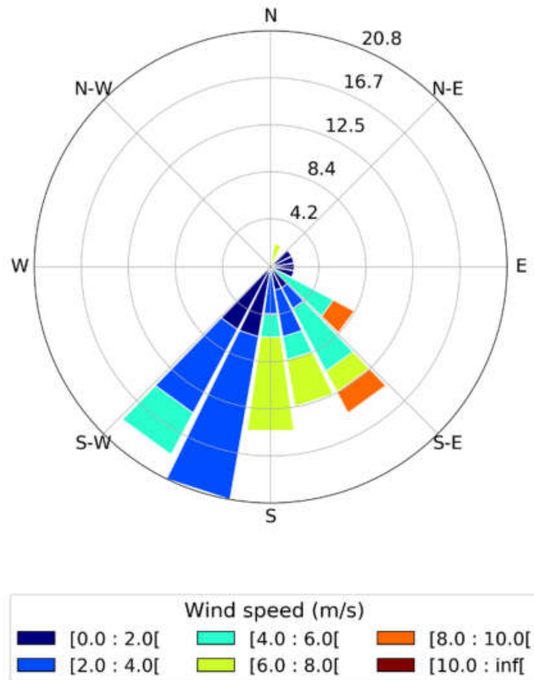
Table 3-35: Julius Nyerere International Airport – Weather station



Site Identification (WMO)	63894
Latitude	6°52'41.20"S
Longitude	39°12'9.45"E
Elevation	55.47 m

The wind rose sampled with the weather station is provided in the Figure 3-39. Wind speeds (measured at 10 m above ground level) were mainly comprised between 2 to 10 m/s. 39% of wind speeds were comprised between 2 and 5 m/s and 33% were ranging between 5 to 10 m/s. The prevailing winds came from the southern, south-western and south-eastern sectors during the studied period. Temperatures were stables ranging from 18.3 to 29.1°C with an average value about 24.7°C. Relative humidity varied from 62 to 91%.

Figure 3-39: Wind rose derived from the Julius Nyerere International Airport during the monitoring campaign (Dar Es Salaam)



3.3.5.4.2 Particulate Matter (PM) resuspension and background concentration

Particle resuspension has been considered for PM_{10} only. The value calculated is 0.14 g/veh./km.

Background concentrations have been derived from measurements performed at background site during the measurement campaign. For the purpose of this study, background concentration represents an integrated and averaged value of the urban pollution far from the road traffic influence.

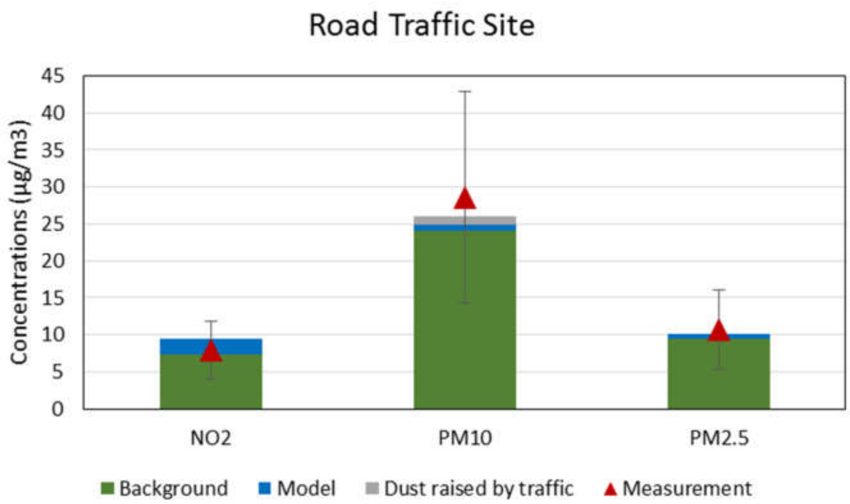
Background concentrations obtained for each pollutant are summarized as follow:

- NO_2= 7.3 µg/m^3,
- PM_{10} = 24.1 µg/m^3,
- $PM_{2.5}$ = 9.5 µg/m^3.

3.3.5.4.3 Concentrations calculated over the road traffic station

Figure 3-40 shows concentrations calculated by ADMS-Roads model and observed at the Road Traffic Site. The green bar represents background level and blue bar represents road traffic contribution over Road Traffic site. The red markers correspond to measurements for the same time period and the black vertical lines represent the uncertainties associated to the measurement (50% for indicative measurement). This figure indicates, considering both background concentrations estimated and PM_{10} resuspension, that ADMS-Roads model reproduces correctly the concentration levels of all selected pollutants. A large contribution of the background has been identified (78%, 93% and 94% for NO_2, PM_{10} and $PM_{2.5}$ respectively).

Figure 3-40: Concentrations cumulated measured and calculated with ADMS-Road over the Road Traffic Site of Dar Es Salaam. Model contribution in the graph corresponds to exhaust emissions.



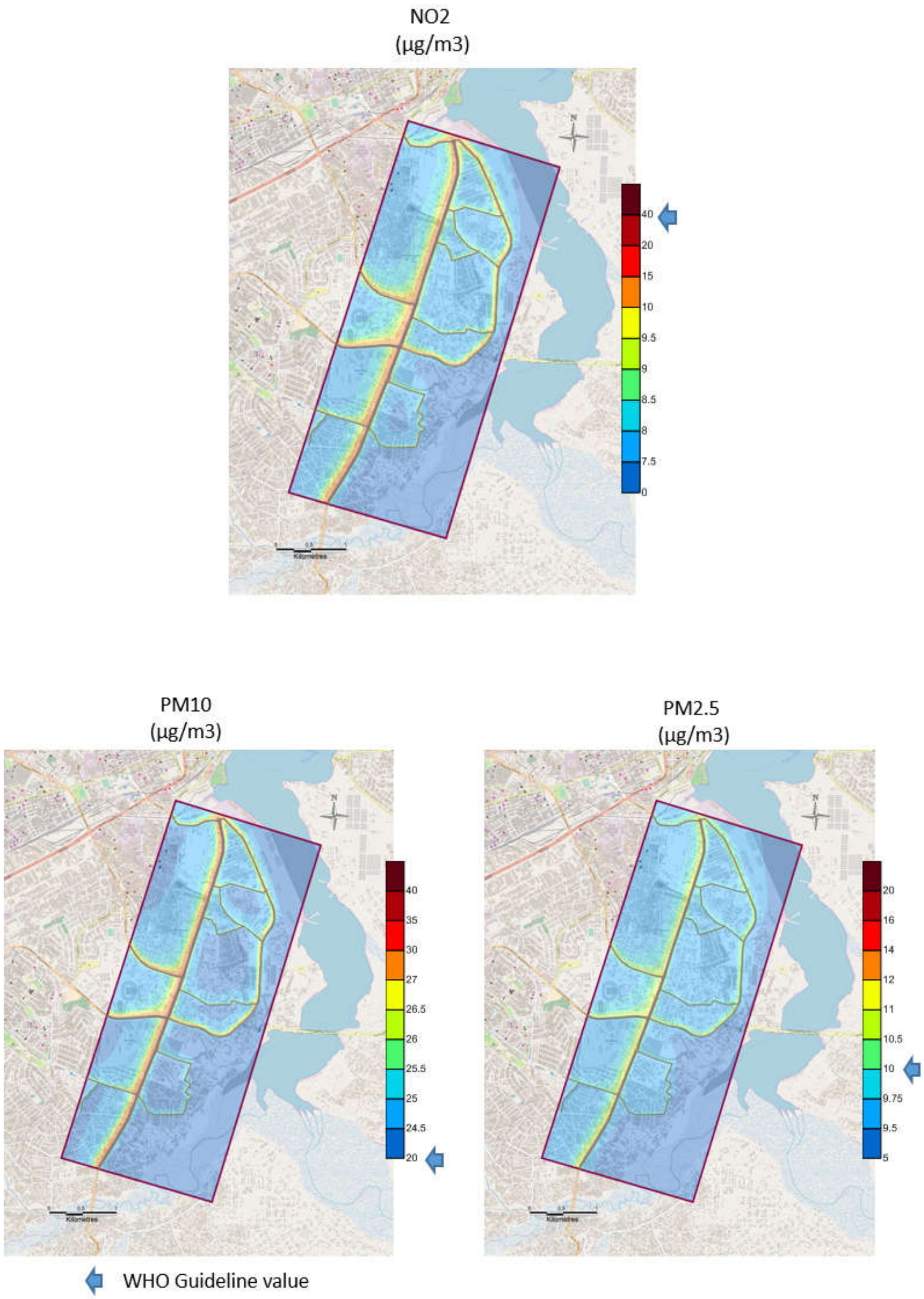
3.3.5.4.4 Mapping of concentrations calculated over the transport corridor

The following figure (Figure 3-41) shows the total concentration (background, road traffic contribution and the particulate matter resuspension) maps for NO_2, PM_{10} and $PM_{2.5}$ over the transport corridor. **Due to the low sulfur content, SO_2 pollutant has not been considered in this study as referred in the Table 3-32.** The major structuring axe of the corridor i.e. the Kilwa road is impacted by the highest levels of pollution regardless pollutants.

For PM pollutants, exceedances of the WHO annual average guideline values (20 and 10 µg/m^3 for PM_{10} and $PM_{2.5}$ respectively) flagged by the blue arrow on the color scale, were identified on a large part of the transport corridor. As described in the previous section this effect is mainly due to the high background concentrations observed during the monitoring campaign. Moreover, the contribution of the road traffic to the total concentrations of PM is low (<6%).

NO_2 concentration levels calculated by the ADMS-Roads model are much lower than the WHO guideline (annual average). The maximum NO_2 concentration is about 18 µg/m^3.

Figure 3-41: Concentration maps of pollutants (NO_2, PM_{10} and $PM_{2.5}$) within the transport corridor in Dar Es Salaam city. Note that WHO guidelines (blue arrows) are based on annual average



3.4 Summary

The table below presents the results obtained in each city, expressed as average concentrations over the sampling period. Results are compared to international WHO Guidelines (daily and annual average) and exceedances (of at least one of the standards) are highlighted in red. Because sampling was made during several hours/days, the daily average guidelines are well suited for comparison, but we can also expect that concentrations close to traffic should not vary considerably from one day to another and it is therefore interesting to compare sampling results to annual guidelines. Measurements should be performed over longer time periods to confirm these observations. From these preliminary measurements in pilot areas, we conclude that concentrations close to traffic are generally much higher than urban background concentrations. This is especially true for NO_2, which is a pollutant mainly emitted by vehicle engines. Note that these observations cannot be used to characterize pollution in the selected cities, as these concentration results are highly dependent on the pilot area chosen for investigation.

Note that SO_2 concentrations are not presented due to high detection thresholds of the sensors used. However, SO_2 concentration maps have been built using the ADMS model (see sections above). Due to significant uncertainties related to measurements of low NO_2 concentrations, all measured values less than 10 µg/m^3 are noted as '<10' in the summary table below.

Table 3-36: Concentrations observed in pilot areas (exceedances of WHO Guidelines are presented in bold)

City	Pollutant	Measurements (µg/m³)			WHO Guidelines (µg/m³)	
		Road Traffic Site		Urban Background	Annual Average	Daily Average
Abidjan		N'Dotré T170 crossroad	Yopougon, First pedestrian bridge	FHB University, Cocody		
	NO_2	<10	**52.0**	<10	40	-
	PM_{10}	**49.4**	**70.2**	18.5	20	50
	$PM_{2.5}$	**15.4**	**17.1**	7.2	10	25
Dar Es Salaam		Kilwa Rd		TANROADS institute		
	NO_2	<10		<10	40	-
	PM_{10}	**28.6**		**24.1**	20	50
	$PM_{2.5}$	**10.7**		9.5	10	25
Lusaka		Lumumba Rd		ZEMA Institute		
	NO_2	10.2		<10	40	-
	PM_{10}	**38.7**		17.7	20	50
	$PM_{2.5}$	9.9		5.8	10	25
Rabat		Agdal Riad District (Hassan II Avenue)	Victoire Rd	National Laboratory of Environment (Mohamed Ben Abdellah Erregragui Rd)		
	NO_2	11.0	36.7	<10	40	-
	PM_{10}	**47.3**	**27.6**	**32.5**	20	50
	$PM_{2.5}$	**17.4**	**14.0**	**12.0**	10	25
Yaoundé		Charles Atangana Avenue		Water bridge (Daniel Essomba Rd)		
	NO_2	<10		<10	40	-
	PM_{10}	**27.6**		14.3	20	50
	$PM_{2.5}$	7.9		4.0	10	25

4. SOCIO-ECONOMIC PART

4.1 Introduction

The project "Transport Emission Mapping and Monitoring Capacity Building In 5 Selected African Cities" contains three main parts, focussing on "emission mapping and monitoring", "socio-economy", and "policy and regulation" respectively.

This chapter contains the reporting of the socio-economic part. The main elements of the socio-economic part are the following:

1. Analysis of transport and energy subsidies, sources of finance and economic Cost Benefit Analysis of low emission transport technologies in one host country
2. Training of staff, preparation and production of manuals.

The socio-economic part, and in particular the first component shall focus on Abidjan in Côte d'Ivoire.

Originally the subject of the training component was focusing on "determination of carbon tokens and financing of projects", but the developments in the carbon emission market and in the international carbon emission regulatory system has left this with little relevance. The previous system with binding reduction targets and tradeable quotas, which gave room for low emission projects to obtain financing through the sales of carbon emission quotas to companies and others that were willing to pay for larger carbon quotas, has been replaced by a system of individual and voluntary carbon reduction targets.

This changed the foundation for parts of the planned training plans, and it was therefore agreed already during the inception phase to redirect this part to focus more on economic Cost Benefit Analysis of low emission transport technologies. Ramboll hence suggested a main focus on the assessment and inclusion of economic benefits, including the health benefits, of the reduced emissions and of the less traffic congestions.

The outputs from this socio-economic part will thus comprise the following:

1. Transport and energy subsidies in Cote d'Ivoire
2. Sources of finance, relevant to low emission transport technologies
3. A description of a recommended model for Cost Benefit Analysis of low carbon transport projects in Africa
4. Cost Benefit Analysis of selected (2) low emission transport technologies applied in Abidjan but with a geographically broader relevance
5. Preparation of a general manual for conducting similar Cost Benefit Analyses of low carbon transport projects in Africa

In addition to this chapter, a general and separate manual for conducting similar Cost Benefit Analyses of low carbon transport projects in Africa has been prepared, as well as training material (see presentation in Chapter 6).

This draft report contains the major part of the physical deliveries in a first draft version. Mainly the training material shall be seen as a first step that provides an understanding of the final contents to be prepared after approval of the draft. The report, the manual and the training material will finally be provided as three separated deliveries.

4.2 Transport and energy taxes and subsidies in Cote d'Ivoire

The energy sector plays a vital role in economic development in Sub-Saharan Africa (SSA), a region where income levels are low compared to the global average. Energy serves as a vital input for all economic activities including the transport sector. The aim of this chapter is to provide an overview of the level of taxes and subsidies on transport and energy in Côte d'Ivoire and to compare this to that of other countries in the SSA region.

The section distinguishes between 1) subsidies provided to consumers of transportation services, which directly affects the demand for such services, and 2) subsidies provided to producers and/or consumers of energy, which indirectly affects the demand for transportation services. The chapter has been developed on the basis of interviews of key people in Abidjan and a comprehensive review of available data and reports.

4.2.1 Subsidies on transportation services

In Cote d'Ivoire the public transport sector is in general operated as a private business. According to the Ministry of Transport, the involved companies do not enjoy any special privilege. There are however a few concrete examples of government subsidies in the public transport sector.

Originally the government awarded an official monopoly on public transport to the bus operator SOTRA, making them the only operator in the formal privatised public transport market. SOTRA operates 84 conventional bus lines including 14 express busses as of 2014. The informal sector consisting of the gbakas and woro-woro, was only allowed to operate in certain areas, but due to an insufficient supply from SOTRA, the informal sector has been continuously growing at their expense, despite government efforts. The gbakas are fixed route minibuses with up to 32 seats, and the woro-woro are a form of shared somewhat fixed route taxis[29]. The SOTRA busses are fully regulated by the Ministry of Transport, whereas only part of the informal sector is effectively regulated, for instance only about half of the gbakas are authorized.

Today, the government supports the SOTRA bus company by subsidizing the lower part of the tariffs. This is done by paying part of the monthly bus passes for selected low income groups. The government pays 80 % of the monthly price of 15,000 FCFA for students and 50 % for civil servants.

Another example of a government subsidy to the privatised public transport sector is a 5 billion FCFA grant that was given by the government to SOTRA to help expand the bus fleet from 600 to 1,000 busses over the years 2013 - 2016[30]. The SOTRA bus company is the only transport provider operating under a formal contract and there is no publicly owned and administered public transport company.

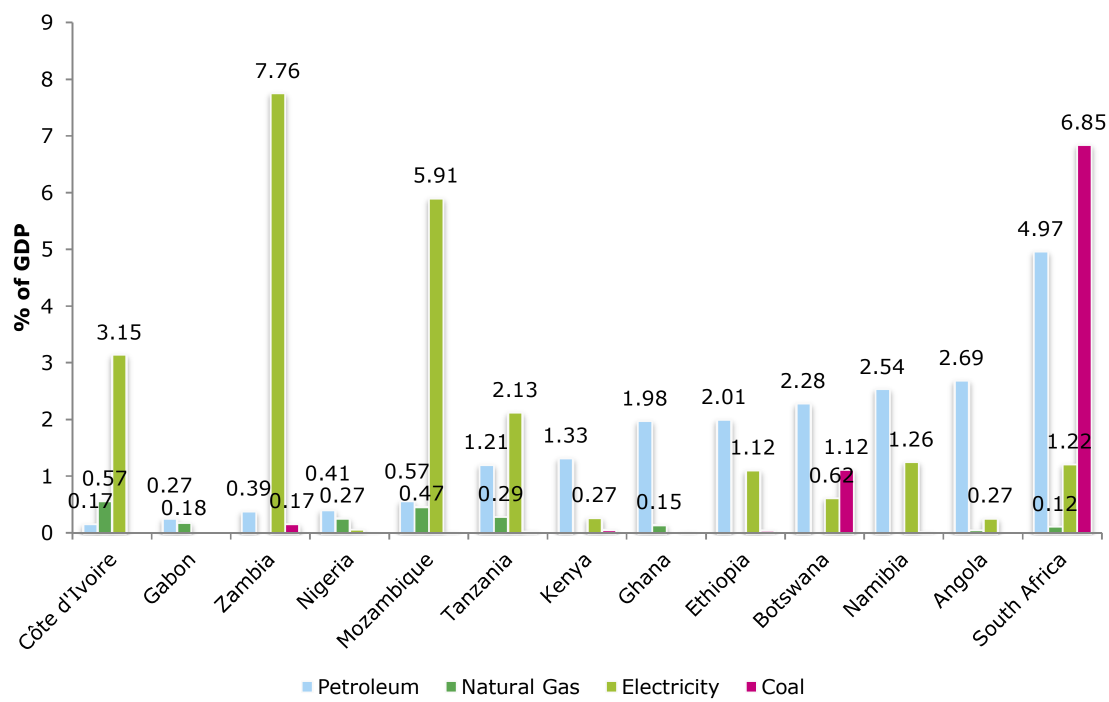
[29]Overview of Public Transport in Sub-Saharan Africa, UITP – International Association of Public Transport (2008), http://www.uitp.org/sites/default/files/cck-focus-papers-files/Transafrica_UITP_UATP_PublicTransport_in_SubSaharan_Africa_2008.pdf
[30] Urban Master Plan vol. 3

4.2.2 Subsidies on energy

Energy subsidies are prevalent in most SSA countries, including Côte d'Ivoire. The arguments in favor of subsidies include protection of domestic consumers to volatile (high) international energy prices, protecting domestic production in energy intensive industries such as oil refining, and increasing the population's access to energy[31].

Between 2000 and 2012, total energy demand in SSA increased by 45%[32]. In 2012, Côte d'Ivoire's energy consumption mix comprised of electricity from renewable sources (16%), natural gas (44%), and oil (40%)[33]. The figure below shows the level of subsidies across these energy types for a selected number of countries in the region. The following sections focus on Ivoirian subsidies on fuel and electricity.

Figure 4-1: Post tax subsidies in selected SSA countries in 2015, % of 2015



Source: IMF. Numbers are based on the notion of post-tax subsidies, which arise when consumer prices are below supply costs plus a tax to reflect environmental damage and an additional tax applied to all consumption goods to raise government revenues.

[31] Whitley S. and van der Burg, L., 2015. Fossil Fuel Subsidy Reform in Sub-Saharan Africa: From Rhetoric to Reality. New Climate Economy, London and Washington, DC. Available at http://newclimateeconomy.report/misc/working-papers.

[32] World Economic Outlook 2014: Africa Energy Outlook. International Energy Agency. Available at: https://www.iea.org/publications/freepublications/publication/WEO2014_AfricaEnergyOutlook.pdf.

[33] Cote d'Ivoire: A regional oil products hub in the making. Ecobank 2013. Available at: http://www.ecobank.com/upload/20130429102712145656rbw5nj8vpb.pdf.

4.2.2.1 Fuel subsidies

The level of energy subsidies in Côte d'Ivoire is relatively low as a percentage share of GDP compared to other countries in the region. In terms of fuel (petroleum) subsidies, the country ranks in the low end with only 0.17% of GDP allocated for this in 2015. According to the IMF, fuel subsidies are especially prevalent in oil-exporting countries, as governments wish to protect domestic consumers from spikes in international oil prices and distribute the benefits of domestic production to consumers[34]. As a net exporter of refined oil products (oil production exceeded domestic consumption by 245% in 2012), it is therefore somewhat surprising that Côte d'Ivoire spends so little on fuel subsidies. This can however be linked to the very low affordability of Côte d'Ivoire's transport sector. Low affordability is both due to an underdeveloped road and rail infrastructure, as private investments in the transport sector have decreased since the mid-2000s[35], as well as due to high domestic fuel prices[36].

In 2010, fuel prices in Côte d'Ivoire were amongst the highest in the region, with prices between 2 and 4 times higher than countries like Nigeria, Ethiopia, Angola and Botswana. As is evident from the figure above, the latter two have significantly higher levels of fuel subsidies, whilst affordable domestic access to transport fuels is an important policy issue in Nigeria, as the country is the largest oil producer in the SSA region. This makes transportation more affordable compared to Côte d'Ivoire. The IMF illustrates this by the fact that average road sector energy spending in Côte d'Ivoire is amongst the lowest in the entire SSA region, where the average spending is 11% of total energy consumption, which is much lower than the world average[37].

The low road sector energy consumption in Côte d'Ivoire is also the result of a very low level of car ownership, with only around 15 cars per 1,000 people in 2012, significantly lower than countries like South Africa (110), Botswana (95), and Namibia (50). As these countries have the highest spending on fuel subsidies in the SSA region, this is hardly surprising. This is supported by the IMF, who finds that lower fuel taxes (or conversely higher fuel subsidies) are associated with higher average road sector energy consumption. The low level of private vehicle ownership hence partly explains why policy makers have given only limited attention to improving road vehicle efficiency[38].

Although energy consumption in the transport sector increased 60% from 2000 to 2012 in the SSA region, the low affordability of transport fuels and underinvestment in road infrastructure hinders further growth in Côte d'Ivoire. On the positive side, this translates into lower levels of GHG emissions, as the IMF finds that lower taxes (higher subsidies) on fuels are associated with higher emission levels. The World Bank estimates that raising the country's infrastructure endowment could significantly boost economic growth. As a negative consequence, however, increasing the affordability of transport is likely to lead to an increase in GHG emissions, unless policy makers simultaneously incentivize investments in more energy efficient transportation modes[39].

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[34] Energy subsidy reform in Sub-Saharan Africa: experiences and lessons — Washington, D.C.: International Monetary Fund, [2013] Available at: http://www.imf.org/external/pubs/ft/dp/2013/afr1302.pdf

[35] Côte d'Ivoire's Infrastructure: A continental perspective (2011). The World Bank. Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/3360/WPS5594.pdf?sequence=1&isAllowed=y.

[36] Fuel Price Subsidies in Sub-Saharan Africa" in The World Bank, "Africa's Pulse". Volume 5, April 2012. Available at http://siteresources.worldbank.org/INTAFRICA/Resources/Africas-Pulse-brochure_Vol5-Section_2.pdf.

[37] World Economic Outlook 2014: Africa Energy Outlook. International Energy Agency. Available at: https://www.iea.org/publications/freepublications/publication/WEO2014_AfricaEnergyOutlook.pdf.

[38] World Economic Outlook 2014: Africa Energy Outlook. International Energy Agency. Available at: https://www.iea.org/publications/freepublications/publication/WEO2014_AfricaEnergyOutlook.pdf.

[39] Côte d'Ivoire's Infrastructure: A continental perspective (2011). The World Bank. Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/3360/WPS5594.pdf?sequence=1&isAllowed=y.

4.2.2.2 Electricity subsidies

No other world region has a more limited access to electricity than Sub-Saharan Africa. As of 2012, 15 million people lacked proper access to electricity in Côte d'Ivoire, equivalent to 75% of the population[40]. Another source, however, indicates that 74% of the population lives in localities with access to electricity, as of 2013[41]. The low income levels in the SSA region means that governments have chosen to set lower average electricity tariffs to ensure affordability for consumers. On the other hand, low tariffs mean that power production becomes economically unviable, and increasingly dependent on government subsidies. These subsidies mainly flow to power utilities, and the IMF argues that they have the adverse effects of preventing cost recovery and thus disincentive private sector investment[42]. This in turn results in an inadequate and costly supply of energy.

As the figure in the previous section shows, electricity subsidies in Côte d'Ivoire amounted to more than 3% of GDP in 2015, only surpassed in SSA by Zambia (7.8%) and Mozambique (5.9%). Despite the high level of electricity subsidies, the electricity sector in Côte d'Ivoire is among the best in the region, and is not hampered by underinvestment. In 2014, the country ranked second in terms of quality of electricity supply, below Gambia[43]. The high success of the Ivoirian electricity sector tracks back to 1990, when the power sector was privatized and the Compagnie Ivoirienne de l'Électricité (CIE) was established to manage private investments in the energy sector.

Since then, several independent power producers (IPPs) have invested in increasing the capacity of the electricity sector, mainly from natural gas plants, which currently represent 70% of electricity production[44]. IPPs are more efficient and deliver more reliable electricity, than could the state owned power utilities. This enables Côte d'Ivoire to meet the growing domestic demand for electricity, whilst simultaneously being a net exporter to other countries in the region.

A key factor behind the success is a model of cascading payments, which increases investing security for IPPs. Additionally, in order to reduce their financial risks, IPPs require a high level of engagement from the Ivoirian state, both in terms of various securities, and direct state investments in transmission and distribution infrastructure[45]. This state engagement translates, in other words, into electricity subsidies, which illustrates why subsidies are at such a high level compared to other SSA countries.

In the future, the main concern is whether or not electricity prices are high enough to sustain continued private investment. The energy ministry has responded by approving higher tariffs, so the sector is better able to finance investments[46]. It has also helped to keep costs flat for poorer domestic consumers, so the higher tariffs do not translate into higher prices. Likely, however, this needs to be financed by an increase in electricity subsidies, which will thus put even more strain on public budgets.

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[40] World Economic Outlook 2014: Africa Energy Outlook. International Energy Agency. Available at: https://www.iea.org/publications/freepublications/publication/WEO2014_AfricaEnergyOutlook.pdf.

[41] Independent power generation: The Ivoirian model (2013). Amidou Traoré. Available at: http://www.proparco.fr/jahia/webdav/site/proparco/shared/PORTAILS/Secteur_prive_developpement/PDF/SPD18/SPD18_Amidou_traore_UK.pdf

[42] Energy subsidy reform in Sub-Saharan Africa: experiences and lessons — Washington, D.C.: International Monetary Fund, [2013] Available at: http://www.imf.org/external/pubs/ft/dp/2013/afr1302.pdf

[43] West Africa Monitor Quarterly, Issue 3 July 2014. AfDB. Available at: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/Quarterly_West_Africa_Monitor_-_Issue_3.pdf.

[44] Ivory Coast's power generation leaves neighbours in the shade. Financial Times. James Wilson, 2015. Available at: https://www.ft.com/content/fe3de4b2-5ad1-11e5-9846-de406ccb37f2.

[45] Independent power generation: The Ivoirian model (2013). Amidou Traoré. Available at: http://www.proparco.fr/jahia/webdav/site/proparco/shared/PORTAILS/Secteur_prive_developpement/PDF/SPD18/SPD18_Amidou_traore_UK.pdf

[46] Ivory Coast's power generation leaves neighbours in the shade. Financial Times. James Wilson, 2015. Available at: https://www.ft.com/content/fe3de4b2-5ad1-11e5-9846-de406ccb37f2?mhq5j=e5

4.3 Sources of finance, relevant to low emission transport technologies

The increasing need for investments in climate change mitigating, low carbon, energy efficient technologies as well as in climate change adaptation has increased the international funding needs considerably, and even if new providers of green capital have emerged, the lack of capital is still an important barrier for the needed climate investments.

According to the Climate Policy Initiative the global need for climate investments over the coming 15 years is 16,500 $ billion or 1,100 $ billion per year, which is compared to a total investment of only 392 $ billion in 2014[47], including investments in both climate mitigating, climate adaptation, and climate resilient growth. In this chapter, the focus shall be on the potential international funding of green, low carbon transport projects in developing countries.

The main international funding sources that have been identified as relevant for large, low emission transport projects in Abidjan are:

1. The Global Environmental Facility Trust Fund, GEF
2. The Green Climate Fund, GCF
3. The Clean Environment Mechanism
4. The Climate Investment Funds
5. Other funds: The Least Developed Countries Fund and the Adaptation Fund
6. The African Development Bank

The funding capacities from these sources are very limited in comparison with the estimated needs, even if their ambitions for co-funding is included. The mentioned climate funds are briefly presented and described in the following.

4.3.1 The Global Environmental Facility Trust Fund, GEF

The Global Environment Facility (GEF) was established in 1991 to address the most pressing global environmental problems. It is the largest global provider of funding for climate change projects aiming at mitigating and/or reducing greenhouse gas emissions, primarily within the focal areas of renewable energy, energy efficiency, sustainable transport, as well as land-use and forestry. The fund enables its 178 member governments to partner up with international institutions, NGOs, and the private sector[48]. GEF funds from its donors are available to developing countries and countries with economies in transition to meet the objectives of the international environmental conventions and agreements. Until present, the Fund has allocated 9$ billion for more than 2,600 projects, as well as having facilitated over 40$ billion in co-financing.

Initially, GEF was intended as a financial mechanism for the UN Convention on Biological Diversity (1992) and the UN Framework Convention on Climate Change (1992). Later, it also became the financial mechanism for the Stockholm Convention on Persistent Organic Pollutants (2001) and the United Nations Convention to Combat Desertification (2003).

The fund provides new and additional grants and concessional funding to cover additional costs associated with transforming a project with national benefits into one with global environmental benefits. GEF provides grants for projects related to climate change, but also for projects that improve biodiversity and combat land degradation, the use of ozone depleting substances, and organic pollutants[49].

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[47] http://www.climatefinancelandscape.org/?gclid=Cj0KCQjwprbPBRCHARIsAF_7gDZGtbit4AE5vLNTHFuhThFEmPXkt-gS3TGOhzSffKJdbFWoNaeZ0YAaAlnAEALw_wcB

[48] https://www.thegef.org/sites/default/files/publications/GEF_STAR_A4_april11_CRA_3.pdf

[49] http://unfccc.int/climatefinance?gefhome

4.3.1.1 The role of the AfDB as a Partnership Agency

The African Development Bank (AfDB) joined the GEF as an Executing Agency[50] in November 2003, with direct access to GEF resources and has had a growing role as a major source of GEF financing. The AfDB typically combines the GEF funding with its own investments to achieve a broader development goal. By bringing public and private partners to co-finance the projects, their impacts are further leveraged. This aligns with the GEF policy as adopted in 2014 to enhance co-funding of GEF financing.

The AfDB engages with national GEF focal points in identifying opportunities for common operations. Eligible countries shall meet the eligibility criteria established by the Conference of the Parties (COP) of the relevant convention, and projects shall address one or more of the GEF Focal Areas and shall be endorsed by the local government. GEF financing is only provided for agreed incremental costs on measures to achieve global environmental benefits.

4.3.1.2 GEF financing conditions

In practice, countries can apply for funding through the System for Transparent Allocation of Resources (STAR), which is GEF's resource allocation system that determines the size of GEF funding available to each eligible country. Here, a Project Identification Form (PIF) has to be produced, including a short description of the project, which GEF uses to determine whether or not the project meets certain criteria for receiving funding[51]. In most cases, the GEF provides funding to support government projects and programs, where governments decide on the executing agency (e.g. civil society organizations, private sector companies, or research institutions).

Countries that are eligible for GEF funding are countries that,

- meet eligibility criteria established by the relevant COP of that convention
- are members of the conventions and are countries eligible to borrow from the World Bank (IBRD and/or IDA)
- are eligible recipients of UNDP technical assistance through country programming

Funded projects or programs must be prioritised and driven by the country and address one or more of the GEF focal areas.

GEF financing can only be applied for the agreed incremental costs on measures to achieve global environmental benefits. Finally, GEF policy and guidelines on public investments stipulate that financing is conditioned on the fact that the project involves the public in project design and implementation.

4.3.1.3 GEF project types and examples

The GEF provides funding through four modalities: full-sized projects, medium-sized projects, enabling activities and programmatic approaches. The selected modality should be the one that best supports the project objectives. Each modality requires completion of a different template.

- Full-sized Project (FSP): GEF Project Financing of more than two million US dollars.
- Medium-sized Project (MSP): GEF Project Financing of less than or equivalent to two million US dollars.
- Enabling Activity (EA): a project for the preparation of a plan, strategy or report to fulfill commitments under a Convention.

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[50] The GEF partners with 18 agencies among which are: the UN Development Programme, the UN Environment Programme, the World Bank, the UN Food and Agriculture Organization, the African Development Bank, the Asian Development Bank, the European Bank for Reconstruction and Development, the Inter-American Development Bank, and the International Fund for Agricultural Development.

[51] https://www.thegef.org/sites/default/files/publications/23470_SCCF_1.pdf

- Program: means a longer-term and strategic arrangement of individual, yet interlinked projects that aim at achieving large-scale impacts on the global environment.

As of 2017, GEF has provided and facilitated financing for 43 carbon emission mitigation projects within the transport sector on a global scale. Eight of these are transport projects in Africa, which all focus on implementing more sustainable transportation within the area of climate change, cf table below.

Table 4-1: GEF financed low carbon transport projects in Africa

Country	Project title	Grant amount ($)	Co-financing total ($)	Project preparation grant (PPG) amount ($)
Botswana	Incorporating Non-Motorized (NMT) Transport Facilities in the City of Gaborone	891,630	1,365,300	25,000
Ghana	Ghana Urban Transport	7,000,000	29,000,000	350,000
South Africa	Sustainable Public Transport and Sport: A 2010 Opportunity	10,999,361	323,941,950	197,313
Egypt	Sustainable Transport	6,900,000	28,570,000	275,000
Burkina Faso	SPWA-CC: Ouagadougou Transport Modal Shift	909,000	3,590,000	25,000
East Africa	Promoting Sustainable Transport Solutions for East Africa	2,850,000	2,825,000	150,000
Nigeria	SPWA-CC: Nigeria Urban Transport	4,500000	100,500,000	-
South Africa	Energy Efficient Low-carbon Transport	1,300,000	6,050,000	-

As the table shows, the main source of financing for these projects is the co-financing, whilst GEF has provided grant amounts in the interval 900,000$ to 11$ million. According to GEF, the most important co-financiers are national governments, GEF agencies such as the AfDB, and the private sector[52]. The Fund argues that national government finance is especially important, as this facilitates national ownership and thus improves project implementation. Information on the projects can be found on the GEF webpage, including project identification forms, government endorsements and project evaluations[53].

In the context of this report, the project in Nigeria on Urban Transport serves as a prime example. The project period spanned from 2009 to 2015. It was launched with the objective of improving the capacity to manage the transport sector in the Lagos metropolitan area. It received co-financing from the World Bank, as well as the Federal Ministry of Environment and Lagos State Ministry of Environment. The overall project aim was to mitigate greenhouse gas emissions by enhancing efficiency of the public transport network through improvements in urban accessibility and transport affordability. Specifically, the project introduced a combination of traffic engineering measures, management improvements, regulation of the public transport industry, and expansion and enhancement of the BRT system.

[52] https://www.thegef.org/sites/default/files/council-meeting-documents/GEF.C.46.09_Co-Financing_Policy_May_6_2014_1.pdf
[53] http://unfccc.int/climatefinance/gef/gef_data

4.3.1.4 The Special Climate Change Fund (SCCF)

The SCCF was established in 2001 under the UN Framework Convention on Climate Change (UNFCC) to finance activities related to climate change as a complement to the financing opportunities provided by the GEF under the focal area of Climate Change (cf. section 4.1.1). It is operated under the GEF with the objective of supporting adaptation and technology transfer projects and programs within the sectors of energy, transport, industry, agriculture, forestry, waste management, as well as activities for economic diversification for fossil fuel dependent countries. The main difference from the GEF Trust Fund is its focus on adaptation rather than low carbon and global benefits, see Table 4-2.

Table 4-2: Key distinctions between GEF Trust Fund and SCCF. Reproduced from GEF material[54].

	Conventional GEF Trust Funds	SCCF
Project must generate global benefits	Yes	No
Project must generate adaptation benefits	No	Yes
Funding allocated according to Resource Allocation Framework or STAR	Yes	No
Projects financed according to the "incremental cost" principle"	Yes	No

The financing conditions under the SCCF are less restrictive than the conventional GEF Trust Funds. Common for all SCCF projects, however, is that they must generate adaptation benefits in terms of activities that address the adverse impacts of climate change. The SCCF hence serves as a prime source of financing for projects aiming at addressing the consequences of climate change in general. Information on the application process can be retrieved from the GEF webpage, including reporting requirements and key steps in the process.

The SCCF is the only adaptation fund open to all vulnerable developing countries. The demand for resources has been much larger than the available funds. Each year, the GEF receives about US$250 million in requests for adaptation support. As of 2017, 47 projects has received funding from the SCCF globally, 16 of which are in African countries. None of these, however, deals with climate adaptation in the transport sector.

4.3.2 The Green Climate Fund (GCF)

The Green Climate Fund (GCF) was established in 2010 as a financial mechanism of the United Nations Framework Convention on Climate Change (UNFCCC). Its goal is both to limit or reduce greenhouse gas emissions in developing countries and help adapt vulnerable societies to the impacts of climate change. It supports actions that are addressing both mitigation and adaptation, and low carbon transport systems is therefore one of its target areas. The GCF is expected to become the main *multilateral* financing mechanism to support climate action in developing countries.

The Fund gives recipient countries access to grants, loans, as well as options for guarantees through 33 accredited national, sub-national, international, regional, and private implementing entities. An Enhanced Direct Access (EDA) allows developing country-based accredited institutions to receive some allocations of GCF finance for distribution according to their own discrete decisions.

54 https://www.thegef.org/sites/default/files/publications/23470_SCCF_1.pdf

4.3.2.1 Investment criteria and current projects

Funding eligibility through the GCF is based on a number of investment criteria under the following headlines[55]:

1. Impact potential: The project's ability to contribute to achieve the Fund's objectives
2. Paradigm shift potential: The project's ability to catalyse a long-lasting impact beyond the one-off investment
3. Sustainable Development potential: The project's ability to generate wider environmental, social, economic and gender-sensitive development benefits
4. Needs of the recipient: The vulnerability and financing needs of the country and population benefitting from the financing
5. Efficiency and effectiveness: The project's cost-effectiveness and efficiency, the amount of co-financing needed, financial viability of the project, as well as considerations on industry best practices.

As of September 2017, the Green Climate Fund has raised USD 10.3 billion equivalent in pledges from 43 state governments. 43 projects have received financing through the GCF benefitting about 140 million people at a total investment value of 2.2$ billion. Out of these, almost half are located in African countries and the majority of the projects span across international borders, i.e. are of multilateral character. The primary financing forms are grants and loans, which together constitute almost 90 percent of total investment value.

Examples of GCF funded projects in Africa are 1) the KawiSafi Ventures Fund in East Africa, which aims at driving a low-carbon paradigm shift from fossil fuel grids to clean energy in Rwanda and Kenya. 2) The Universal Green Energy Access Programme, which contributes to universal access to electricity in Sub-Saharan Africa through up-scaling of investments in renewable energy.

Common for these projects is that they take the long-term perspective in terms of creating a shift away from fossil fuel dependency towards implementation of clean energy technology.

4.3.2.2 GCF as financing partner in Côte d'Ivoire

Côte d'Ivoire submitted a readiness proposal to the GCF in 2015, in which the Ministry of Environment, Urban Sanitation and Sustainable Development requested funding for the establishment and strengthening of National Designated Authorities (NDAs), as well as strategic frameworks for engagement with the GCF in preparing programmes to address environmental issues in the country. As a consequence, the country nominated the Bureau of Climate Change as the NDA to the GCF in August 2016, which thus serves as the focal point between the Government and the GCF[56].

In an interview, the Bureau stresses three sectors, in which the GCF could fund potential paradigm-shifting programmes, namely 1) energy and transport, 2) agriculture and forestry, and 3) waste management. Naturally, these areas have high importance in the country's Intended Nationally Determined Contributions (INDCs), which was effectuated after the COP21 in Paris in December 2015. Here, the Ivorian Government's target towards 2030 is to decrease GHG emissions with more than 28 percent compared to the 2012 level, of which 8 percent and 6 percent are to be accomplished in the energy and transport sectors, respectively[57].

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55 http://www.greenclimate.fund/documents/20182/239759/Investment_Criteria.pdf/771ca88e-6cf2-469d-98e8-78be2b980940

56 http://www.greenclimate.fund/-/gcf-spotlight-on-cote-d-ivoire?inheritRedirect=true&redirect=%2Fnewsroom%2Fgcf-spotlight-list

57 http://www4.unfccc.int/ndcregistry/PublishedDocuments/C%C3%B4te%20d%27Ivoire%20First/INDC_CI_22092015.pdf

"Côte d'Ivoire views GCF as the principle mechanism to finance our pipeline of projects and programmes to combat climate change and build sustainable development. We are counting on the Fund." – Richemond Agré Assie, UNFCCC National Focal Point, Bureau of Climate Change.

4.3.3 The Clean Development Mechanism (CDM)

The Clean Development Mechanism (CDM) was defined in Article 12 of the Kyoto Protocol in 2004 along with other market-based mechanisms to limit carbon emissions.

The CDM allows emission reduction projects in developing countries to earn certified emission reduction (CER) credits that can be sold and used by industrialized countries to meet part of their emission reduction targets under the Kyoto Protocol[58]. It thus provides a funding option for carbon emission reducing actions in developing countries, and the mechanism thereby stimulates sustainable development and emission reductions. At the same time it gives industrialized countries some flexibility in how they meet their emission reduction targets.

For various reasons, the volume of CER credits that have been sold, in particular by African countries has been relatively limited. Most African CDM projects have been cook-stove projects and other energy projects, and no African CDM projects have apparently been seen in the transport sector.

The demand has been falling, and the perspectives for the future are weak, in particular after the COP21 Paris Agreement, according to which the emission reduction targets are voluntary. The Paris Agreement thus requires all parties to put forward their best efforts through "nationally determined contributions" and to gradually strengthen these efforts in the coming years. The monitoring is based on regular reports on emissions and implementation efforts from all parties

Historically, African countries have lagged behind in the utilization of the CDM facility, and have had plans to raise awareness of this opportunity to increase the investments in mitigating actions. This may, however, prove inadequate or useless, as the future potential of sales of CERs depends on the developments in the voluntary carbon markets.

The CDM projects have been validated and verified by competent teams of designated operational entities (DOE's), who are under contractual arrangements with project participants based on approved CDM methodologies. In carrying out its validation and verification work, the DOE shall follow the standard and determine whether the project activities meet the CDM requirements and guidelines; they assess the information provided by project participants, and determine whether it is reliable and credible.

4.3.4 The Climate Investment Funds (CIFs)

Since 2008, the 8.3 $ billion Climate Investment Funds has also been an important source of funding for adaptation and low carbon projects in Africa and in other developing and middle-income countries[59]. CIF has focused on the energy, climate resilience, transport and forestry sectors and offered soft loans through its four programs:

- The Clean Technology Fund (CTF) with its 5.6 $ billion provides middle income countries with concessional funds for technology transfer and demonstration in the target areas;
- The Pilot Program for Climate Resilience (PPCR) with 1.2 $ billion helps developing countries to integrate climate resilience into development planning;
- The Scaling up Renewable Energy Program (SREP) with 0.78 $ billion is focusing on renewable energy projects in the world's poorest countries; and
- The Forest Investment Program (FIP) with 0.78 $ billion promotes sustainable forest development in developing countries.

[58] https://cdm.unfccc.int/about/index.html

[59] https://www.climateinvestmentfunds.org; https://climatepolicyinitiative.org/wp-content/uploads/2016/06/The-role-of-the-Climate-Investment-Funds-in-meeting-investment-needs.pdf

The funds are managed by the World Bank and jointly implemented by the AfDB and other MDBs. The 8.3 billion fund is expected to attract another 58 $ billion in co-financing. However, this source of funding seems to be of less importance and relevance for low carbon transport investments in Cote d'Ivoire.

4.3.5 Other Climate Funds

Other funds have been established to address the huge financing needs concerning adaptation.

This is the case for the Least Developed Countries Fund (LDCF) which was established under the United Nations Framework Convention on Climate Change (UNFCCC) to support the 51 least developed countries that are especially vulnerable to the adverse impacts of climate change in their efforts to prepare and implement national adaptation programs.

The Adaptation Fund was also established to finance concrete adaptation projects and programs in developing countries that are vulnerable to the adverse effects of climate change. It was established under the Kyoto Protocol of the UNFCCC 2010 and has provided funding for climate adaptation and resilience activities.

4.3.6 African Development Bank (AfDB)

In addition to its role as the Implementing Agency for the GEF and the GCF, the AfDB also has its own internal bank funds that are designated for programs in the fields of environment, clean energy, climate change mitigation, and adaptation. AfDB provides both cheap concessional loans and ordinary loans.

AfDB has also developed a climate finance tracking methodology for transport projects[60], and the Bank prepares a five-year country strategy papers with the governments, in which they have listed the indicative areas and concrete projects that will be funded over the planning period.

4.4 A recommended model of Cost Benefit Analysis

4.4.1 Introduction

Cost Benefit Analyses (CBAs) of a few selected low carbon technologies in Côte d'Ivoire shall be undertaken to illustrate the importance of benefits categories such as health, environment and congestion impacts in the overall assessment of low emission transport projects and policies. Two main alternative projects or policies have been identified and are assessed on the background of a baseline situation, which may either be a "do-nothing situation" or a most likely alternative development. The aim is to illustrate how the wider benefits of low emission transport may occur and be quantified and valued in economic terms. By doing this, the inclusion of such benefits in CBAs will be promoted and hence increasingly taken into account in future project assessments.

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[60] https://www.afdb.org/fileadmin/uploads/afdb/Documents/Policy-Documents/Climate_Finance_Tracking_Guidance_Manual_-_Transport_Sector.pdf

Before conducting the Cost Benefit Analysis, the general principles of a proposed CBA methodology shall be outlined. The applied methodology has been based on the various existing models that are used by countries and international institutions, and it will be designed in a way and with a focus that is relevant and appropriate for low carbon emission transport projects. Among the models that will be used as inspiration are the CBA models and manuals of the World Bank[61], The Asian Development Bank[62], The European Union[63], and the Danish Ministry of Transport[64]. The proposed methodology and the main principles behind it will be briefly described below.

4.4.2 A general CBA model for assessing low carbon transport projects

The proposed methodology is described in the following. It will focus on two main aspects, namely

1. Overall purpose and principles
2. Valuation and estimation of benefits and costs

These two aspects are addressed at a general level in the following. More practical details shall be given in a separate manual that is based on the same methodology.

4.4.2.1 Overall purpose and principles of the CBA

The aim of an economic CBA is to include and give a systematic assessment of all socio-economic benefits and costs of a policy or a project. All costs and benefits shall be included in the analysis, whether they are carried by the public sector, a private stakeholder or institution in the country in question.

Only benefits to in-country stakeholders are included in an economic CBA. The national boundaries are thus important for the identification and estimation of both costs and benefits and both initial investments and current impacts are taken into account. Together these costs and benefits provide the basis for determining the economic value of a project, which indicates to what extent a project affects positively or negatively the total welfare of the country. In principle, the CBA could also be done for a group of countries, for a region of a country or for the entire World, but traditionally it is undertaken for a country with a strict focus on the geographic area, the citizens, enterprises and institutions of this particular national entity.

According to welfare economics, distributional impacts do not affect welfare, as such impacts will be costs for one part and benefit for another, and they are thus disregarded in economic studies. Only the resulting net impacts on costs and benefits thus contribute to the result of the CBA, which means that transfers from one group of citizens to another or from the citizens to the public sector do not affect total welfare and hence shall not affect the net results of the CBA.

With the purpose of measuring the economic value of a project, a CBA model typically compares the present values of the annual, year by year benefits and costs over the project lifetime with initial investment costs of the particular project or policy. A real discount rate of typically 3-5% p.a. is used for the calculation of present values. This means that costs and benefits that have to be carried immediately or early in the project lifetime gets a higher weight than future costs and benefits in the longer term, the value of which will be reduced as a result of the discounting. If the net present value of all benefits and costs is positive, the project is considered economically viable.

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[61] Pedro Belli, Jock Anderson, Howard Barnum, John Dixon, and Jee-Peng Tan: Handbook on Economic Analysis of Investment Operations, The World Bank, 1998.
[62] Asian Development Bank: Cost benefit analysis for Development. A Practical Guide. ADB 2013.
[63] European Commission, Regional and Urban Policy: Guide to Cost Benefit Analysis of Investment Projects, 2014.
[64] Danish Ministry of Transport: Manual for Economic Analysis in the transport sector, 2015.

In order to estimate both costs and benefits, a very clear and well-defined baseline situation or counterfactual situation has to be established. The investments and the annual benefits and costs are then all estimated on the basis of a comparison to this. The baseline shall be considered a realistic, natural alternative to the project. It may be defined as a "do nothing situation" where the current situation will be assumed to continue without any other changes than those necessary and expected to take place. Alternatively, the baseline may also be defined as an alternative project that is considered necessary to remediate acute traffic problems.

The economic CBA is applied as a key tool for decision-making in the whole planning, design and implementation process, but it may be applied differently in the various phases. It may e.g. be undertaken for prioritizing several alternative policies or projects at an early stage in a planning process to provide a good basis for the selection of the economically most favourable project, or it may be used for the comparison of alternative concrete solutions or alternative versions of a project just before implementation to provide a basis for the final scope and design and to see which solution is economically the most favourable.

The cost estimates shall reflect the opportunity costs to society of the project activities. They may be investment costs and/or the operating costs of a planned infrastructure, which may e.g. be a road, a bridge, a metro or a BRT system.

The benefits may include the benefits of the users in terms of value of saved time and saved vehicle operating costs. It may also include externalities, such as the value of climate impacts, an improved environment, improved health, accidents, congestion, or other external impacts that are considered relevant to include in an economic assessment.

4.4.2.2 Categories of benefits and costs

As mentioned, the cost estimates shall reflect the opportunity costs to society of the project activities, and similarly the economic benefits shall reflect the value or the increased welfare to society of the various impacts of the project.

The costs and benefits of a transport project will typically include the following:

Table 4-3: Typical costs and benefits of a transport project

Costs:	**Benefits:**
Investment costs	Time saving
Maintenance costs	Saved vehicle operation costs
Consumption of fuel, tires and lubricants	Saved accident costs
Repair and maintenance costs	Improved environment and health
Other operating costs	Climate benefits

The occurrence and values of each of these categories will vary from case to case, depending on the types of projects that are analysed, but some general approaches to the estimation of the various effects shall be outlined and applied.

To the extent possible, all benefits and costs of a project vis a vis the defined baseline shall be quantified and estimated in comparable monetary terms. We suggest that this is done in real prices (without inflation) and at a given nominal price level, which may e.g. be the price level at the time of planning (e.g. 2017 price level). This means that only the price developments that are not a consequence of the general inflation should be reflected in the applied values over time.

The valuation may be done in an international currency or in the domestic currency. If domestic prices of tradeable products and services deviate considerably from international prices or the border price level, the latter should be applied. The border prices are here defined as f.o.b. for exports and c.i.f. for imports, excl. duties and taxes[65].

Differences between domestic prices and border prices may occur for several reasons. The current market prices do not always reflect the economic cost of a product or service. Market imperfections and distortions, such as the presence of monopolies, taxes and subsidies, or managed currency rates are among the most frequently seen factors that create significant differences between the observed local market prices and the actual cost of a product or service as reflected in the border prices.

4.4.2.3 Benefit estimation methods

A number of benefits are not tradeable and do not have a market price, neither domestically nor at the border. In such cases, the values will have to be estimated with the use of alternative methods. This is e.g. the case for congestion and saved time, environmental improvements, health impacts, accident cost and similar effects. A number of different methods may be applicable in different cases. Some examples are the following:

- The contingent valuation method that involves directly asking people, in a survey, how much they would be willing to pay for certain services
- The contingent choice method that is a hypothetical method where people are asked to make choices based on a hypothetical scenario, and where values are inferred from the hypothetical choices or tradeoffs that people make.
- The benefit transfer method that estimates economic values by transferring existing benefit estimates from studies already completed for another location or issue.
- The hedonic pricing method is used to estimate economic values for environmental effects that directly affect market prices. Variations in housing prices are then assumed to reflect the value of local environmental attributes.

No such studies will be conducted as part of this project. The choice of appropriate valuation technique depends on the type of project and the impact to be valued, the data, time, and financial resources available for the analysis, and the sociocultural setting within which the valuation exercise shall be undertaken. We suggest that only well-known, conventional approaches to the estimation of user benefits and benefits of externalities shall be used. This is relevant for the three benefit categories that shall be particularly addressed in the following: Value of reduced congestion, value or reduced carbon emissions, and the value of reduced emission of particulate matter.

4.4.2.4 User benefits for existing and attracted users

User benefits will often have to be estimated for both existing and new, attracted users. If a road connection or the public transport system improves travellers may thus be attracted from alternative connections or alternative transport systems.

In such cases, it must be taken into account that in comparison with the baseline, the benefits are different for the two groups. If, e.g. a new and faster bus connection is established, the existing passengers will experience the full timesaving per trip, but the attracted passengers must be assumed to have travelled before in a way that was better than the former bus connection, but less attractive than the new connection.

[65] F.o.b. (free on board) means that the buyer pays for the freight and carries the risk while the goods are shipped. C.i.f. (cost, insurance, freight) means that the seller arranges for and pays the carriage of goods to a port of destination.

The conventional practise in such cases is to assume that the benefits to the attracted passengers vary from 0 (for those that just exactly find the new connection attractive) to the full time saving (for those that were just at the fringe of changing to the former connection). It is further assumed that the new passengers are evenly distributed between these two extremes, which means between 0 and the full benefits of existing passengers, and the average benefit to this category of users is therefore 50% of the benefits to the existing passengers.

4.4.3 The value of reduced congestion

The costs of congestion or the value of reduced congestion may be measured as the time spent in the traffic or as a consequence of the traffic congestion. Depending of the nature of a project, the time saved in the traffic as a direct result of it may be estimated by means of an estimated average traffic speed with and without the project and the number of travellers. On top of that, in case a project has such a big positive impact on congestion that it becomes easier for citizens in general to move around in the city, an additional value of reduced congestion may be estimated. This may be done e.g. by estimating the average time saving per citizen in or visitor to a given area of the city (per day or per year). However, such an impact will be an uncertain and rare benefit and it should not be assumed to occur with significant impacts but in a few cases.

In determination of the value of time, we may distinguish between working time (adults), non-working time (adults), and non-working time of children. However, in many cases it is not possible to quantify these groups and an estimated, weighted averages may then be applied.

The value of working time may be determined as the average per capita GDP or the average wage rate per person in the labour market in Côte d'Ivoire. The value of adult non-working time may e.g. be estimated at 30 percent of this amount, and the value of children's time, half of this[66], i.e.15 percent. However, if such details are not available an average value of time may be estimated.

4.4.4 Value of reduced carbon emissions

A special issue concerns the valuation of the reduction of carbon emissions. As long as emission rights are traded internationally, the market price is the correct value to use in the CBA, but without international trade in carbon emissions, the traditional use and interpretation of the economic CBA would prescribe that the economic benefit of reduced emissions is only the saved economic costs of the part of the climate change that is due to the reductions of their own emissions that shall be counted. It may therefore be argued that the value is zero even for a country experiencing high costs from climate change. The climate change may have considerable effects in the country, but as long as there is no connection between their own emissions and the climate effects, the true and isolated value of reduced emissions in the country would be zero.

On the other hand, current international efforts to avoid climate change may be an argument for applying another, higher value. In a situation without international trade in emission rights, the value of reduced emissions may thus be set by the individual countries as an integral part of their objectives and policies regarding national reduction of carbon emissions.

4.4.4.1 Current practises

The usual way of assessing the benefits of reduced carbon emissions in economic studies, as mentioned, is to attach the current market price of carbon emission quotas to the reduced number of tonnes carbon emitted, but often the aspect is just neglected. A third approach is to use an estimated global value of carbon emissions as the economic value.

[66] World Bank 1998: Handbook on Economic Analysis of Investment Options

The World Bank does not suggest any specific methods for estimating the effects of carbon emission but addresses the need to include environmental externalities in economic Cost Benefit Analysis[67].

The Asian Development bank suggests a more concrete approach in their Guidelines for Cost Benefit Analysis from 2013. They refer to Nordhaus and Stein, among others, and their use of integrated assessment models. They however also acknowledge the lack of one precise estimate, when it comes to determining the social cost of carbon, following in particular from the lack of consensus on the social discounting rate[68].

4.4.4.2 The market price method

The use of the current international price of quotas makes sense as long as carbon emission rights were traded internationally and as long as excess quotas could be sold at the international market. However, after the Paris Convention on Climate Change this may no longer take place except at the voluntary market and in markets where quota systems still prevail internally. With a new regime, it is most likely that the price of carbon emission rights will fall drastically (which has already taken place) and fall below any estimate of the global, social value of carbon emissions. It is therefore suggested that an estimated global, social value may be used as the economic value of reduced emissions.

An argument against such a practice is that the global social value of carbon emissions is not the value to the country in which a project is planned. For the individual country, the costs of climate change may be considerable, but the isolated value of reducing carbon emissions per ton will still be extremely low for the individual country. This is a typical "free rider" case, (where those who benefit from resources, goods, or services do not pay for them, which results in an under-provision of such goods or services). There is thus a strong incentive for the individual countries not to take the costs of emissions into account as the economic cost per tonne of their own higher emissions will be very limited.

In markets where a quota system still prevails, the use of the market price method still makes sense, but current prices are low.

4.4.4.3 The estimated social value of carbon emissions

The social cost of carbon emissions is usually defined as the net present value of climate change impacts over the next hundred years or more, of one additional tonne of carbon emitted today; that is, the marginal global damage cost of carbon emission[69]. Extensive research work has been done over recent years, but this has not resulted in any good and mutually agreed unit value of reducing carbon emissions.

Research literature on the social cost of carbon emissions focuses mainly on integrated assessment models. These models are general equilibrium models based on the Ramsey model[70] including climate investments as an optimization parameter. A general equilibrium model is a macro econometric model, the aim of which is to determine the optimal path of growth for different variables in the long term. It is composed of a number of equations that depend on the same input parameters or starting values. These input values are typically economic growth rates, real interest rate, consumption, and for this type of models various climate data such as climate temperature sensitivity coefficients[71]. The model is solved by first setting up a number of equations or equilibrium conditions, plugging in the input parameters and then performing numerical optimization to find the optimal growth path that satisfies all the equilibrium conditions.

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[67] Handbook on Economic Analysis of Investment Operations, The World Bank (1998)
[68] The rate of time preference in regards to social costs and/or externalities
[69] The Impacts and Costs of Climate Change, Watkiss (2005)
[70] The Ramsey model is a neoclassical growth model based on the work of Frank P. Ramsey
[71] Estimates of the Social Cost of Carbon: Concepts and Results from the DICE-2013R Model and Alternative Approaches, Nordhaus (2014)

The integrated assessment models include the DICE model (Dynamic Integrated Model of Climate and the Economy), the PAGE model (Policy Analysis of the Greenhouse Effect) and the FUND model (Framework for Uncertainty, Negotiation and Distribution).

Some research papers use willingness-to-pay studies to determine the cost of carbon emissions. To place this in an African context we have looked at a study from Schiphol airport in Amsterdam, where the cost of carbon emissions is examined for airline passengers from all parts of the world, and the effect of regionality on the willingness-to-pay for carbon emission is also examined. This showed that the average price of 25 €/tC, that passengers are willing to pay to compensate for their carbon emission, is a valid estimate, also for international travellers from the African region.

The main objective of these different methods is to determine a unit price for the social cost of carbon, which can then be used for policy evaluation of different alternatives. There is, however, a great amount of uncertainty, and the methods and models vary a lot in their levels of sophistication and to what extent they specify climate consequences of carbon emission[72].

This is reflected in the very different estimates of the social cost of carbon emissions, varying from smaller negative prices up to several hundred dollars per ton of carbon.

Table 4-4: Research based estimates of the economic value of reduced carbon emissions

Source	SCC estimate	Model type
Investing.com	5 €/tC	Market price
LSE (2016)	31 €/tC	DICE – IAM
Nordhaus (2014)	18.6 $/tC	RICE (extension of DICE)
OECD – Watkiss (2005)	75 £/tC	FUND – IAM
OECD – Watkiss (2005)	61 £/tC	PAGE – IAM
Brouwer (2008)	25 €/tC	WTP study
Stern et al (2006)	314 $/tC	PAGE – IAM

In a highly quoted article by Clarkson and Deyes, the authors sum up the many different social cost of carbon estimates they have seen over time. They narrow it down to the wide interval of 9-197 $/tC[73]. In another meta-study by Richard Tol the estimates vary from -2.5 up to 1,666 $/tC[74]. This shows the huge uncertainties that dominate this field.

A paper on the social cost of carbon by Nordhaus (2014), which is mentioned in both the Asian Development Bank's Guidelines for Cost Benefit Analysis and in a number of different papers on the social cost of carbon, concludes that the unit social cost of carbon emissions, determined on the basis of model calculations can be estimated at $18.6 per ton. As this figure has received a broad methodological back-up, we suggest that this unit value be used in the economic analysis of transport projects until better estimates may occur.

4.4.5 Value of cleaner air

An important benefit of many transport projects and in particular urban projects is the resulting impact on air quality. Cleaner air has a positive impact on the health of citizens and frequent visitors, which may be estimated, quantified and valued. Air pollution consists of a number of various emissions that are presenting risks to health.

[72] A global warming damage function must be specified and included in the model
[73] Estimating the Social Cost of Carbon Emission, Clarkson & Deyes (2002)
[74] The Social Cost of Carbon: Trends, Outliers and Catastrophes, Tol (2008)

Fine particulates or particulate matter is usually assumed to be the most harmful pollutant and threat to public health, and it is therefore the focus in this study. Other pollutants like ozone nitrogen dioxide, sulphur dioxide, and lead, are less important and more difficult to quantify and they are therefore not included in the study. Their roughly estimated impact, however, may be included as a percentage of the estimated morbidity effect of pm.

Other impacts of pollution are the acidification of soils and freshwater systems and the damage of buildings, constructions and monuments, the reduction of which are also disregarded here because of the limited importance in the overall picture.

Particulate matter emissions have very well-documented effects on mortality and morbidity both from short-term and long-term exposures.[75] It is therefore important to include this in the estimation of benefits of low carbon transport sector projects in order to get a more complete picture of the important elements of costs and benefits of such projects.

Long term exposure to $PM_{2.5}$ increases mortality primarily due to cardiopulmonary and lung cancer, and PM_{10} increases mortality due to respiratory diseases and morbidity primarily due to chronic bronchitis, lower respiratory illness in children, and other respiratory symptoms. To be able to include these health effects in a CBA, they have to be quantified and monetarised.

Our methodology, which is inspired by the World Bank and Ostro[76], can briefly be summarized in the following 5 steps.

a) Monitoring data on air pollution

The current (baseline) $PM_{2.5}$ and PM_{10} levels in Abidjan and expected reductions in these as a result of the lower particulate matter emissions that may follow the implementation of a given transport project.

b) Estimation of the number of people in the exposed areas

The total population in Abidjan was 4.7 million in 2016, which constituted about 20 % of the total population in Cote d'Ivoire. The size of the population in the areas that are affected by a given project and hence exposed to changes in $PM_{2.5}$ and PM_{10} concentrations depends on the character of the project and the spatial distribution of residential areas and spatial movements of individuals. This is a difficult parameter to estimate with any high accuracy, and the amount of people affected will often have to be a rough percentage estimate based on the more detailed description of the projects in question.

c) Assessing health impacts

The health impacts that follow from a reduction in the $PM_{2.5}$ and PM_{10} are estimated with the use of exposure-response functions to set up of coefficients for various health impacts and epidemiological data.

On the basis of previous works, the main health impacts from exposure to $PM_{2.5}$ and PM_{10} on mortality and morbidity are estimated for the following categories of cases.

[75] Outdoor Air Polution, Ostro (2004)
[76] Kosovo – Country Environmental Analysis, The World Bank (2013), Outdoor Air Polution, Ostro (2004)

Table 4-5: Main health impacts from exposure to $PM_{2.5}$ and PM_{10}

Mortality cases	Morbidity cases
• Cardiopulmonary (CP) mortality • Lung cancer (LC) mortality • Mortality due to acute lower respiratory infections (ALRI) among children under the age of 5	• Chronic bronchitis • Respiratory hospital admissions • Emergency room visits • Restricted activity days • Lower respiratory illness in children • Respiratory symptoms

The change in mortality rates due to a change in PM-emissions (Relative Risks or RR) are calculated using exposure-response functions for long-term exposure to $PM_{2.5}$ and PM_{10} provided by Ostro (2004). These indicate how much impact 1 µg/m³[77] of PM will have on the mentioned mortality rates:

- RR (CP): exp(0.00893*(µg/m³ $PM_{2.5}$ above baseline)
- RR (LC): exp(0.01267*(µg/m³ $PM_{2.5}$ above baseline)
- RR (ALRI): exp(0.00166*(µg/m³ PM_{10} above baseline)

Using relative risk calculations[78], available data on the current mortality rates from the Institute for Health Metrics and Evaluation (IHME)[79], and estimates of the PM concentrations before and after a project, estimates of the resulting reductions in the number of cases of cardiopulmonary mortality, lung cancer mortality and mortality due to lower respiratory illness in children under the age of 5, attributable to the reduced air pollution in terms of PM-emissions are determined.

We make use of demographic and health related data for Cote d'Ivoire as Abidjan data has not been available. According to Index Mundi, the crude death rate is 9.4 per 1,000 population, and the number of deaths among children under five is estimated at (extrapolated) 97.9 per 1,000 live births. Data on death causes have been collected from IHME (2016), and the following key figures have been determined.

Table 4-6: Mortality data for Cote d'Ivoire

	Deaths/100K	Mortality share
Tracheal, Bronchus and Lung cancer	3.9/100K	0.41% of total
Cardiovascular diseases	85.7/100K	12.06% of total
Lower respiratory infections, u.5	251.5/deaths u 5	9.11% of u.5

Source: https://vizhub.healthdata.org/cod/

To estimate morbidity as a consequence of lower PM_{10} emissions we use the exposure-response coefficients, suggested by Ostro (1994) and Abbey et al (1995). Exposure-response coefficients describe the change in effect on an organism caused by different levels of exposure to a stressor after a certain exposure time. They are here a measure of, how much impact 1 µg/m3 of PM_{10} will have on the number of the above-mentioned morbidity cases. This may apply to individuals (e.g.: a small amount has no significant effect, a large amount is fatal), or to populations (e.g.: how many people or organisms are affected at different levels of exposure?

[77] 1 µg is one micro gram or 0,000001 gram
[78] (RR-1)/RR
[79] https://vizhub.healthdata.org/cod/

Table 4-7: Morbidity exposure response coefficients

Health impacts (PM10)	Impact per 1 µg/m3
Chronic bronchitis per 100,000 adults	0.9
Hospital admissions per 100,000 population	1.2
Emergency room visits per 100,000 population	23.5
Restricted activity days per 100,000 adults	5,750
Lower respiratory illness in children per 100,000 children	169
Respiratory symptoms per 100,000 adults	18,300

Source (Abbey & et al., 1995), (Ostro, 1994)

d) Estimation of physical health impacts

The estimates of reduced numbers of mortality and morbidity cases can then be converted into a common measure to better allow for comparison between different low emission initiatives.

A common measure of impacts on mortality and morbidity is achieved by converting both types of health impacts into *disability adjusted life years* (DALYs). The applied approach was suggested by Murray & Lopez (1996) and is now widely used to establish such common measures.

The following estimates of DALY's per mortality and morbidity cases are applied. Similar estimates have been used by a number of World Bank studies of costs of environmental degradation. Some studies add about a third to the morbidity impacts in order to take the impacts of other air pollutants into account.

Table 4-8: DALY's per mortality and morbidity cases

	DALYs pr. case
CP mortality DALY per case	8
LC mortality DALY per case	8
ALRI mortality DALY per case	34.0
Chronic bronchitis DALY per case	2.200000
Respiratory hospital admissions DALY per case	0.016000
Emergency room visits DALY per case	0.004500
Restricted activity days DALY per case	0.000300
Lower respiratory illness in children DALY per case	0.006500
Respiratory symptoms DALY per case	0.000075

Source: The World Bank (2013) for mortality and Bjorn Larsen (2004) for morbidity

e) Translation of impacts into monetary terms

The economic valuation of health impacts requires a transformation from physical cases into a monetary assessment, which is facilitated by the use of DALYs as suggested by Murray & Lopez (1996). DALYs may be converted into monetary terms by alternative methods. We suggest the Human Capital approach according to which the economic value of one DALY is equal to the annual GDP per capita.[80]. In comparison with other methods, the Human Capital Approach is a rather conservative approach.

The GDP per capita in Cote d'Ivoire according to the data portal Index Mundi was 3600 USD, corresponding to 1,972,008 XOF (West African Francs), with an exchange rate of 547.778 (September 2017).

[80] (WHO), D.W. Brown (2008) http://media.marketwire.com/attachments/EZIR/627/18192_FinalJournalManuscript.pdf

4.4.6 Accident costs

In a CBA, the reduction of traffic accident cost that may be caused by a transport project shall be included as a benefit. Traffic accident costs include the economic value of the resulting loss of lifes as well as cost to police and rescue, medical treatment, loss of earnings, and loss of life quality due to disability and/or restricted activity.

The estimation of accident costs, however, is outside the scope of this study.

4.5 Cost Benefit Analysis of selected low emission transport projects

According to the SDUGA Master Plan (Schema Directeur Urbanisme du grand Abidjan), traffic congestion is already a serious and widespread issue. Many transport projects have been planned, but they are yet to be implemented. From 2007 to 2011 the registered number of cars in Abidjan grew by 8-10 % per year, increasing the pressure on the existing road network considerably and hence leading to intensifying congestion, air pollution and increased carbon emissions.

In the following, two transport projects shall be briefly described and be subject to a simple Cost Benefit Analysis, where the economic impacts, including both investment and operating costs and the expected impacts on congestion, air pollution and carbon emissions are assessed and taken into account in a comparison to respective baseline situations.

These projects will only be designed at a level of detail that allows an assessment of very overall costs and benefits, sufficient to illustrate the CBA process and the interpretation of the applied methodologies for the quantification and assessment of various types of benefits of the respective transport projects of results and conclusions concerning the relevance and relative economic viability of the projects and to illustrate.

Alternative transport projects have been selected to create an exercise of benefit estimation and Cost Benefit Analysis. As mentioned, the projects will not be designed in all details, and as the necessary data have not been available, the calculations are done on the basis of assumed project impacts and unit prices. The main aim is here to illustrate how the economic assessment is done and how the various types of benefits of alternative transport systems may be quantified and assessed and included in the overall CBA.

The following two alternative projects have been selected for the illustration of the use of Cost Benefit Analysis:

1. Replacement of old vehicles with new ones
2. A metro in Abidjan

A presentation of the economic analysis of the two projects is given in the following.

4.5.1 Replacement of old gbakas with new vehicles

There are more than 6,000 authorized gbakas in the streets of Abidjan, with an estimated average age of 15 years. The gbakas are diesel fueled minibuses, and due to their age, they are categorized by a high fuel consumption and thereby high emissions of carbon and particulate matter.

Replacement of all 6,000 gbakas may therefore be justified by the impacts in terms of reduced fuel consumption and resulting reductions of Carbon emissions and cleaner air. A simple cost benefit analysis (CBA) is undertaken in the following to roughly assess the main benefits of this in comparison with the costs of new vehicles and hence the economic viability of such an action.

The replacement of the gbakas is compared with a baseline scenario in order to estimate costs and benefits. In the replacement scenario, the old gbakas are replaced with similar new vehicles requiring less fuel, lower operational costs, and lower emissions, whereas in the baseline scenario, we assume that the existing fleet of gbakas remains unchanged in the sense that the 6,000 vehicles are maintained to keep the average performance constant as experienced today.

The CBA shall indicate, whether the present value of benefits over the planning period are higher than the upfront costs of replacing the old gbaka vehicle fleet.

4.5.1.1 Investment costs

The new gbakas should fulfill the same purpose as the old ones and have a comparable passenger capacity. The gbakas have a capacity of approximately 14–32 seats. An 18 seat Toyota Dyna is assumed to represent the typical gbaka. An alternative to the old Toyota Dyna could be a Toyota Hiace minibus with 15 seats. This model does not have identical seating capacity, but we assume that it is close enough to be a good representative for replacement vehicles.

The new Toyota Hiace comes at an approximate price of 25 thousand USD which means that replacing 6,000 gbakas requires a total investment cost of 150 million USD. It is further assumed that the average value of the old gbakas is about zero, and the capital investment required for the replacement therefore corresponds to the price of the new vehicles.

Table 4-9: Investment cost in new gbakas

Replaced gbakas (Toyota Hiace)	6,000
Price per new vehicle (1,000 USD)	25
Scrap value of replaced gbakas (1,000 USD)	0
Total investment cost (1,000 USD)	**150.000**

4.5.1.2 Operating savings

The new gbakas have a lower fuel consumption and is assumed to have a lower maintenance costs than the old ones. The vehicles of the current fleet of gbakas are expected to consume 20 l/100 km on average. The new Toyota Hiace minibuses are listed by Toyota to have a diesel consumption of 8.9 l/100 km. In addition to fuel consumption, the old gbakas are more expensive in terms of annual repair and maintenance costs. The difference is conservatively assumed to amount to one percent of the price of a new Toyota Hiace, or 250 USD per year. For 6,000 gbakas this amounts to 1.5 million USD per year.

The new gbakas drive the same fixed routes, and perform the same annual mileage and average number of passengers as the old ones in the baseline scenario. The replacement of gbakas, therefore, is not expected to have any significant impact on congestion, travel time, or on the number of traffic accidents throughout the analysis period.

The average annual mileage per gbaka is assumed to be about 60 thousand km, and the current fuel price (as factor price) is assumed to be 0.89 USD per liter. With these assumptions, the annual fuel costs for the baseline scenario and the project alternative are as described in Table 4-10. These costs are assumed to remain unchanged during the five-year analysis period.

Table 4-10: Fuel and other operating savings

	Annual fuel costs (1,000 USD/year)	Annual other operating costs (1,000 USD/year)	Annual total operating costs (1,000 USD/year)
Baseline (without replacement)	64,777	-	-
Project (with replacement)	28,826	-	-
Difference (baseline - project)	**35,951**	**1,500**	**-37,451**

Source: Own estimates based on assumption of annual gbaka mileage, diesel consumption and prices as well as general assumptions regarding other operational costs such as maintenance.

4.5.1.3 Carbon emission savings

In addition to the direct benefit to the operator of the gbakas, the reduced fuel consumption also contributes with a climate benefit through lowered climate costs from saved emissions.

The estimate of the annual costs of Carbon emissions are based on the assumption that a liter of diesel results in 0.0026 tons of CO2 emitted and the economic costs of Carbon emissions have been estimated at 18.6 USD per ton. The resulting carbon emission costs are shown in Table 4-11.

Table 4-11: Annual CO2 emission savings

	CO2 emission (Tons)	Costs emission costs (1,000 USD/year)
Baseline scenario (without replacement)	193,182	3,593
Project Alternative (with replacement)	85,966	1,599
Difference (baseline - project)	107,216	1,994

Source: Estimations based on own assumptions

4.5.1.4 Air and health benefits

The reduced fuel consumption further contributes to an improved urban air quality and hence with health benefits for the population of Abidjan. The most important health impact from the traffic stems from the emissions of particulate matter (PM_{10} and $PM_{2.5}$).

With the assumption of an average annual mileage per gbaka of slightly more than 60,000 km the reduced PM_{10} and $PM_{2.5}$ emissions as a result of the replacement of 6,000 gbakas are estimated as reported in table 12 based on emissions calculation and dispersion modeling[81].

Table 4-12: PM emission and concentration with and without new gbakas

Vehicle		PM emission (kg/km)	Annual PM emission (kg/year)	PM concentration (µG/M³)
$PM_{2.5}$	Old fleet	0.3660	133,927	0.115
	New Fleet	0.0766	28,029	0.014
PM_{10}	Old fleet	0.3280	120,022	0.131
	New Fleet	0.0387	14,161	0.027

Source: Ramboll estimates

The reduction in the PM emissions from gbakas in Abidjan is assumed to affect the air quality for all the 4.7 million inhabitants of Abidjan and an urban area of 422 km^2. As described in an earlier section, the impacts of lower PM emissions are measured in terms of a reduced number of Disability Adjusted Life Years (DALYs) lost per year. The resulting health benefits as shown in table 13 are estimated at 56.43 DALY's per year resulting in an annual economic value of 200 thousand USD. To take other pollutants other than PM2.5 and PM10 into account additional 33 % morbidity have been added. The total amount of DALY's saved per year then becomes 62.42 which is equal to an economic value of 228 thousand USD per year.

[81] Using the COPERT 5 emissions calculation tool and the ADMS dispersion model

Table 4-13: Change in DALYs per year and annual economic value of improved health

	DALYS per year	Economic Value (1,000 USD/year)
CP mortality	27.51	97
LC mortality	1.77	6
ALRI mortality	8.98	32
Chronic bronchitis	6.08	21
Respiratory hospital admissions	0.09	0,3
Emergency room visits	0.51	2
Restricted activity days	5.29	19
Lower respiratory illness in children	1.98	7
Respiratory symptoms	4.21	15
Total, PM2.5 and PM10	**56.43**	**200**
Other pollutants influence on morbidity	5.99	21
Total pollutant influence	**62.42**	**221**

Source: Ramboll Management Consulting, based on estimates and assumptions

4.5.1.5 Conclusion

Table 4-14 shows the overall results of the economic analysis. The present values of investment costs and of the benefits in terms of saved fuel costs, other saved operating costs, CO2 emission savings and air & health benefits.

Table 4-14: Net present value, in 1,000 USD

	NPV - 1,000 USD
Investment costs	-150,000
Total costs	**-150,000**
Fuel savings	142,757
Other operating savings	6,945
Carbon emissions savings	7,919
Health benefits	1,241
Total benefits	**158,862**
Net present value	**8,862**
Benefit-cost ratio	**1.06**

As it is seen from table 14, the gbakas replacement project has a positive net present value indicating that the project is economically viable. This is also seen from the benefit-cost ratio which is above one which is the case when benefits exceed the costs incurred. The benefit-cost ratio indicates that for each economic cost incurred the society can expect to receive total benefits exceeding the cost by 6 %.

It is observed that the estimated value of the health effect, although it is almost 14% of the NPV, is rather modest in comparison with the value of other impacts. There may, however, be several reasons for that. At first, the project is quite limited in comparison with the number of vehicles in the streets of Abidjan,

Next, the estimation has been based on rather uncertain data and assumptions concerning the health situation in Abidjan, where national figures have been applied, and concerning the potential fuel consumption and PM emissions before and after the replacement of gbakas.

The total PM contents in the air in Abidjan is at least 20 to 30 times higher than the reduction that has been assumed here. Finally, a homogenous spatial distribution of the population in Abidjan has been assumed, and in reality, there is most likely a higher concentration in areas where the pollution is highest.

4.5.1.6 Sensitivity

To determine the robustness of the analysis to variations in some of the key parameter assumptions a sensitivity analysis has been conducted. The analysis shows the sensitivity of the estimated NPV of the project to variations in the following parameters.

- Value of time
- Investment in capital
- Real interest rate
- Fuel consumption of old gbakas
- Fuel price
- CO2 emissions per liter fuel

The alternative assumptions and the resulting variation in NPV are shown in Table 4-15.

Table 4-15: Sensitivity (NPV in 1,000 USD)

	NPV – 1,000 USD 2017	
	low	High
Main result	**8,862**	
Investment cost (+10%/-10%)	-6.138	23.862
Real interest rate (5%/3%)	6.692	11.093
Fuel consumption (18 km per l / 22 km per l)	-22.792	40.517
Fuel price (-10%/+10%)	-5.413	23.138
CO2 emissions (0.002/0.0033 tons per liter fuel)	6,945	10,845

The conclusion is that the resulting NPV of the project is quite robust to changes in the selected parameters, but that the achievable savings in fuel consumption is very important for the result.

4.5.2 A Metro project

The Abidjan Metro project (also called Abidjan Urban Train project) is a proposed metro-type urban rail network that will serve the Abidjan area, from Anyama in the north to Félix-Houphouët-Boigny international airport in the south, via the business district. Implementation of a metro line is expected to change the mode of transportation for the citizen of Abidjan moving traffic from the roads to the public transportation system.

The costs of the project will be investments, operating and maintenance costs, and the benefits will consist of the value of saved time spent in the traffic by the users of the metro and their saved vehicle operating costs, as well as the time saved by other travellers when the road congestion is eased as a result of the metro. Depending on the assumptions concerning the generation of power for the metro, environmental impacts in terms of lower carbon emissions and cleaner air may also be foreseen.

4.5.2.1 Investment, operational and maintenance costs

Construction of a metro line requires major investments in rail network, platforms and rolling stock. According to the Abidjan urban master plan the first phase of the metro line is estimated to total cost of 1,352 million USD where 75% of these, i.e. 1,014 million USD, are assumed to relate to capital investments. These investment costs are expected to be spread equally between the four years prior to operation start.

Rail, platforms and rolling stock requires regular maintenance, and keeping a metro line running requires personnel, fuel and other operating costs. The Abidjan master plan assumes an annual operational and maintenance costs related to the metro project (phase 1) of approximately 108 million USD.

4.5.2.2 User Benefits

The metro project will affect the transportation time and costs of travellers in Abidjan. Some will gain from changing their transportation mode and use the new metro, and others will gain from the reduced traffic congestion that is expected as a result of this project.

If traffic model calculations were available these would provide the time and travel cost savings per mode of transportation, but in this case the benefits are determined, mainly based on own estimates and assumptions.

Time savings

About 300,000 passengers per day is expected to use the metro. The demand is expected to increase during the first years of operation to reach a full capacity of 500,000 after five years of operation. Half of the metro passengers are assumed to be changing from transport in passenger cars. These passengers will save time, depending on the duration of their alternative transport patterns. They are here assumed to save on average approximately 13 minutes per trip, corresponding to an 8-km. urban trip by car, some may save more, others less. This gives a total time saving of the users of the metro of 12 million hours per year in the first year of operation and with an estimated value per saved hour of 1.8 USD[82] this results in an economic value of approximately 22.7 million USD during the first year of operation. The second half of the metro passengers, changing from other modes of transportation (e.g. walking or public transportation) are assumed to have a benefit of half of those changing from car to metro. These passengers will then have a benefit of 11.4 million USD in the first year of operation.

The metro will also save time for other travellers in the city of Abidjan as the traffic congestion must be expected to be eased a bit. Considering the composition and size of the urban traffic and assuming an average speed increasing from 34 km/hour to 35 km/hour after inauguration of the metro, the total time savings from the higher speed will be approximately 17.9 million hours per year. This is further based on an assumption of 3 passengers per passenger vehicle and per taxi, one passenger per truck and 40 passengers per bus.

The time savings are assumed to increase at an annual growth rate of 7 % due to an increased traffic and the resulting intensification of the traffic congestion in the baseline scenario without the metro.

The value of an hour spent in the traffic is again estimated to be 1.8 USD, and the total estimated value of time saved due to the opening of a metro is thus 32.6 million USD during the first year of operation.

[82] This is estimated using international unit values adjusted to an Ivorian context by correcting for purchasing power (purchasing power parity as specified by the World Bank).

Vehicle operating cost savings

When traveling, a direct cost is incurred. The direct cost is determined as a unit cost per vehicle kilometre for each mode of transportation taking into account the costs of fuel, motor oil, tires, reparation, and maintenance.

The saved vehicle operating costs are saved by those users that change their mode of transportation from e.g. cars and taxis to the metro. 300,000 daily passenger are expected to take the metro instead of a car, a taxi, a bus, or a bicycle, but some of them may also have walked or not travelled at all, if the metro was not there.

We assume that half of the metro passengers would go by car (private or taxi) in the baseline situation without the metro, and that they would be on average 3 in a car. Thereby, 50,000 vehicle trips are saved during the first year and with the increased number of metro passengers, this would increase at more than 80,000 trips after five years. We assume that their trips would be an average of 8 kilometres, and that the average vehicle operating costs per kilometre is 0.25 USD.

Table 4-16: Vehicle cost savings first year of metro operations

Passengers per year, metro (1.000)	109,500
Car passengers changing to metro (1.000)	54,750
Car trips substituted by metro (1.000)	18,250
Kilometers saved in traffic (8 km per trip, 1.000)	146,000
Economic value (0.25 USD per trip, 1.000 USD)	**36,500**

4.5.2.3 External benefits

Two types of externalities are considered: CO2 emission and air quality which is affected by changes in the emissions of particulate matter.

The effects of the project on carbon emissions and on the emissions of particulate matter depends on the reduction of the vehicle mileage and on the power generation for the metro.

Considering that carbon emissions will increase as a result of the activities during the construction phase and afterwards during operations as long as the power for the metro is generated on the basis of fossil fuel, no reduction can be expected in the carbon emissions. However, the PM emissions are assumed to decrease and hence improve the air quality, due to the reduction in the use of vehicles. It is assumed that the increased power generation takes place outside the city of Abidjan. The estimated impact on air quality is shown in the table below

Table 4-17: Emission and particulate matter with and without the metro during the first year of operation

Pollutant µg/m^3	2020 without Metro	2020 with the Metro (due to traffic limitation)	2020 with metro (traffic + congestion limitation)	Difference
PM_{10}	1.941	1.867	1.713	0.228
$PM_{2.5}$	1.187	1.160	1.017	0.170

The resulting value of lower mortality and morbidity due to cleaner air has been estimated at 443,000 USD.

4.5.2.4 Conclusion

Table 4-18 shows the results of the economic analysis. The present values of investment costs and of the benefits in investment costs, operating costs, time savings, vehicle cost savings and air & health benefits.

Table 4-18: Net present value of costs and benefits

	NPV – 1.000 USD 2017
Investment costs	-956,966
Operating costs	-1,652,889
Total costs	**-2,609,855**
Time savings, metro	818,762
Vehicle cost savings, metro	875,872
Time savings, congestion	1,300,773
Emission	0
Particulate matter	6,804
Total benefit	**3,002,212**
Net present value	**392,356**
Benefit-cost ratio	**1.15**

As it is seen from Table 18, the NPV is positive, and the metro project is thus economically viable under the applied estimates and assumptions. This is the result of the assumptions on time savings, and in particular on the reduced congestion. The benefit-cost ratio indicates that for each economic cost incurred the society can expect to receive total benefits exceeding the cost by 15%. The uncertain input data, however, shall be underlined, and it shall be stressed that the calculations serve as an illustration rather than as a concrete assessment of the project.

4.5.2.5 Sensitivity

As the economic analysis involves some uncertainties there is a need for an assessment of the robustness of the analysis. The sensitivity of the resulting NPV to changes in the following uncertain parameters has therefore been analyzed.

- Investment in capital
- Real interest rate (the rate of return which can be expected from similar projects)
- Expected traffic growth
- Kilometers saved due to introduction of the metro line
- Value of time unit cost

Table 4-19 shows the sensitivity of the NPV to changes in the key assumptions. It is seen that the economic value of the project is very sensitive to the identified parameters and are changing considerably as a result of relatively minor changes in the parameter values. Especially the assumptions of the future traffic growth, the saved mileage per passenger, and the monetary value of time are important for the economic viability of the metro project.

Table 4-19: Sensitivity (NPV in 1,000 USD)

	NPV – 1,000 USD 2017	
	low	High
Main result	**392,356**	
Investment costs (+25%/-25%)	153,115	631,598
Real interest rate (5%/3%)	159,689	691,879
Annual traffic growth (4%/10%)	-72,731	1,206,414
Kilometers saved pr. metro passenger (6/10 km)	-31,302	816,015
Monetary value of time (1,6/2,0 USD/h)	138,549	604,980

5. REVIEW OF REGULATORY AND INSTITUTIONAL FRAMEWORK

5.1 Introduction

This chapter assesses the existing regulatory and institutional framework in the five cities as stipulated in the terms of reference. In effect, all the cities are covered by national legislation and predominantly governed by national institutions when it comes to air quality standards and transport emissions, so in that sense the findings in the assessment will often have a wider scope applicable for the country as whole.

The assessment is mostly based on a desktop review of existing legislation, policies and available organisational descriptions supplemented by brief interviews conducted on the ground with key stakeholders in the five cities.

The assessment is a so-called gap assessment where the findings are measured up against a number of pre-defined indicators, which are further elaborated in the methodology section below. The assessment part is completed by a recommendations part (in Chapter 6) where the identified gaps are addressed through a number of policy, regulatory and/or institutional initiatives or suggestions which apply to a number of the five cities.

5.2 Methodology

The methodology for the policy, regulatory and institutional review concerning emission monitoring in transport infrastructure development is based on pre-defined indicators with the objective of measuring the environmental compliance in the five cities. The indicators were assessed through desk research and interviews performed by Ramboll with the key stakeholders on the ground in the five cities. A targeted interview guide was developed and used for guiding the interviews and the stakeholders were identified and mapped in advance as part of the preparation for the interviews. The different key elements in the methodology are presented in the below.

5.2.1 Indicators

The first step in preparing for the data collection was to develop a set of indicators to measure the environmental performance in the five cities up against. Based on the nature and scope of the assignment the following indicators have been applied:

1. Existence of air quality standards
2. The access to relevant environmental data[83], statistics and information is adequate
3. The environmental legislation (framework) helps achieve the agreed standards
4. Environmental management is mainstreamed and well-integrated into the public-sector governance
5. The country/city has the required institutional capacity to handle transport emissions
6. The country/city has an effective and sustainable environmental monitoring system in place

The review was steered by these indicators and the subsequent interview guide was also a product of these indicators. The purpose of the review was to establish to which degree the cities were able to meet these standards. In many instances, the conditions applicable for the city is in fact applicable for the entire country (e.g. legal framework, environmental policies etc.).

[83] Relevant environmental data is defined as information related to air quality and emissions.

5.2.2 Interview guide

Based on the indicators above the next step was to develop an interview guide to be applied for the different interviews to be conducted with the relevant stakeholders in the field. The semi-structured interview guide applied in the field was as follows:

1. How are you measuring the air quality and air pollution today (i.e. how do you collect, store and analyse data concerning air pollution)?
2. How would you describe the access to environmental data and statistics in your city or country?
3. Could you give us an overview over how you manage air quality and transport emissions in your city?
4. Can you give any examples of how you have successfully shifted towards more efficient and greener transportation modes in your city?
5. Can you mention any initiatives you have taken to improve the quality of vehicles and fuels (e.g. sulphur reduction) in your city?
6. How do you coordinate environmental initiatives with other relevant stakeholders (and who are they)? Can you give any examples?
7. How would you assess your institutional capacity to manage air quality? What is working well and where are your struggling?
8. What are the currently available sources of financing for monitoring air pollution and/or environmentally friendly solutions?
9. Have you considered alternative sources of funding for monitoring air pollution and promoting environmentally friendly solutions? What could be a sustainable funding solution in your opinion?

The interview guide was used as the starting point for each interview, but alterations and deviations were made in the process based on the specific interview and the information provided during that interview.

5.2.3 Categories of stakeholders

As part of the desk research a **stakeholder mapping** exercise was also conducted, which resulted in a list of relevant stakeholder categories to meet and interview during the field work and data collection activities. The type of stakeholder available varied in the five cities, however, the main categories of respondents were the following:

- Ministry of Environment
- Environmental Agency
- City authority
- Air quality monitoring authority
- Ministry of Transport

5.3 Regulatory and institutional Assessments

5.3.1 Assessment Abidjan

The interviews in Abidjan were conducted in the period 20-25 July 2016. A list of the institutions and organisms interviewed (for all the cities) can be found in the annex to this report.

5.3.1.1 Legal and institutional framework

Prior to and after the field work and the interviews substantial desk research had been undertaken to assess the available legal framework and standards guiding the environmental management and air quality in Abidjan. The main legal documents reflected in this assessment can be seen in the table below:

Table 5-1: Legal overview

No.	Name of the Law	Date and Number of Issue
1	Law No 96-766 - The Environmental Code	3 October 1996
2	Law No 96-894 - Rules and procedures applicable to studies relating to the environmental impact of development projects	8 November 1996
3	Decree No 91-662 – Establishment of CIAPOL and determining its responsibilities, organisation and functioning	9 October 1991
4	Decree No 97-363 – Establishment of ANDE	9 July 1997

In the table below an overview of the key institutions relevant to air quality management in Abidjan and their overall responsibilities are presented.

Table 5-2: Institutional overview

Institution	Roles and Responsibilities
Ministry of Environment (Ministère de l'Environnement et du Développement Durable)	The Ministry is responsible for the implementation and monitoring of the government's environmental policy, urban safety, improvement of living conditions and sustainable development. This entails (among other things): • Planning and control of environmental policy, evaluation, study and plan; • Implementation of the Environmental Code and the law on Protection of Nature and Environment; • Management and monitoring of projects funded by the Global Environment Facility (GEF) and the United Nations Development Programme (UNDP);
CIAPOL (Centre Ivoirien Antipoluttion)	CIAPOL is responsible for (among other things): • Assessment of pollution and nuisances; • The establishment of a monitoring system called "National Network Observation - Ivory Coast (RNO-CI)" in relation to the various departments and agencies in the context of environmental protection; • Collection and capitalization of environmental data; • Dissemination of environmental data and results of the National Observation Network (RNO-CI); • Address pollution of the environment Issues.
ANDE (**Agence Nationale de l'Environnement)**	ANDE's roles and responsibilities are: • To coordinate the implementation of development projects of an environmental nature; • Build and manage a portfolio of environmental investments; • Ensure integration of environmental concerns into development projects and programs; • Ensure the establishment and management of a national environmental information system; • Implement the impact assessment process and the assessment of the environmental impact of macroeconomic policies; • Establish an ongoing relationship with NGO networks • Develop environmental profiles and local government management plans • Conduct environmental audit of works and undertakings • Educate, inform and communicate to the protection of the Environment.

Institution	Roles and Responsibilities
	The organigram of the Ministry is available on its official website[84].
BNETD (Bureau National d'Etudes Techniques et de Developpement)	Parastatal body under the President involved in (among other things) infrastructure and transport projects, e.g. impact studies, engineering work, advice and control in the implementation of major development projects.
Ministry of Transport (Ministère des Transports)	The Transport Ministry's main task, with regards to environmental management, is to monitor and implement the Government's policy on transport to modernize the transport system.
District Authority of Abidjan (District Autonome d'Abidjan)	The key overall responsibilities for the District Authority (among other things) are: • Environmental protection at the scale of the district; • Planning the management of the autonomous district; • The fight against the harmful effects of urbanization;

Based on the above institutional overview, the core functions of air quality management in Abidjan are allocated to the relevant institutions in the overview below:

Table 5-3: Overview of responsibilities

Air Quality Roles and Responsibilities	
Core Functions	**Institutional responsibility**
Overall policy development	Ministry of Environment
Planning and formulation of strategies	Ministry of Environment (national level), District Authority (local level)
Formulation of legislation	Ministry of Environment
Monitoring/assessing performance	Centre Ivoirien Anti-Pollution (CIAPOL)
Measurement/data collection	Centre Ivoirien Anti-Pollution (CIAPOL)
Dissemination of public information	CIAPOL (and Environmental Agency - ANDE)
Impact studies of major infrastructure projects	The National Engineering Office (BNETD)

5.3.1.2 Main findings

- **Indicator 1: Existence of air quality and vehicle emissions standards**

  There is currently no specific regulation or prescriptions concerning air quality standards in Ivory Coast and Abidjan. According to the Ministry of Environment a decree encompassing air quality norms should be approved by the government "soon", which could then be integrated into a law.

  Nevertheless, during the data collection for this assessment it has not been possible to document the existence of any air quality standards or data and consequently the assessment finds that there is currently a clear gap when it comes to air quality standards and air quality monitoring in Abidjan (and in Ivory Coast).

[84] http://environnement.gouv.ci/organigramme.php

- **Indicator 2: The access to relevant environmental data, statistics and information is adequate**
  As there is currently very limited environmental data available with regards to monitoring emissions and air quality, the access to relevant environmental information cannot be said to be adequate. According to Decree 91-662 CIAPOL is supposed to collect and disseminate environmental data, but without specifying the type of data that has to be processed. In any case, CIAPOL is not publishing environmental data in relation to air quality or emissions for Abidjan, and consequently the access to relevant environmental data is limited. Currently, several research works related to Air Pollution in Abidjan are performed by the LAPA ("Laboratoire de Physique de l'Atmosphère", University Felix Houphouet Boigny), especially in the framework of the DACCIWA[85] international program. So far, only limited air pollution datasets have been published and are available for the public.

- **Indicator 3: The environmental legislation (framework) helps achieve the agreed standards**
  The Environmental Code is the main document guiding environmental management including air quality. The code includes definitions in relation to air and pollution, but other than that Articles 20, 57, 74 and 79 there is little reference made specifically to Air. The Articles in the Law state general provisions, but do not provide guidance for more specific implementation, which is common for this type of Law.

  Article 20 states that "…motor vehicles…must be designed and operated in accordance with technical standards for preservation of the atmosphere". However, these "technical standards" are not defined in the Code or elsewhere in the legal framework. In Article 57 it is specified that the state determines the critical level for air pollution, but again this level could not be documented as part of our assessment. Article 74 stipulates that an observatory on the air quality should be created, and Article 79 that any emissions in the atmosphere that do not comply with regulations is forbidden. However, at what level those emissions would be forbidden could not be established by this assessment.

  Article 40 sets minimum standards for conducting Environmental Impact Assessments (EIA) and Law No 96-894 sets out the rules and procedures relating to the environmental impact of development projects. Article 5 of that law empowers the Ministry of Environment to decide whether an EIA is needed, while article 12 stipulates the content of an EIA. Annex 1 of the law provides a list of projects concerned by EIA. This list includes highway and urban projects. EIA, which must be performed by national experts (no more than 1/3 by international experts) is reviewed by the "Bureau d'étude d'impact environnemental", which is a part of ANDE. However, the content concerning air quality in EIAs of road and urban projects is generally limited and does not include a quantitative assessment.

  According to CIAPOL, the document "Stratégie Nationale de Développement Durable" has been developed, but it is yet to be approved by the government and can therefore not be said to give a clear strategic direction to the management of air quality in Abidjan yet. Ramboll was also not able to identify the updated national development plan ("Plan National de Développement de Côte d'Ivoire, 2016-2020"), which apparently has not been distributed publicly yet.

  To that effect, the environmental legislation and framework is considered to be rather weak when it comes to ensuring the air quality in Abidjan (and in Ivory Coast) because of the lack of relevant secondary legislation and any detailed provisions for the management of air quality and emissions.

[85] http://www.dacciwa.eu/

- **Indicator 4: Environmental management is mainstreamed and well-integrated into the public sector governance**
  The conducted interviews indicate that the Ministries of Transport and Environment do not work closely together and also that they see and prioritise environmental issues quite differently. As mentioned previously, it is explained that there is currently no operational monitoring network when it comes to measuring air quality. It is expected that CIAPOL will undertake a leading operational role in this regard, but they rely on the Ministry of Environment for funding and this area has not been prioritised so far.

  According to Degree 91-662 CIAPOL is administered by a Management Advisory Committee with 8 ministers, including the minister of transport or his representative. According to the "Schéma Directeur d'Urbanisme du Grand Abidjan" (SDUGA report, 2014)[86], CIAPOL's board is currently represented by 13 ministers, but notably without the Ministry of Transport on the board.

  According to discussions with the Ministry of Transport, replacement of old transport vehicles (e.g. replacement of 2000 old mini-buses or "Gbakas" by new Indian vehicles) was initially motivated by security reasons (decrease in number of accidents) and not by environmental Issues.

  The assessment finds that the effectiveness of the environmental management in relation to air quality and transport emissions could be improved with the Ministry of Transport being represented on the board and/or more specifically with a stronger cooperation and coordination mechanism between CIAPOL and the Ministry of Transport than what seems to be the case today.

- **Indicator 5: The country/city has the required institutional capacity to handle air pollution and transport emissions**
  The establishment of CIAPOL can be seen as an important step towards building the institutional capacity to handle air pollution and emissions. However, the SDUGA report states that CIAPOL has not been able to handle its monitoring responsibilities in relation to transport emissions and other domains. Apparently, data and documentation has been lost over the last 10 years as a result of the country's political crisis and CIAPOL does not have yet the appropriate equipment to ensure the monitoring of the pollution.

  This conclusion is confirmed by the interviews conducted by Ramboll in Abidjan for this project, where it is stated that CIAPOL does not yet have the capacity to do all the monitoring of air pollution. A possible explanation is also given, which is that emissions in Africa (especially GHGs) is still at a low level as a whole, and consequently there are only weak arguments and incentives supporting the allocation of resources and capacity building on this issue. This is confirmed by CIAPOL, who explains that comprehensive monitoring has not been a high priority so far. However, it seems that new projects

[86] The Urban Master Plan for Greater Abidjan (SDUGA), JICA/MCLAU, 2014

- **Indicator 6: The country/city has an effective and sustainable environmental monitoring system in place**
  According to CIAPOL there is currently no operational monitoring network in Abidjan and only some temporary measurements are being done. However, a number of upcoming initiatives in this area was mentioned such as the acquisition of a mobile laboratory by CIAPOL, new measurements to be conducted by Abidjan University (LAPA), and the establishment of an international research programme (DACCIWA project). The District Authority of Abidjan is also involved in different initiatives related to improving the air quality. A Partnership about Air Quality is currently building with the City of Nice in France and its Air Quality Agency Air PACA. Last but not least, the project "Abidjan Integrated Sustainable Urban Planning and Management", has recently been approved and a request for proposal was in the process of being launched at the time of writing this report. One of the planned activities in this project will be to develop a monitoring network for Abidjan.

  Note also that a traffic model has been developed for Abidjan in the framework of the SDUGA. This model allows to calculate traffic data for a baseline scenario (2017), but also for future scenarios including transport and infrastructure projects: Y4 Ring Road, Urban Train, new bridges,…That represents a crucial step as data provided by this model can be directly used to calculate air emissions and pollutants concentrations. It is important to highlight that this model is currently operated by the BNETD, which has the right capacities to run and maintain the tool. This data should be shared and used by CIAPOL and University FHB, but it is not currently the case.

  Based on the above findings it is clear that Abidjan does not have an effective and sustainable monitoring system in place yet. However a number of initiatives seem to be underway and the challenge will be to establish a system that will be utilised in a longer-term perspective with an appropriate and sustainable funding mechanism.

5.3.2 Assessment Rabat

The interviews in Rabat were conducted in the period 27-29 July 2016. A list of the interviews can be found in the annex to this report. Rémy Bouscaren, a French International Expert who has a large experience in the field in Morocco, has been interviewed during the same period.

5.3.2.1 Legal and institutional framework

Prior to the field work and the interviews substantial desk research had been undertaken to assess the available legal framework and standards guiding the environmental management and air quality in Rabat. The main documents reflected in this assessment are:

- Morocco Case Study Analysis of National Strategies for Sustainable Development, 2004;
- Environmental Performance Reviews – Morocco, United Nations, 2012-2013;
- « Recueil des lois relatives à l'environnement, Ministère délégué auprès du Ministère de l'Energie, des Mines, de l'Eau et de l'Environnement, chargé de l'Environnement » ;
- « Loi Cadre N°99612 Portant Charte Nationale de l'Environnement et du développement durable, Ministère délégué auprès du Ministère de l'Energie, des Mines, de l'Eau et de l'Environnement, chargé de l'Environnement ».

The Following documents have also been consulted to assess the local context:

- « Programme Pilote Qualit'Air : Accompagnement de la région Marrakech-Tensift-Al Haouz – Gourvernance et renforcement des capacités en matière de qualité de l'air », Fondation Mohammed 6, draft report 2014 ;
- « AUDIT du réseau de mesure de la Qualité de l'Air au Maroc », EnviroConsult Report, 2005.

Table 5-4: Legal overview

No.	Name of the Law	Date and Number of Issue
1	Dahir 1-03-59 of Law 11-03 – Protection and enhancement of the environment	12 May 2003
2	Dahir 1-03-60 of Law 12-03 – Environmental impact studies	12 May 2003
3	Dahir 1-03-61 of Law 13-03 – Fight against air pollution	12 May 2003
4	Dahir 1-14-09 of Law 99-12 – National charter for the environment and sustainable development	6 March 2014
5	Decree 2-09-286 – Settting the air quality standards and air monitoring arrangements	8 December 2009
6	Decree 2-09-631 – Fixing the emission limits of air pollution	6 July 2010

Table 5-5: Institutional overview

Institution	Roles and Responsibilities
Ministry of Environment (Ministère chargé de l'Environnement)	The Ministry is the overall responsible for monitoring, development and implementation of policies in the field of environment and sustainable development. This includes (among other things): • Elaboration of the national strategy of sustainable development and monitoring its implementation and evaluation, in coordination and collaboration with the ministerial departments concerned; • Proposal of draft laws and regulations on environmental protection and control of their application in accordance with the legislation in force; • Government representation in bilateral and multilateral negotiations in the field of environmental protection and sustainable development; • Participation in the development, implementation, monitoring and evaluation of national environmental programs in collaboration with relevant departments; • Establishment of structures for the observation and monitoring of the state of the environment and collecting environmental data and information at national and regional level in collaboration with relevant departments. Within the Ministry there is a specific department tasked with the prevention of air pollution ("Service pour la Prévention de la Pollution de l'Air"). This Department is a part of a wider division called "Division de la Prévention de la Lutte contre la Pollution". The organigram of the Ministry is presented on the Ministry website[87].
The National Council of the Environment (Conseil National de l'Environnement, CNE),	The main tasks of the CNE are: • To work towards the protection and improvement of the environment, the aim of which is to preserve the ecological balance of the natural environment, in particular water, soil, air, fauna, flora and landscape; • To prevent, tackle and reduce pollution and nuisances of all kinds; • To improve the framework and living conditions. Under the CNE are the Regional Councils of the Environment (CRE) and the Councils of Environment of the Wilayas with the responsibility of reporting and presenting annual reports on the local situation to the CNE.

[87] http://www.environnement.gov.ma/fr/secretariat-etat/2015-03-05-11-53-51/2015-03-05-11-58-41/organigramme

Institution	Roles and Responsibilities
The National Environmental Observatory (Observatoire National de l'Environnement et du Développement Durable, ONEM)	Under the Direction of the Observation, Studies and Planning of the Environment Ministry, the ONEM is in charge to: • Collect data and indicators, from national institutions and specialized bodies, related to the environment and sustainable development; • Adopt environmental data and information in the development of policies and tools; • Initiate and carry out specific studies and surveys on the environment in relation to sustainable development; • Publish and disseminate environmental information; • Promote programs of data exchange and partnership (national, regional and international); • Contribute to the development of the national strategy of sustainable development.
The National Laboratory (Laboratoire National des Etudes et de la Surveillance de la Pollution, LNESP)	Directly under the General Secretary, the National Labooratory: • Is in charge of studies and monitoring of pollution; • Controls the pollution in the framework of environment management plans; • Contributes to the international and national commitments; • Participates in the coordination of the network of laboratories operating in the field of the environment and contributes to the implementation of the emission standards; • Actively assuring public authorities for the resolution of certain environmental conflicts; • Contributes to the environmental upgrading of the private sector by providing the necessary analytical services.
National Directorate of Meteorology (Direction de la Météorologie Nationale, DMN)	As part of the memorandum of management of air quality monitoring stations established in January 2008 between the DMN and the National Laboratory (LNESP) under the authority of the Ministry, the management of all the stations is entrusted to the DMN, with a connection of all the stations to the central station located in the LNESP.

Table 5-6: Overview of responsibilities

Air Quality Roles and Responsibilities	
Core Functions	**Institutional responsibility**
Overall policy development	Ministry of Environment
Planning and formulation of strategies	Ministry of Environment
Formulation of legislation	Ministry of Environment
Monitoring/assessing performance	Ministry of Environment (National Monitoring and Surveillance Committee for Air Quality) and Regional Air Monitoring and Surveillance Committees (local level)
Measurement/data collection	National Directorate of Meteorology (DMN) and National Laboratory (LNESP)
Dissemination of public information	Ministry of Environment, National Directorate of Meteorology (DMN), National Environmental Observatory

5.3.3 Main findings

5.3.3.1 Indicator 1: Existence of air quality and vehicle emissions standards

Morocco, and therefore Rabat, has established sets of air quality standards including thresholds in an annex to Decree 2-09-286. Article 6 of the same Decree stipulates that the air quality thresholds are set jointly by the Ministry of Environment, Health and Interior after consultation with the Ministry of Transport, and Industry. Furthermore, the Decree establishes the modalities for the implementation of monitoring networks. Article 11 prescribes the mission of the network, which includes ensuring the functioning of monitoring stations, collecting air quality data and adopting measures to improve air quality.

Decree 2-09-631 sets the limit values for the emission of certain polluting substances emanating from fixed sources of pollution and defines the methods of their control.

One of the important standards relates to vehicles emissions. According to local information all new vehicles must be EURO 4 for both passenger cars and for heavy vehicles since 1 January 2015. Vehicles assembled in Morocco are supposedly subject to this requirement as of 1 January 2016. However, we have not been able to identify official documentation relating to this obligation.

Imported, used vehicles must be less than 5 years or they will not be registrable (after customs clearance services). Existing vehicles are subject to regulation which dates back to 1995.

We have not been able to find validated information concerning pollution controls. However, there was an important reform from 2007 attempting to reduce corruption in this area. Apparently, there is currently a reform of that reform as it has not worked as intended. Consequently, Morocco is still far from having reliable information on emissions of vehicles.

5.3.3.2 Indicator 2: The access to relevant environmental data, statistics and information is adequate

An annual national report containing air quality data for all regions is supposed to be published every year. However, according to our information the last available report dates back to from 2013, which gives an indication as to the access to updated reliable environmental data. In addition, weekly reporting of available air quality measurements is also published, but not all of these are publicly available, which again can be seen as a limitation to the accessibility of data.

An air quality forecasting system has been developed for Casablanca and air quality data is currently being produced and made public through the ”Direction de la Météorologie nationale” (DMN) website. The system should potentially also cover Rabat, but it has not provided information for a long time. According to the interview with the DMN, which operates the AQ monitoring network, the station in Rabat doesn’t work correctly and the values are not available/usable.

5.3.3.3 Indicator 3: The environmental legislation (framework) helps achieve the agreed standards

Dahir No. 1-14-09 sets the frame for the national sustainable development strategy. It declares that the government is responsible for the “continuous monitoring of the quality of the environment, the data collection, and dissemination of information relating to the state of the environment”.

Norms and standards are catered for in Law 11-03 on the protection and enhancement of the environment. In Article 57 the law specifies the creation of a national observatory of the environment and regional observing networks responsible for the control and continuous monitoring of the quality of the environment.

Law 12-03 defines the projects that should be subject to an environmental impact assessment (Article 2 and annex). Article 6 in the same law stipulates what the EIA should include while Article 8 establishes national and regional committees with the mandate to oversee the implementation. However, the air quality impact of road and urban projects is generally not considered.

In line with Article 35 in Law 99-12 a "Police de l'Environnement" has been created recently and is operational since February 2017, with 40 inspectors from the Environment Ministry and specific vehicles (Green and Black 4x4 vehicles). However, we were not able to assess their role and efficiency concerning traffic emissions.

Overall, the legal provisions and the institutional framework for air quality management in Rabat (and Morocco) is relatively detailed and considered to be sound. The challenge lies in the implementation of the legislative and institutional framework where it appears that e.g. the operation of the monitoring network for air quality in Rabat is not functioning. Also, there is a lack of secondary legislation to facilitate an effective implementation of the law. Furthermore, the laws do not provide explicit powers of inspection and enforcement to the environmental authorities[88].

Due to a lack of compliance control, environmental authorities prioritize regulatory culture largely based on negotiations, consensus-building and voluntary approaches[89].

5.3.3.4 Indicator 4: Environmental management is mainstreamed and well-integrated into the public sector governance

As mentioned under indicator 1 the air quality standards are established as a joint process which involves both the Ministry of Environment and the Ministry of Health and where the Ministry of Transport is consulted. In that sense, the formal cooperation is well-established.

Furthermore, according to Article 13 of the Decree 2-09-286 a national monitoring surveillance committee for air quality shall be set up in the Ministry of Environment to, among other things, ensure coordination and harmonization with regional air monitoring committees. These committees include several public sectors, such as Environment, Transport, Security, National Meteorology but also local authorities (Wilayas). However, it doesn't exist operational and regional air quality agencies administrated by several Ministries and local authorities and commissioned to handle air quality.

5.3.3.5 Indicator 5: The country/city has the required institutional capacity to handle air pollution and transport emissions

According to an expert interview the institutional capacity to handle air quality management and transport emissions in Rabat leaves room for improvement. Although delegation of a part of the maintenance of the equipment to a specialized sub-contractor, the DMN is in need of qualified staff to ensure proper maintenance of their equipment and in order to carry out the required validation activities.

A thorough review of weekly bulletins published by the DMN to Marrakech and Essaouira was done by Ramboll Environ and this examination revealed that some bulletins were missing and that the data available were not always robust.

[88] "Environmental Performance Reviews" for Morocco, UN, 2014
[89] Ibid.

5.3.3.6 Indicator 6: The country/city has an effective and sustainable environmental monitoring system in place

In Decree 2-09-286 Article 9 caters for an air quality monitoring network to be set up in every region. Article 13 ascertains the responsibility of the Ministry of Environment to establish a National Air Quality Monitoring Committee with the responsibility of monitoring the air quality and ensuring coordination between the standing air quality monitoring committees at the regional level. This entity should furthermore ensure the data collection procedure, the validation, exchange and dissemination of information.

In essence, this responsibility is placed in the hands of the National Environmental Observatory (ONEM), while the collection of data involves the National Directorate of Meteorology (DMN).

The DMN operates 29 stations in Morocco and 1 station in Rabat, but this last station has not been fully operational since 2009 and consequently DMN does not have data available for Rabat. This is not only a challenge for Rabat but also for other Moroccan cities. According to one of our interviews, the monitoring system for Marrakech is also affected by invalid data due to poor maintenance of the equipment and lack of validation activities, which also seems to be the case for Rabat. Consequently, air pollution data cannot always guide the decision-making process for air quality management.

In addition to the network, the National Directorate of Meteorology (DMN) in 2012 integrated an urban air modelling system for the greater Casablanca region, which is supposed to provide daily maps of the air pollution. The data is publicly available on the DMN website[90]. A similar system is scheduled to be rolled out in Marrakesh and Safi and potentially Rabat as well, but operated in this case by the Ministry of Environment.

A previously developed 10-year old national air quality modelling system (called MOCAGE Maroc and developed in collaboration with Meteo France) is no longer working and according to interviews the activity level of the DMN and the effectiveness of the monitoring system could be a challenge for the coming years.

5.3.4 Assessment Dar es Salaam

The interviews in Dar es Salaam were conducted in the period 5-8 September 2016.

5.3.4.1 Legal and institutional framework

Prior to and after the field work and the interviews substantial desk research had been undertaken to assess the available legal framework and standards guiding the environmental management and air quality in Dar es Salaam. The main documents reflected in this assessment are:

- The National Environmental Action Plan (NEAP) 2013-2018, 2013
- The National Environmental Policy, 1997
- National Transport Policy, 2003
- Sectoral Environmental Action Plan 2011-2016, Ministry of Works, 2011

[90] http://www.marocmeteo.ma/aircasa/public/

The main legal documents reflected in this assessment can be seen in the table below:

Table 5-7: Legal overview

No.	Name of the Law	Date and Number of Issue
1	The Environmental Management Act	No. 20 of 2004
2	The Environmental Management (Air Quality Standards) Regulation	2007

In the table below an overview of the key institutions relevant to air quality management in Dar es Salaam and their overall responsibilities are presented.

Table 5-8: Institutional overview

Institution	Roles and Responsibilities
The Vice President's Office – The Environment Division	The Division of Environment is responsible for the overall environmental policy and regulation, formulation, coordination and monitoring of environment policy implementation in the country. The Minister may issue general guidelines to the Sector Ministries and other Government Departments as well as local authorities for the purposes of implementation of or giving effect to the provisions of the Environmental Management Act. The Environment Division is responsible for coordination of national and international matters related to environmental conservation and management. The Division is led by a Director and comprises of three Sections (Environmental Natural Habitats Conservation, Management of Pollution, and Impact Assessment). The Director of Environment is responsible for preparing and issuing a report on the state of the environment in Tanzania.
National Environment Management Council (NEMC)	• Carry on environmental audit; • Undertake and co-ordinate research, investigation and surveys in the field of environment and collect, and disseminate information about the findings of such research, investigation or survey; • Enforce and ensure compliance of the national environmental quality standards; • Monitor emission concentration and nature of pollutants emitted; • Publish and disseminate manuals, codes or guidelines relating to environmental management and prevention or abatement of environmental degradation; • Render advice and technical support, where possible, to entities engaged in natural resources and environmental management so as to enable them to carry out their responsibilities.
National Environmental Advisory Committee (NEAC)	The NEAC is an advisory body to the Minister on all matters relating to the protection and management of the environment and environmental degradation. The NEAC reviews and advises on environmental standards, guidelines and regulations which are to be made pursuant to the provisions of the Environmental Management Act.
Ministry of Works, Transport and Communication (TANROADS)	The Ministry of Works is responsible for development and maintenance of roads, equipment and plants, bridges, safety and environment, ferries and Government buildings. This responsibility is handled by the TANROADS agency.
Dar es Salaam City Council	• Promote environmental awareness in the area on the protection of the environment and the conservation of natural resources; • Gather and manage information on the environment and utilization of natural resources in the area; • Prepare periodic reports on state of the local environment; • Monitor the preparation, review and approval of Environmental impact assessments for local investments.

Institution	Roles and Responsibilities
Tanzania Bureau of Standards **(National Environmental Standards Committee)**	Shall develop, review and submit to the Minister proposal for environmental standards and criteria in relation to air quality including: • Prescribe criteria and procedure for measurement for air quality; • Establish ambient air quality standards; • Establish occupational air quality standards; • Establish emission standard for various sources of air pollution; • Prescribe criteria and guidelines for air pollution control for both mobile and stationary sources; and • Prescribe any matter touching or affecting air emission quality standard.

Based on the above institutional overview, the core functions of air quality management in Dar es Salaam are allocated to the relevant institutions in the overview below:

Table 5-9: Overview of responsibilities

Air Quality Roles and Responsibilities	
Core Functions	**Institutional responsibility**
Overall policy development	VP's Office – The Environment Division
Planning and formulation of strategies	VP's Office – The Environment Division, NEMC, Local Government Authority, Sector ministries
Formulation of legislation	VP's Office – The Environment Division
Monitoring/assessing performance	NEMC, VP's Office – The Environment Division
Measurement/data collection	NEMC
Dissemination of public information	NEMC
Appeals mechanism	Environmental Appeals Tribunal (EAT)

5.3.5 Main findings

5.3.5.1 Indicator 1: Existence of air quality and vehicle emissions standards

Tanzania and therefore Dar es Salaam has established sets of emissions and air quality standards including thresholds in The Environmental Management (Air Quality Standards) Regulation of 2007[91]. The standards specify the different types of pollution and establish the limit level as well as the test method. That includes threshold values for ambient air quality and air emissions. It must be noted that limit values for vehicle emissions seems not consistent with the age of the vehicle fleet (65% of the vehicles are 15 years and above according to UNEP in 2011)[92].

According to an Environmental Impact Assessment Report on Air Quality in Dar es Salaam from 2012[93] Tanzania's approach to air quality is preventive and the limits for some parameters are relatively more stringent as compared to those of the more industrialized countries.

The National Environmental Standards Committee is responsible for the establishment of these standards and the Minister is tasked with publishing the information. However, it has not been possible to find any information or data confirming that the standards are used and adhered to.

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[91] http://extwprlegs1.fao.org/docs/pdf/tan151537.pdf
[92] Transport, Environnent and Development in Africa, National Workshop on Investments for people and Mobility, UNEP, October 2011.
[93] Air Quality Impact Assessment, Kinyerezi, Dar Es Salaam, Tanzania, 2012

5.3.5.2 Indicator 2: The access to relevant environmental data, statistics and information is adequate

The production of reliable and regularly updated environmental data in relation to air quality in Tanzania and in Dar es Salaam is limited, which is confirmed by the National Environmental Action Plan[94]. It appears that air quality assessments are carried out on an ad hoc or a project basis, e.g. in connection with Environmental Impact Assessments.

According to the interview with NEMC an air assessment survey was carried out between 2005 and 2007, but since then no such assessment has been carried out and material used is out of order. The interview indicated that the University of Dar es Salaam has a department dedicated to air quality research, but the team was unable to meet with them.

The Ministry of Transport publishes an annual Transport Statistical Report. However, the report from 2014 does not contain any data on transport emissions.

According to an older UNEP presentation from 2006 air pollution was at the time not seen as a serious problem in Tanzania due to the inadequate data and information on air pollution available to policy makers.

5.3.5.3 Indicator 3: The environmental legislation (framework) helps achieve the agreed standards

The environmental legislation is assessed to be sound and quite elaborate in terms of both the Environmental Management Act and Regulation containing stipulations on the air quality standards.

Section 8 in the Environmental Management Act concerns "Pollution Prevention and Control", but does not specifically address air pollution, unlike e.g. water pollution.

Section 16 in the Act on Compliance and Enforcement introduces the concept of environmental inspectors and it also proscribes offences in relation to environmental standards.

Section 18 establishes a National Environmental Trust Fund with the objective of strengthening environmental management.

In part II of the Regulation the National Standards Evaluation Committee and its role in setting minimum standard of air quality is established. These standards are included in schedules as part of the Regulation.

Though air quality compliance and enforcement is stipulated in part V of the Regulation, the main issue in Tanzania and Dar es Salaam seems to be the enforcement of the legislation and regulation, which appear to be weak. To that effect the environmental legislation sets a good framework for air quality management in Tanzania and Dar es Salaam but there is a need to utilize the available provisions better.

[94] National Environmental Action Plan (NEAP), 2013-2018; page 27.

5.3.5.4 Indicator 4: Environmental management is mainstreamed and well-integrated into the public sector governance

There are a number of different documents in addition to the legal framework that are supposedly guiding environmental management in Tanzania and Dar es Salaam. The National Environmental Policy (NEP) from 1997 encompasses strategic priorities for the area of transport (among other areas) and has an ambition of reducing pollution and controlling transport emission gases. Furthermore, chapter four of the NEP introduces environmental impact assessments as mandatory for all development projects. This requirement is further specified in the Environmental Management Act, chapter 6 where the principles for conducting EIAs are described. A guideline explaining the procedures for carrying out an EIA as well as a training manual can be found on the National Environment Management Council's website[95]. A relevant example of an EIA dealing with the question of air quality in Dar es Salaam can be studied in the Second Central Transport Corridor Project (CTCP2) where the uncertainties in the available data on the air quality are highlighted[96].

In accordance with the Environmental Management Act section 132, the NEP provides for stronger emphasis on local Government authorities to participate in the management of air quality.

The intention with the "National Environmental Action Plan" (NEAP) is to follow in the footsteps of the NEP and mainstream environmental concerns into development policies, plans and strategies. Among other things, NEAP highlights the status of urban pollution, including air and noise pollution, but unfortunately the suggested actions in the NEAP only address urban pollution in general and does not include any actions specifically targeting air quality.

According to one of the interviews conducted too many agencies and departments are involved in road and traffic development and there is an issue with the lack of coordination of transport policies and initiatives as can be seen from the statement below:

"Today there is no real coordination between the national agencies and the local government for the development of new road projects."

However, an ambitious attempt to streamline and strategically coordinate the most important projects has been undertaken through the JICA Master Plan for Dar es Salaam from 2008. One of its recommendations was to create a coordination unit (Dar es Salaam Urban Transport Authority - DUTA) dedicated to road and traffic management as well as air monitoring. However, the assessment was not able to establish whether such a unit or function actual exits today. It appears that there is currently still room for improvement in the management and coordination of environmental efforts in Dar es Salaam.

5.3.5.5 Indicator 5: The country/city has the required institutional capacity to handle air pollution and transport emissions

The assessments points to a need for strengthening the institutional capacity of the environmental management agencies and in relation to transport emissions specifically. As mentioned in the above the formal legal and institutional framework appear to be in place. However, there is an issue with the capacity to undertake environmental monitoring, which is currently not being carried out regularly. The latest air assessment survey was carried out by NEMC in 2005-2007 and the project was US funded. It appears that NEMC neither have the funding nor the experience to effectively address air pollution.

[95] http://www.nemc.or.tz/publication_categories/guidelines-and-manuals

[96] https://www.afdb.org/fileadmin/uploads/afdb/Documents/Environmental-and-Social-Assessments/Tanzania_-_Dar_es_Salaam_BRT_Project_ESIA_Phase_2_3_Report_-_04_2015.pdf

5.3.5.6 Indicator 6: The country/city has an effective and sustainable environmental monitoring system in place

As indicated in the above there is currently no environmental monitoring system in place in Dar es Salaam. Part IV of the Environmental Management Act (Air Quality Standards) Regulation inaugurates a Central Environmental Information System under the NEMC. The system is supposed to include annual reports on the implementation of the Regulation, which evidently entails the enforcement of the emission targets. However, it has not been possible for the team to retrieve any updated data on transport emissions in Dar es Salaam coming out of NEMC annual reports or through other sources of information.

5.3.6 Assessment Lusaka

The interviews in Lusaka were conducted in the period 30 August-2 September 2016. A list of the interviews can be found in the annex 4 to this report.

5.3.6.1 Legal and institutional framework

Prior to and after the field work and the interviews substantial desk research had been undertaken to assess the available legal framework and standards guiding the environmental management and air quality in Lusaka. The main documents reflected in this assessment are:

- Ministry of Lands, Natural Resources and Environmental Protection: "National Biodiversity Strategy (2015-2025)";
- Ministry of Transport and Communication: "Strategic Plan 2014-2016".

The main legal documents reflected in this assessment can be seen in the table below:

Table 5-10: Legal overview

No.	Name of the Law	Date and Number of Issue
1	The Environmental Management Act, 2011	No. 12 of 2011
2	Road Traffic Act, 2002	No. 11 of 2002

In the table below an overview of the key institutions relevant to air quality management in Lusaka and their overall responsibilities are presented.

Table 5-11: Institutional overview

Institution	Roles and Responsibilities
The Zambia Environmental Management Agency (ZEMA) **(previously the Environmental Council)**	The Agency is responsible for ensuring the sustainable management of natural resources and protection of the environment, and the prevention and control of pollution. This responsibility encompasses (among other things): • Advising the Minister on the formulation of policies on all aspects of the environment; • Co-ordinating the implementation of activities of all ministries, appropriate authorities and conservancy authorities in matters relating to the environment; • Developing and enforce measures aimed at preventing and controlling pollution; • Developing, in liaison with the relevant appropriate authority, standards and guidelines relating to the protection of air, water, land and other natural resources and the prevention and control of pollution, the discharge of waste and the control of toxic substances; • Initiating, conducting and promoting research, surveys, studies, training and investigations in environmental management; • Ensuring the integration of environmental concerns in overall national planning through co-ordination with appropriate authorities;

Institution	Roles and Responsibilities
	• Undertaking general educational programmes for the purpose of creating public awareness on the environment; • Monitoring trends of natural resources, their use and impact on the environment and make necessary recommendations to the appropriate authority; • Publicising information on any aspect of the environment and facilitate public access to information on the environment.
Lusaka City Council	The City Council's main responsibility in relation to roads and traffic management is to construct and maintain public roads, streets, sanitary lanes, bridges and water courses and remove all obstacles thereof.
Road Transport and Safety Agency (RTSA)	The RTSA's functions are: • To regulate traffic; • To manage road transport through regulation; • To manage road safety engineering; • To conduct road safety campaigns through education and publicity; • To register and licence drivers, motor vehicles and commercial vehicle operators; • To licence and register driving schools and driving instructors; • To conduct physical and technical examination on motor vehicles to ascertain their physical details and road worthiness; • To implement international treaties and protocols on road transportation within Zambia and across its territories; and to regulate cross boarder transportation.
Zambia Meteorological Department (ZMD)	The functions and responsibilities of ZMD relevant to the transport sector and air quality are: • To establish and maintain a network of surface and upper air stations for the purpose of observing various weather elements; • To organize telecommunications system for the rapid collection and dissemination of meteorological data and products required for internal and international use; • To process and analyze meteorological data for use in the planning of economic development and rational exploitation of natural resources; • To provide Meteorological Information Service to Government Departments, Public Corporations and the general public; • To conduct research in meteorology and co-operate with organizations concerned with meteorological research and applications.
Zambia Bureau of Standards (ZABS)	ZABS is serving the country in the field of standardization, standards formulation, quality control, quality assurance, import and export quality inspections, certification and removal of technical barriers to trade.

Based on the above institutional overview, the core functions of air quality management in Lusaka are allocated to the relevant institutions in the overview below:

Table 5-12: Overview of responsibilities

Air Quality Roles and Responsibilities	
Core Functions	**Institutional responsibility**
Overall policy development	Ministry of Lands, Natural Resources and Environmental Protection and ZEMA
Planning and formulation of strategies	ZEMA
Formulation of legislation	Ministry of Lands, Natural Resources and Environmental Protection and ZEMA
Monitoring/assessing performance	ZEMA and ZMD
Measurement/data collection	ZEMA and ZMD
Dissemination of public information	ZEMA and ZMD
Appeals mechanism	Ministry of Lands, Natural Resources and Environmental Protection

5.3.7 Main findings

5.3.7.1 Indicator 1: Existence of air quality and vehicle emissions standards

The Environmental Management Act states that the Environmental Management Agency (ZEMA) is responsible for establishing air quality and emission standards and guidelines as well as methods for monitoring air contaminants.

Ramboll Environ has not been able to identify any relevant air quality standard for Lusaka or Zambia as such. The interviews refer to standard "ZS 560" concerning inspection of used road vehicles, which only indirectly relates to the air quality, but supposedly the standard contains some vehicle emission requirements. However it has not been able to obtain the standard to check its relevance.

It is important to note that the Eastern African Standard Organisation has published an Air Quality Specification Guideline[97] which includes Air Quality limit values that could be applied in Zambia.

5.3.7.2 Indicator 2: The access to relevant environmental data, statistics and information is adequate

The team had difficulties in accessing relevant environmental data in relation to transport and air quality. The conducted interviews made it clear that the Zambia Bureau of Standards (ZABS) are not involved in any data collection in relation to transport emissions and air quality.

The Zambia Meteorological Department (ZMD) are producing monthly data on two meteorological stations, but neither are related specifically to air quality.

According to the Lusaka City Council the data should normally be done by ZEMA, but apparently the equipment (2 devices) they have for air quality measurement is not working at the moment.

According to the Environmental Management Act the "Minister" is supposed to publish a State of the Environment Report every five years as well as a National Environmental Action Plan every ten years. However, the latest versions that could be found on ZEMA's website were the "Zambia Environment Outlook" as well as "The Lusaka State of Environment Outlook Report" from 2008. The latest retrievable "National Environmental Action Plan" was from 1994. In that sense, the access to relevant environmental information is outdated.

ZEMA is also supposed to establish and operate a Central Environmental Information System in which shall be stored any findings, data and statistics generated by both public and private

[97] Eastern African Standard Organisation, 2010. Air Quality Specification Guideline (CD/T/66/2010)

bodies in the course of environmental observation and management. However, the existence of such a system could not be documented.

The JICA Master Plan seems to be the most relevant document for the state of the environment in Lusaka, but according to the Ministry of Transport it does not include a report on air emissions specifically. However, the team was unable to obtain the JICA report to assess the available data independently.

5.3.7.3 Indicator 3: The environmental legislation (framework) helps achieve the agreed standards

As mentioned in the above the environmental legislation does assign the responsibility for formulating air quality standards to ZEMA and it prescribes ways of taking stock of the environmental situation in the country. The challenge is that the provisions in the Act do not appear to be enforced.

Ramboll Environ also find that the Environmental Act cannot stand alone as a way of ensuring environmental standards in Zambia and in Lusaka. There is a definite need for secondary legislation and more specific regulations and guidelines as to how to go about the more concrete formulation and execution of air quality standards in Zambia and Lusaka.

The legislation also encompasses the Environmental Protection and Pollution Control (Environmental Impact Assessment) Regulation from 1997 providing for procedures and requirements for compulsory briefs and EIA. Furthermore, the Environmental Council of Zambia (later ZEMA) published a guideline on the EIA process which defines the term and includes key questions to be covered e.g. in relation to air quality such as type and amount of emissions. However, the guideline is considered to be rather general and in need of an update.

To that effect, the overall legal framework in relation to the air quality in Lusaka and Zambia is assessed to be weak when it comes to establishing clear guidelines for the formulation of relevant standards.

5.3.7.4 Indicator 4: Environmental management is mainstreamed and well-integrated into the public sector governance

The conducted interviews indicate that environmental management in Lusaka is scattered and that there is little if any coordination between the key stakeholders when it comes to air quality management.

Different attempts have been made to integrate environmental management through e.g. the “Inter-agency Environmental Coordinating Committee” referred to on ZEMA’s website. However, at best this initiative seem to be outdated as the website still refer to ZEMA as the Environmental Council of Zambia, which is the Agency’s former name from before 2011. Apparently one of the Committee’s future tasks would have been to establish a monitoring system for air quality.

Seemingly, the JICA Master Plan recommends the creation of a coordination unit (Urban Transport Planning Unit - UTPU) for road and traffic management as well as air monitoring, but the unit has not been established yet, so it remains to be seen whether this initiative will be successful in mainstreaming environmental management in relation to air quality.

The Environmental Management Act requires that each Ministry formulate an environmental management strategy. The Ministry of Lands, Natural Resources and Environmental Protection has a national biodiversity strategy (2015-2025), which however does not address air quality management. The Ministry of Transport and Communication has a Strategic Plan (2014-2016), but the Plan does not include anything on the physical environment.

To that effect environmental considerations cannot be said to be mainstreamed in public sector governance in Zambia.

5.3.7.5 Indicator 5: The country/city has the required institutional capacity to handle air pollution and transport emissions

At the time of this assessment it seems evident that there is currently little institutional capacity to handle air quality and transport emissions. However, it has been difficult to establish the capacity of e.g. ZEMA, as the leading authority on environmental management in the country, as the team were not able to meet with them. However, as already mentioned the interviews and the research did raise the lack of a consistent framework to guide air quality management and the poor inter-agency coordination in this domain. The interviews also pointed to the decisions makers' unwillingness to follow the Master Plan for the city and the lack of coherence in following established priorities.

5.3.7.6 Indicator 6: The country/city has an effective and sustainable environmental monitoring system in place

The Environmental Management Act stipulates that ZEMA should establish an inspectorate with the necessary technical staff and facilities required to administer, monitor and enforce measures for the protection of the environment and the prevention of pollution.

The interviews and the research find that there is currently no well-functioning inspectorate or monitoring mechanism in place to measure the air quality and/or the impact of transport in Lusaka. A monitoring station operated by ZEMA in the past does no longer works. According to the Lusaka City Council, traffic monitoring is done visually without any traffic modelling software or equipment.

5.4 Assessment Yaounde

The data collection activities in Yaounde were carried out between 4-7 October 2016. A list of the interviews can be found in the annex to this report.

5.4.1 Legal and institutional framework

Prior to and after the field work and the interviews substantial desk research had been undertaken to assess the available legal framework and standards guiding the environmental management and air quality in Yaounde. The main document reflected in this assessment is:

- Elaboration d'un plan de déplacements urbains de la ville de Yaoundé

The main legal documents reflected in this assessment can be seen in the table below:

Table 5-13: Legal overview

No.	Name of the Law	Date and Number of Issue
1	Law No 96/12 – Respecting the Management of the Environment	5 August 1996
2	Decree 2011/2582	23 August 2011
3	Decree 2012/250	9 December 2011
4	Decree 2012/431	1 October 2012
5	Decree 2013/0171	14 February 2013

In the table below an overview of the key institutions relevant to air quality management in Cameroon and Yaounde and their overall responsibilities are presented.

Table 5-14: Institutional overview

Institution	Roles and Responsibilities
Ministry of Environment, Nature Protection and Sustainable Development (Ministère de l'Environnement, de la Protection de la Nature et du Développement Durable, MINEPDED)	The Ministry's main mission is the development, implementation and monitoring of environmental policy and protection of nature. The Ministry has defined a program from 2009 that integrates six axes: • Improvement of environmental management of ecosystems and conservation of biological diversity; • Promotion of international cooperation on environment and nature protection; • Sensitization of populations to restoration of the environment; • Pollution management and disaster prevention and natural hazards; • Promoting the urban environment and environmentally sustainable industrial development, • Development and strengthening of institutional capacities and human resources. Air Quality Issues are addressed by the Unit called "Inspection de l'Air et de l'Atmopshère", which is a part of the "Brigade de l'Inspection Environnementale" (BRIE).
Ministry of Transport (Ministiere des transports)	The Ministry of Transport is responsible for the development and implementation on behalf of the Government in the field of transport and road safety. As such, they are responsible for studying and participating in the development and implementation of legislative and regulatory measures relating to transport.
Yaounde Agglomeration (Communaute Urbaine de Yaounde – CUY)	CUY is in charge of the Development and the Urban Planning of the agglomeration through the C2D program ("Contrat de Désendettement et de Développement") supported by International Funding (e.g. the French Agency for Development or AFD).

Based on the above institutional overview, the core functions of air quality management in Yaounde are allocated to the relevant institutions in the overview below:

Table 5-15: Overview of responsibilities

Air Quality Roles and Responsibilities	
Core Functions	**Institutional responsibility**
Overall policy development	Ministry of Environment
Planning and formulation of strategies	Ministry of Environment
Formulation of legislation	Ministry of Environment and Ministry of Transport
Monitoring/assessing performance	Ministry of Environment (Inspection de l'air et de l'atmosphère)
Measurement/data collection	N.A.
Dissemination of public information	Ministry of Environment

5.4.2 Main Findings

5.4.2.1 Indicator 1: Existence of air quality and vehicle emissions standards

According to the interviews conducted there are no air quality standards for Yaounde and Cameroon, but the Ministry of Environment explain that they generally rely on WHO standards.

Furthermore, there are no norms on allowed emissions from cars or any age limitation or other requirements for imported cars.

Effectively, this indicates that there is no functioning regulation concerning air quality and vehicle emissions in Yaounde and more generally in Cameroon.

5.4.2.2 Indicator 2: The access to relevant environmental data, statistics and information is adequate

The assessment team have not been able to retrieve any relevant environmental data in relation to the air quality in Yaounde. According to one of the interviews there are no relevant studies concerning this subject since 2004.

Based on the interviews and the conducted research, access to relevant environmental data in relation to the air quality and traffic is considered to be poor.

5.4.2.3 Indicator 3: The environmental legislation (framework) helps achieve the agreed standards

According to Article 10 of the "Environmental Law" (96/12), the Government (the Ministry of Environment) is responsible for establishing quality standards for air as well as preparing reports on pollution and the state of the environment in general. However, as mentioned previously such standards have not been established.

There is secondary legislation (e.g. Decree 2011/2582) covering the implementation, including AQ monitoring, but it is primarily establishing the principles and functions to be governed, which in practice are not followed.

The Environmental Law (Article 21) also specifies that it is forbidden to affect the quality of the air, but as there is no supporting legislation or standards specifying the principles for such violations the implementation of the law becomes unclear.

The Decree No 2003/0171 lays down the rules for conducting environmental and social impact studies[98] with the Ministry of Environment being the central EIA authority. Supposedly both a guide and a manual for implementing and EIA have been published in 2008 and 2010.

Evidently, the Environmental Act, and to some extent the secondary legislation, contains the relevant Articles to guide the principles of environmental management for Yaounde and Cameroon. However, the legislative framework is in need of more specific standards and guidelines to effectively steer air quality management in the right direction.

5.4.2.4 Indicator 4: Environmental management is mainstreamed and well-integrated into the public sector governance

The interviews indicate that environmental management is scattered and that there is practically no collaboration between the Ministry of Environment and other ministries, apart from a task force about classified industrial facilities, which includes the Ministry of Health.

According to the Environmental Law the initiative should come from the Ministry of Environment in terms of:

- Initiating research on the quality of the environment, e.g. through a National Environment Management Plan every five years and a bi-annual report on the state of the environment;
- Coordination;
- Publishing and disseminating information on the protection and management of the environment.

Furthermore, the law emphasizes the importance of engaging the citizens through the production of and free access to environmental information, consultative mechanisms, advisory bodies, advocacy and environmental education.

As already mentioned and as seen in the above, the legal framework does encompass a number of relevant prescriptions for streamlining environmental management. However, the challenge lies in the implementation and integration of the Environmental Law in operational policies.

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[98] http://www.eia.nl/en/countries/af/cameroon/eia

5.4.2.5 Indicator 5: The country/city has the required institutional capacity to handle air pollution and transport emissions

According to an interview with the Ministry of Environment, the organizational structure of the Ministry is considered to be complete with all units established, including entities responsible for “environmental inspection” and “air and atmosphere inspection”.

The Ministry admits that even though they are formally set up for managing the air quality they are in reality not effective in addressing this issue. Also, there is no dedicated national Agency to handle this responsibility (e.g. like CIAPOL in Ivory Coast). It seems clear that the Ministry lacks the capacity to handle this responsibility both in terms of human resources and technical capability. The institutional weaknesses are strengthened by the fact that pollution and air quality are not high on the agenda in the Ministry where “managing the traffic” is considered to be more important. The low priority given to air quality management and transport emissions is confirmed by the Director of Meteorology in the Ministry of Transport, which according to Decree 2012/250 is responsible for controlling background air pollution at country level.

5.4.2.6 Indicator 6: The country/city has an effective e and sustainable environmental monitoring system in place

The legal framework specifies the need for an effective environmental inspection and monitoring system. Decree 2011/2582 obliges the establishment of air quality control stations where the pollution is presumed to be greater than the set limit values (which are however not set).

Furthermore, the Decree imposes that information and data collected from those monitoring stations is sent quarterly to the Ministry of Environment for wide dissemination. Unfortunately, there is no equipment or stations for air quality monitoring, so in that sense the Decree is not enforced.

The Decree 2012/431 establishes the principles for general inspection as well as an Information Centre for Documentation and Environment (Article 67). The Centre should handle information exchange including the collection and centralization of relevant environmental monitoring information and environmental compliance. According to our information these functions are not carried out in relation to air quality.

Based on the above research it can be concluded that there is currently not an effective and sustainable air quality monitoring system in place for Yaounde.

5.4.3 Assessment Conclusion

The assessment of the five cities generally shows that there is a long way to go to achieve a strong regulatory and institutional framework for guiding air quality and emissions monitoring in any of the five cities. Only two out of the five cities/countries (Morocco and Tanzania) have stablished air quality standards.

The production of, and access to, publicly available environmental data (e.g. with respect to air pollution) is very limited in all five cities. Consequently, there is limited accountability and political attention associated with ensuring good air quality in any of the five cities.

Environmental legislation is, to some degree, in place in all of the five cities. Overall, there is a legal framework in place to guide the improvement of air quality and emission reductions. The main challenges in the legal framework is the poor enforcement of available provisions and the lack of a specific air quality components in the mandatory local EIAs.

Another issue identified by the assessment is the general poor level of coordination between the stakeholders involved in environmental management, specifically related to air quality and emissions. This can partially be blamed by the limited institutional capacity in regions where few dedicated environmental agencies have been established (i.e. CIAPOL). Additionally, the competences and experiences of the employees supposedly working with air quality issues in the cities is often restricted.

Finally, the assessment finds that the level and quality of an effective monitoring system in the air quality domain is hampered and practically non-existent (or non-efficient) in most of the five cities. However, there are effective monitoring stations in other cities of Morocco, such as Casablanca or Marrakech.

6. TRAINING AND MANUALS

The following chapter compiles (in table format) the main content of the different training sessions delivered during the project:

- Air quality monitoring and data collection,
- Software implementation for air quality mapping, and
- Cost Benefit Analysis.

These tables highlight topics presented and the related learning objectives.

The training sessions delivered took between 0.5 and 4 days. The software training session has been split over two modules, emissions calculations and dispersion software configuration.

Last sections of this chapter provide the list of participants for the training courses and the list of the training material (available as stand-alone documents).

6.1 Content and objectives

The following tables list for each training session the main focuses (tasks / content) and the related objectives.

Table 6-1: Content of monitoring training session and objectives

Tasks / Content	Learning Objectives
Collect and analyze information coming from: - Continuous air quality monitoring system (Cairnet), - Weather stations (DAVIS Vantage Pro 2), - HD Camera recording systems.	Understand the general concepts associated with ambient air monitoring using the Cairnet system, in-situ weather station, and a video camera dedicated to road traffic recording. Be able to implement such instrumentation.
Vehicle count surveys	Understand the techniques for manual counts, how to complete survey forms, and best safety practices.
Implementation of a monitoring campaign including the choice of optimal locations that meet the project goals (i.e. assessing the contribution of road traffic on Air Quality concentrations).	Knowledge of local conditions and constraints applicable to monitoring location, including background and road traffic locations. Knowledge on the important interplay between meteorology and local pollutant contribution. Knowledge of best practices regarding sampling of vehicle fluxes (e.g., main roads, distance from crossroads, and buildings). Identify and flag exceptional events, such as the presence of interference (local sources of pollution, traffic jams, etc.).
General maintenance and upkeep of the instruments implemented.	Knowledge of how to ensure monitoring system is operated properly and is kept in good operating order.
Validation of air quality monitoring data	Understand how to analyze monitoring data in a technical uncertainties context.

Table 6-2: Content of emissions training session and objectives

Traffic emissions module	
Tasks / Content	**Learning Objectives**
Determination of Average Daily Traffic (ADT) Volumes from manual vehicle counts performed during Monitoring Campaign.	Conversion from 15-min vehicle number to ADT Volumes. Understand the limitations due to potential periods without sampling (for instance, during the night).
Review of assumptions taken for the construction of the vehicle fleet.	Understand the limitations and future improvements in order to refine the vehicle fleet (access to new databases, performance of additional vehicle counts and campaigns, etc.)
Presentation of the various pollutant sources from vehicle emissions (i.e. exhaust (fuel combustion) and non-exhaust (resuspension, evaporation, abrasion)). Identification of pollutant type per emission source.	Basic knowledge and understanding of the main processes of pollutant emissions due to road traffic.
Review and determination of credible emission factors for exhaust and non-exhaust emissions	Basic knowledge and understanding of the limitations of emission factors.
Presentation of the simple and flexible Average Equivalent Vehicles (AEVs) methodology	Understand the AEV benefits in simplifying the estimation of emission factors in order to be consistent with the limited level of detailed data obtained in each city.
Ability to prepare estimates of mobile source emissions using the COPERT 5 model	Understand (i) how to use the COPERT 5 model, (ii) where to obtain up-to-date input information to use with COPERT 5, and (iii) of the relative importance of various factors in terms of their influence on model performance.
Ability to convert emissions calculated with the COPERT 5 model to AEV emissions	Knowledge of the process of conversion using Microsoft Excel
Ability to spatialize AEV emissions with the Emi'Road tool.	Knowledge of how to spatialize AEV emissions over a road network according to ADT volumes estimated on each road section.

Table 6-3: Content of air quality modeling training session and objectives

Air Quality Model module	
Tasks / Content	**Learning Objectives**
Ability to interpret the major atmospheric processes driving air pollutant dispersion from mobile sources: • Influence of meteorology, • Street canyon effects, • Noise barriers, etc.	Basic understanding of the scientific concept associated with dispersion modelling within transport corridor.
Ability to use ADMS-Roads model for the following applications: • Industrial point sources, and • Small road networks.	Basic knowledge of how to setup and run ADMS-Roads for selected simple applications. Basic knowledge of how to use the internal GIS tool embedded in ADMS-Roads.
Ability to analyze simple dispersion modelling output concentration results and perform comparison against international and national standards/guidelines.	Basis knowledge of how to ensure modelling setup was correctly performed, proper meteorological data was used, and emissions sources locations were correctly setup. Basic understanding of Air quality guidelines and standards (i.e. notion of percentiles, period of integration, etc.).
Ability to produce Air Quality concentration maps over transport corridors.	Advanced knowledge of the internal GIS tool embedded in ADMS-Roads.
Comparison of model results to concentrations sampled during the monitoring campaign.	Background and application of receptor models for source contribution identification and quantitative of mass apportionment of pollutants. Understandhow to calibrate the model by comparing against observations.

Table 6-4: Content of Cost Benefit Analysis training session and objectives

Cost-Benefit Analysis module	
Tasks / Content	**Learning Objectives**
Presentation of the most common economic analyses dedicated to transport projects assessment	Gain a better understanding of the most used economic analyses for transport projects (financial, CBA, etc.). Importance to policy-makers and link to impact assessment. Importance to regulated utilities and infrastructure investment. Guidance documents.
Basic issues in cost-benefit analysis	Understand how to define the baseline. Identify costs and benefits and affected stakeholders. Transfers and distributional impacts. Using market prices to value impacts. Discounting: • How to discount future impacts • What discount rate to use
How to quantify costs and benefits	Challenges in quantifying costs and benefits. Methods of collecting data and analyzing impacts (modelling, case studies). Assessing the additionality of impacts.
How to value non-market impacts	Understand why non-market impacts are important. Techniques for valuing non-market impact using existing valuations (international references). Examples of how to value non-market impacts (time savings, carbon impacts, health impacts)
Cost Benefit Analysis of a Metro line scenario in Abidjan	Review of assumptions made for this specific assessment. Results analysis.

6.2 Participants

The following table indicates the list of participants for the training courses.

Table 6-5: List of particpants for the training sessions

City	Affiliation	Name of participants	contact
Abidjan	University of Felix Houphouët Boigny	Pr. YOBOUE Veronique	Yobouev@hotmail.com
		GNAMIEN N'DOUFFOU KONAN Sylvain	gnkonans@gmail.com
		MADINA Doumbia	doumbiamadina@yahoo.fr
		KEITH Sékou	sekkeith@yahoo.fr
		BAHINO D. Julien	julienbahino@gmail.com
		TOURE N. Evelyne	ndatchoheve@yahoo.fr
	Bureau National d'Etudes Techniques et de Développement (BNETD)*	AMANI Jean Brou	abrou@bnetd.ci
		DEMBELE Djonmassa Ahmed	ddembele@bnetd.ci
		KOUTOUAN Evrard	ekoutouan@bnetd.ci
	Centre Ivoirien antipollution (CIAPOL)	Pr. YAPO Ossey	yapossey@yahoo.fr
		BONI Juste-Geraud	justboni@hotmail.com
		YAPO OSSEY Bernard	yapossey@yahoo.fr
		KONAN N'GUESSAN Yves	konanyvesf@yahoo.fr
	Institut Pasteur	Pr. KOUAME Kouadio	kouadiokouame@yahoo.fr
Rabat	Secrétariat d'Etat Chargé de Développement Durable / Service Air (SEDD / SA)	BENHANNI Mohamed	benhanni@environnement.gov.ma
	Laboratoire National des Etudes et de Surveillance de la Pollution (LNESP)	OTMANI Anas	Otmani.anas@gmail.com
Lusaka	Zambia Environmental Management Agency (ZEMA)	SIMWANZA Chrispin	csimwanza@zema.org.zm
		SICHINGA Chembo	ccsichinga@zema.org.zm
		MULENGA Emmanuel	ecmulenga@zema.org.zm
Dar Es Salaam	Tanzania National Roads Agency (TANROADS)	LUHURO Julius	jluhuro@yahoo.com
		MOLLEL Ebenezer	Ebenezer.mollel@tanroads.go.tz
		AKO Chrispianus	chrispianus.ako@tanroads.go.tz
Yaoundé	Ministry of Environment, Protection of Nature and Sustainable Development	NDOMO Jules Christian	jcndomo@yahoo.com
		FOSSI Aurélien	fossif@yahoo.fr
		BELINGA NICAISE	cassyberling@gmail.com
		HAMADJODA	hamadjodago@yahoo.fr
		Constance BAEY Kum épse BUH	baey_cbuh@yahoo.co.uk

* Emissions / modelling and CBA training sessions only

6.3 Training course material

The training course material have been compiled in a specific zip file, attached to this document and called "Training Material". This file contains three directories:

- CBA (Cost-Benefit Analysis),
- Monitoring, and
- Software.

Within the CBA folder the PowerPoint slides ("CBA_Presentation.pptx") that accompanied the presentation of the CBA method in each city investigated, are available. This presentation titled "Cost-Benefit Analysis – Low Emission Transport Project" reviews the main tasks/objectives highlighted in the section 6.3 with a focus on the Abidjan Metro Line project as an example of the implementation of the economic methodology.

The Monitoring folder is about the training session related to the implementation of measurements needed for the project study i.e. vehicle number traffic counts, pollutant concentrations and meteorological parameters measurements. This folder includes two user's guides in both French and English for:

- The DAVIS in situ weather station Vantage Pro2 and the Cairsens system ("User Guides_Monitoring.pdf"), and
- The traffic counting ("Traffic Counting Memo.pdf") that compiles all information in order to implement a manual or an automatic vehicle number count campaign.

The Software folder is divided into several sub-folders that focus on material delivered during the software training session in each city (Abidjan, Dar Es Salam, Lusaka, Rabat, Yaoundé). Another sub-folder called 'Program install" compiles all software and freeware tools (installation and documentation) needed for the purpose of the training session i.e.:

- ADMS roads,
- COPERT 5,
- Emi'Road, and
- Libre Office (in order to provide a free spreadsheet program).

In each country sub-folder, there are five PowerPoint presentations given during training sessions:

1. "Introduction.pptx" –lists the training program,
2. "Emissions Calculation.pptx" –focuses on the methodology for the calculation of emissions of pollutants,
3. "ADMS Roads Overview.pptx" –provides a brief overview of the main options in the model that are designed for realistic modelling of road traffic conditions, and
4. "Modelling Case study "name of the city".pptx" – This presentation reviews the main results of the monitoring campaign, of the modeling and the main assumptions made for the calculation of the vehicle fleet.

Two PDF documents are also available:

- "Agenda.pdf" – that lists training modules considered, and
- "Attendance_list.pdf" – a blank form used during each session for people registration.

Finally, a last folder called "Methodology files" provides all data in order to generate step-by-step the complete process developed in this project (including inputs and outputs) i.e. from assumptions made initially in order to develop the vehicle fleet to the maps of pollutant concentrations within a transport corridor. In addition, another directory has been considered in order to compile the example data used for the training on the ADMS Roads model. Due to the large amount of files, this folder has been organized to improve user's access to information on the data used:

1. From COPERT 5 to AEV – providing all inputs/outputs for emission calculation,
2. EAV to ADMS-Roads – focusing mainly on emissions data handling with Emi'Road,
3. ADMS-Roads – giving all inputs/outputs for the modelling study in each city,
4. Results – map concentrations, comparison against measurements, etc., and
5. ADMS example – including files for small road network and industrial sources.

7. MAIN FINDINGS AND RECOMMENDATIONS

7.1 Introduction

This chapter summarizes the main findings resulting from the project, with focus on the measurements performed in pilot areas, on the socio-economic analysis, and on the institutional framework of each city/country. Finally, a set of recommendations and a follow-up program for scaling-up the monitoring to the whole city, as well as all other cities in African developing countries, is provided.

7.2 Main findings

7.2.1 Air Quality in Transport Corridors

In order to train key local stakeholders during the project, measurements have been performed in one or two pilot area(s) of each city (Rabat, Abidjan, Yaounde, Dar es Salaam and Lusaka). Measurements have been used to calibrate a dispersion model tailored for each city and high resolution air quality maps have been built for NO_2, PM_{10}, $PM_{2.5}$ and SO_2 in each transport corridor. Results have been compared to international WHO Guidelines (daily and annual average) and exceedances of these Guidelines were highlighted.

Because sampling was made during several hours/days, the daily average guidelines are well suited for comparison. It can also be expected that concentrations close to traffic should not change significantly fromday-to-day, therefore comparison of measurements to annual guidelines is also interesting. From these preliminary measurements in pilot areas, we conclude that concentrations close to traffic are generally much higher than urban background concentrations. This is especially true for NO_2, which is a pollutant mainly emitted by vehicle engines. Results show also that WHO guidelines are most always exceeded in Transport corridors, but also at background locations (i.e. far from the traffic) in several cities.

Of course, measurements should be performed on longer time periods to confirm the observations, but at least preliminary measurements are consistent with International Literature. According to a recent study of Amegah and Agyei-Mensah (2016)[99], air quality in cities of Sub-Saharan African (SSA) countries has deteriorated due to rapid population growth and associated increased vehicle ownership. Additionally, poor air quality is caused by the use of solid fuels for cooking and heating, industrial expansion in these cities, and poor waste management practices. Exposure to ambient air pollution is a major threat to human health in SSA; 176,000 deaths and 626,000 DALYs in the region are attributable to ambient air pollution exposure. According to Brauer et al. (2012)[100], some of the highest fine particles levels in the world have been recorded in cities of SSA and in other developing regions. $PM_{2.5}$ concentrations in SSA cities has been estimated at around 100 µg/m^3, which is much higher compared to <20 µg/m^3 in most European and North American cities. Such high levels were not observed during our measurement periods, however, further investigations should be performed by local air quality agencies, including at locations close to unpaved roads networks.

Finally, it is important to note that micro-sensors used for SO_2 measurements in the framework of this project were not able to reproduce correct levels due to having low accuracy at low concentrations. These sensors are generally used to monitor high SO_2 concentrations around industrial plants and there may be potential interferences (according to the Provider Environnement SA) with particular local meteorological conditions (i.e., high humidity) and with significant concentrations of other pollutants (i.e.,CO).

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[99] Amegah A. K. and S. Agyei-Mensah, Urban Air pollution in Sub-Saharan Africa: Time for Action, Environmental Pollution 220, 738-743, 2016

[100] Brauer, M., Amann, M., Burnett, R.T., Cohen, A., Dentener, F., Ezzati, M., et al., Exposure assessment for estimation of the global burden of disease attributable to outdoor air pollution. Environ. Sci. Technol. 46 (2), 652e660, 2012.

7.2.2 Financial Sources for Low-Emissions Transport and Cost Benefit Analysis

In the framework of this socio-economic part, the following analysis have been performed for a selected city, according to the terms of reference:

1. transport and energy subsidies;
2. A screening of sources of finance for low emission transport projects;
3. A description of methodologies for an economic Cost Benefit Analysis of low emission transport projects with a particular focus on congestion and health impacts.

This socio-economic analysis part focuses only on Abidjan in Côte d'Ivoire, and includes the preparation of a Manual in Cost Benefit Analysis and training of staff in the same subject. The main findings of our investigations are summarized below.

7.2.2.1 Transport and energy taxes and subsidies

The *transport* sector is subsidized in various ways in Cote d'Ivoire:

- Government pays 80 % of the monthly price for students and 50 % for civil servants;
- Government paid a 5 billion FCFA grant to the privatized to expansion of the bus fleet.

In comparison with other countries in SSA, Cote d'Ivoire has low fuel subsidies, measured as percentage of GDP (0.17%). In comparison with other countries in SSA, Cote d'Ivoire has high electricity subsidies, measured as percentage of GDP (3%). This may reflect high state long term investments in transmission and distribution rather than in devastating short-term subsidization of electricity prices.

7.2.2.2 Sources of funds

The amounts of funding available for climate projects in developing countries are increasing, but obviously far from sufficient to cover the needs if the present climate forecasts are valid. This may have a negative effect on the financial sources, available for low emission transport projects.

There is an increasing focus on adaptation projects and therefore, relatively less focus on carbon reduction. The Global Environment Facility (GEF from 1991) and the Green Climate Fund (GCF from 2010) focus on carbon emissions. GCF also addresses adaptation.

The Climate Investment Fund (CIF from 2008), the Special Climate Change Fund, (SCC0 from 2010), the Least Developed Countries Fund (LDCF from 2001) and Adaptation Fund (from 2001) all focus on Adaptation.

An increased focus on adaptation makes sense for African countries, but it may limit funds available for air quality improvements. The limited size of an air quality monitoring system in an African city may not satisfy the criteria for the major international funding sources. A way forward may be to integrate equipment and follow-up maintenance in a planned major transport or energy project and to try having the full package funded by the Green Climate Fund. Alternatively, common project might be developed for 5-6 or more major African cities and thereby achieving a considerable scope and impact that might find funding from e.g. the GCF.

In addition, local and central governments should realize that cleaner air will have a direct financial value for the city and the country. That might actually justify their own contribution of funds for the monitoring of air quality.

7.2.2.3 Economic analysis of congestion and health impacts

A general approach to economic Cost Benefit Analysis is described in the report and methodologies for assessing benefits of reduced congestion and improved health impacts are presented. In particular the congestion has a significant importance on benefit estimates of many transport projects.

Reduced congestion means less time spent in traffic, which may be quantified by estimating the average speed of the traffic in an area before and after an improvement. The value of the saved time per hour shall in principle be determined as the average wage rate of the population in the area for the part of traffic that is either commuter or other business-related traffic. The remaining traffic may be valued at a lower rate. A correct economic value of one hour is difficult to estimate, and it is suggested that an average value for all traffic is estimated and applied, and that the sensibility of the results to changes in the hourly value is analysed.

Cleaner air and in particular a reduced level of ambient PM in the air has a significant impact on health and hence on both mortality and morbidity. Internationally recognized formulas for explaining the health impact has been applied for the estimation of health impacts of transport projects that affect the PM level. Mortality and morbidity impacts are converted into economic values with the use of Disability Adjusted Life Years, and one DALY is assumed to have a value corresponding to the average per capita GDP.

7.2.3 Regulatory and institutional framework

Existing regulatory and institutional framework of the five cities have been assessed during this project.

This gap assessment was mostly based on a desktop review of existing legislation, policies and available organisational descriptions supplemented by brief interviews conducted on the ground with key stakeholders in the five cities. The findings were measured up against a number of pre-defined indicators with the objective of measuring the environmental compliance in the five cities.

Based on the nature and scope of the assignment the following indicators have been applied:

1. Existence of air quality standards
2. The access to relevant environmental data[101], statistics and information is adequate
3. The environmental legislation (framework) helps achieve the agreed standards
4. Environmental management is mainstreamed and well-integrated into the public-sector governance
5. The country/city has the required institutional capacity to handle transport emissions
6. The country/city has an effective and sustainable environmental monitoring system in place

The review was steered by these indicators. The purpose of the review was to establish to which degree the cities were able to meet these standards. In many instances, the conditions applicable for the city is in fact applicable for the entire country (e.g. legal framework, environmental policies etc.).

Based on the indicators above, an interview guide has been developed to be applied for the different interviews to be conducted. Then, a stakeholder mapping exercise was also conducted, which resulted in a list of relevant stakeholder categories to meet and interview during the field work and data collection activities, mainly Environment and Transport Ministries, Municipalities and Environmental agencies.

[101] Relevant environmental data is defined as information related to air quality and emissions.

The main findings of this assessment are the following:

- There is still way to go to achieve a strong regulatory and institutional framework for guiding the air quality and emissions monitoring in any of the 5 cities.
- Only two out of the five cities/countries (Morocco and Tanzania) have stablished air quality standards and the adherence to these or any standard is unclear.
- Level and quality of an effective monitoring system in the air quality domain is practically non-existent in most of the five cities (although effective monitoring stations in other cities of Morocco such as Casablanca or Marrakech).
- The production of and access to publicly available environmental data, e.g. in relation to air pollution, is very limited in all five cities. Consequently, there is limited accountability and political attention when it comes to ensuring the air quality in any of the five cities.
- General lack of specific air quality component in the mandatory Environmental Impact Assessments (EIAs).
- The environmental legislation is to some degree in place in all the five cities. Overall, there is a legal framework in place to guide the improvement of the air quality and reduce emissions. The main challenges is the poor enforcement of available provisions.
- General poor level of coordination between the stakeholders involved in environmental management including air quality and emissions.
- Part of this can be assigned to the limited institutional capacity in the area where few dedicated environmental agencies have been established (e.g. CIAPOL) and the competences and experience of the employees supposedly working with air quality issues in the five cities is often very restricted.

7.3 Main recommendations

7.3.1 Introduction

This section proposes recommendations for developing air quality management in selected African cities, considering the following two major pillars:

- Institutional and regulatory recommendations, based on the gap analysis performed in the framework of this project;
- As a follow-up to the capacity building project, technical recommendations are provided for scaling-up and implementing a sustainable monitoring air quality network at the scale of a city.

7.3.2 Institutional Recommendations

Based on the above assessment, this chapter will suggest a number of important recommendations that will allow the project to successfully contribute to improved air quality in all five cities. We have selected and focused on the most essential recommendations in order to make the implementation manageable and realistic rather than providing a very broad catalogue of possible approaches. The recommendations have paid tribute to what is considered to be institutional best practice with reference being made to EU standards when possible. Local specificity and constraints as considered as well.

The recommendations seek to address the issues identified by the assessment report. The suggested starting point involves diagnosing the current situation with regard to air quality in all five cities because t air quality knowledge and available information is quite limited. Secondly, the institutional framework needs to establish all the relevant institutions that will oversee air quality monitoring. The legal framework is also in need of an overhaul, in particular with regard to updated air quality standards and mandatory requirements to integrate air quality considerations in EIAs.

Furthermore, as the issue of air quality is a relatively new topic in most of the five cities, there is a need to ensure that sustainable capacity is available in the newly established institution through relevant education, training, and exchange programs. Finally, the report finds that there is a need for stronger coordination between the involved stakeholders in air quality and an increased reporting of ongoing activities as well as available environmental data to involve a larger community in the pursuit of improved air quality.

- **Recommendation 1: Conduct air quality diagnostic exercise**
  This project will ensure that all five cities will have monitoring equipment available to take stock of the existing level of air pollution. The assessment shows that the current knowledge and available information concerning the air quality is very low in all five cities, and consequently the project finds that it would be a valuable starting point to establish the "state of the cities" before implementing any other measures to improve the situation, with the expectation that there is room for improvement.

  Ramboll suggests that the selected beneficiaries in each of the five cities will take the initiative to measure the ambient air quality as soon as the equipment is readily available and the relevant training activities, as part of this project intervention, have been carried out. The information retrieved will offer valuable first insights as to the areas of intervention, and the pollution hotspots in the different cities, to prioritise under the newly established structure, which will be suggested in the following recommendations.

  This recommendation will form the basis for any future measurements conducted and will as such establish a baseline for air quality data in each of the five cities. This diagnostic exercise can be seen as "one-off" or as the starting point for any of the other recommendations suggested by this project, but it is recommended that a similar diagnostic exercise is carried out regularly and at the city scale to track progress or setbacks.

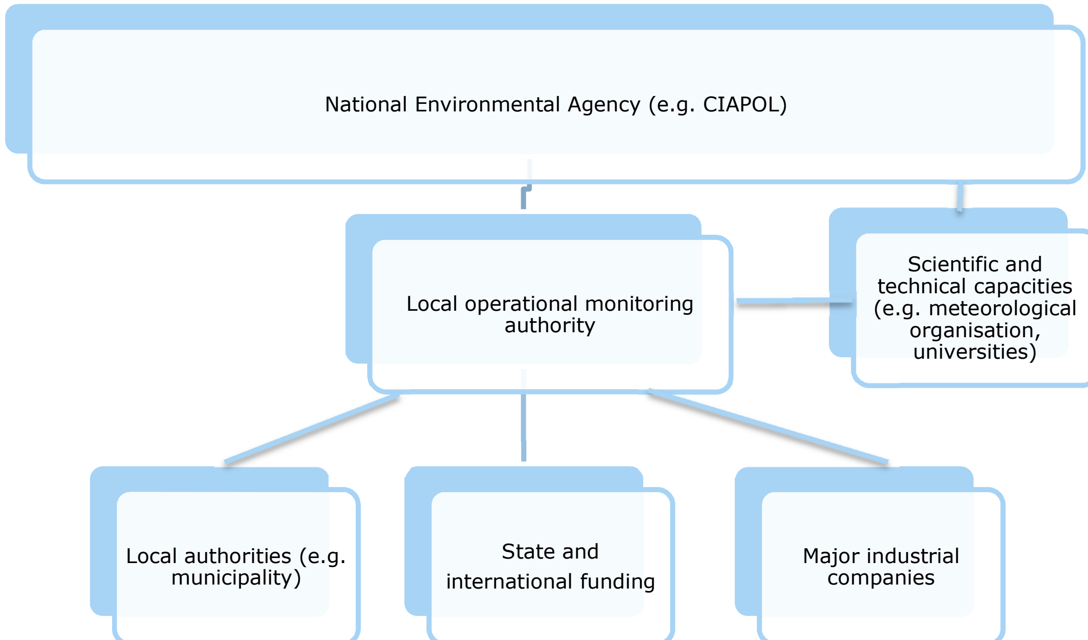
  Development of a sustainable monitoring network and its technical implementation (equipment, campaigns to undertake) are presented in more detailed later in the last section of this chapter.

- **Recommendation 2: Establish institutional framework for air quality monitoring**
  The assessment shows that Ivory Coast and Abidjan is the only jurisdiction with an operational monitoring agency (CIAPOL) under the Ministry of Environment. The Agency is tasked with collecting and assembling relevant environmental data as well as monitoring the development in transport emissions and the air quality. The other jurisdictions have different types of organisations tasked with the same responsibilities but the tasks are often scattered or placed with an organisation without the required capacity to undertake this responsibility.

  The key element for the five cities is not only to have operational monitoring agencies, but to have an entire institutional framework in place that can provide effective air quality measures. To this effect, previous benchmarking exercises have been undertaken to establish the principles for a well-functioning institutional framework[102]. In essence, international best practice suggests that a national network on air quality monitoring should be established under a national environmental agency as an overarching structure for the local authorities to report to. The local authorities should be given the operational responsibility coupled with the technical capacity to report in adherence to the agreed standards. Finally, the system relies on the polluters and other institutions to support the funding of the measures. An overview of the institutional set-up can be seen in the figure below.

[102] e.g. Programme Pilote Qualit'Air, Azad Environnement, Rabat, June 2014

Figure 7-1: Institutional Framework Overview



Ramboll suggests that all five institutional frameworks should include dedicated environmental agencies typically under the Ministry of Environment, who would be delegating the operational monitoring responsibility to an appropriate existing or newly established local authority. The Agency should oversee the dissemination of environmental information and act as the extended arm of the ministry as the operational law enforcement entity, in the event that the designated local authority does not deliver in accordance with expectations. It is important that the Agencies are given a clear legal mandate to act and sanction relevant counterparts if deficiencies in meeting the standards are detected. The agencies' composition should consist of a variety of profiles including regulators as well as environmental researchers. The latter would also be the case for the local authority.

As illustrated in the figure the foundation and the funding for the operational monitoring at the local level could come from a combination of: already allocated resources to the local authorities, earmarked funding from the ministry or environmental agency to carry out air quality monitoring, and potential taxes or fines from local companies violating the environmental standards. More efficiently, international funds dedicated to major transport and urban projects could be a good way to support regional and national air quality monitoring (see section 1.2.2.2).

The process for establishing these institutions would be for the ministries of environment to request for their creation and securing the operational expenses from the abovementioned sources. Ideally some of the existing tasks and staff that are currently placed in the ministries would be able to transfer, but it is foreseen that new staff and additional resources would be needed for the agencies' creation.

Assuming there is political will to make way for such operational agencies through legal and institutional reform, the next challenge will be for the agencies to attract and build the capacity of qualified personnel to handle their monitoring responsibility. This aspect will be addressed more specifically under recommendation 4.

- **Recommendation 3: Formulate Air Quality Standards**
  The assessment indicates that three out of the five cities/countries have not specified the desired Air Quality Standards. It is evident that without such standards the need to commit legally and politically towards an improved air quality is weak. The formulation and adoption of such standards will not automatically ensure an improved air quality, but it is a necessary starting point for specifying the desired targets to be achieved.

  The team suggest that the respective ministries of environment in Ivory Coast, Zambia and Cameroon takes the initiative to formulate a set of appropriate Air Quality Standards considering comparable regional standards and based on the international best practice as can be seen in e.g. the EU Standards, which refer to 13 key pollutants[103]. The WHO standards can serve as a guide and will require technical guidance from the institutions.

  It is foreseen that the ministries would establish an internal working group tasked with formulating a suggested set of standards, which can then be approved by the Minister and adopted by the Parliament.

  The recommendation is considered to be low hanging fruit that should be implementable for all three countries concerned in the near future. Furthermore, the costs for implementing such standards are assessed to be minimal as this should fall under the ministries' existing tasks. However, there could be a need for engaging an international consultant to assist with the actual formulation of the standards and any legal aspects that may occur in connection with its adoption.

  The effectiveness and sustainability of the formulated Air Quality Standards in the three countries will to a large extent depend on the success of some of the other recommendations (e.g. recommendations 2 and 4), as the standards will need capacitated monitoring agencies to take charge of the enforcement.

- **Recommendation 4: Ensuring sustainable capacity in air quality monitoring**
  In many ways air quality monitoring is a new discipline in most African countries. The data collection for the assessment showed that the area does not receive a lot of attention and that it does not hold a high priority. In that sense, it is not surprising that the area appears to fall short of qualified candidates and that it has been difficult to maintain the existing capacities.

  It is recommended that sufficient resources are allocated to the establishment of the new agencies including a considerable budget for attracting staff and for conducting relevant training activities in order to build the capacity of the newly recruited staff. In that sense, this recommendation will follow immediately after the establishment of the monitoring agencies and the training activities should be scheduled at an early stage after their initiation.

  As a supplement to the training activities, it could be considered introducing a career programme in the agencies to make it clearer what the outlook for their professional development in an environmental agency would be. This could include the possibility of exchanging staff with similar but more mature agencies in the region or overseas or arranging for on-the-job training sessions led by experienced specialists.

  Cities and countries should approach UNEP and International Consultancies for technical assistance. US EPA for instance is supporting the national enforcement and compliance networks in Rwanda, Burundi, Tanzania, Uganda and Kenya to strengthen their domestic environmental programs including air quality. The World Bank through its Pollution Management and Environmental Health (PMEH) Program, is also supporting Bangladesh with 11 monitoring stations installed to date in eight cities to generate real time air quality data.

[103] http://ec.europa.eu/environment/legal/law/5/e_learning/module_2_4.htm

The scope of this recommendation is broad and should be seen as a strategic policy ambition vested in the newly established operational agencies. Ideally the new agencies would be able to establish partnerships with international companies or universities and training institutions as a way of ensuring the technical expertise and as a potential source of financing through sponsorships or alike. Budget information is provided in the last section of this chapter, where potential sources of financing are discussed in part related to Recommendations 2 (see above) and section 1.2.2.2.

- **Recommendation 5: Integrate mandatory quantitative air quality component in EIAs**
  All five jurisdictions have legislation guiding the principles of undertaking an EIA. However, it is only Zambia where the legislation contains specific provisions on including air quality as part of a domestic EIA. As already indicated, the assessment finds that the issue of air quality does not receive a lot of attention in any of the jurisdictions when it comes to planning and implementing e.g. local transport and infrastructure projects.

  It is therefore suggested that a requirement to include an assessment of the potential impacts on the air quality is part of every EIA (when applicable), including a Cost/Benefit analysis (CBA) to also highlight positive effects of "green" transport projects. In practice, this requirement should be added to the existing legislation guiding EIAs and be included in the available practical guidelines on how to conduct EIAs. The assessment finds that the existing guidelines are generally quite broad, so ideally the updated guidelines would be as specific as possible in terms of how to incorporate a quantitative assessment of the air quality encompassing forecasting measures with reference to the Air Quality Standards.

  In practice, this recommendation requires that there is political will to update the legislation and any relevant guideline, which could take a bit of time, but which should not be a complicated and costly process. The actual formulation may require international expertise, but more importantly the updated framework should ideally be complemented by best practice practical examples and training activities that can help ensure that the new legislation is implemented and enforced.

  In case of projects supported by International Institutions, IFC Guidelines about Air Emissions and Ambient Air Quality[104] should always be considered.

- **Recommendation 6: Strengthen coordination of air quality efforts**
  The assessment shows that the limited existing efforts targeting air quality are scattered in all the five jurisdictions. It is evident that in particular the ministries of transport and the ministries of environment tend to be in opposition towards one another. In some countries attempts have been made to introduce various coordinating units involving the most relevant counterparts in relation to environmental issues in general. However, few if any of these units appear to have been very successful in their coordination efforts.

  As an attempt to remedy previously failed attempts, it is suggested for the newly established environmental agencies (and CIAPOL in Ivory Coast) to take the initiative to create and lead an AQ coordination unit drawing on capacities from e.g. the ministry of environment, the ministry of transport, the city authority, the meteorology institute, and universities.

[104] http://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/sustainability-at-ifc/policies-standards/ehs-guidelines

As lead, it is important that the agencies establish incentives for all counterparts to be part of the unit as a way of ensuring its relevance for all participants. Sitting allowances is a normal practice in many of the jurisdiction involved and though not a strong motivator for achieving results, it could be a prerequisite for the meetings to take place. Another option would be for the coordination unit to flag projects of common interest where there are political achievements to be made for all counterparts. An example of this could be infrastructure projects where air monitoring stations or EIAs (including an air quality component) are an integral part of the project implementation and where the success of the project will depend on all of these distinct elements.

The intention is that the members of the unit will be able to inform and involve each other in planned initiatives and to cooperate on relevant activities where there is a shared interest and capacity.

The establishment of the unit should come shortly after the monitoring agencies have been established, but apart from that the initiative should not require more than political will from the involved institutions and the costs connected with arranging the coordination meetings.

- **Recommendation 7: Increase transparency in air quality reporting**
  Apart from Morocco and Casablanca[105] there does not seem to be any published air quality measurements available in any of the five jurisdictions. In that sense, the awareness of potential air quality issues in either of the five cities is very low, and consequently there is no public pressure in terms of ensuring and demonstrating an acceptable air quality.

  In connection with this project and the instalment of air quality monitoring stations in the five cities, it is suggested to make all the measurements publicly available on the responsible authority's website, e.g. along the same lines as for Casablanca. Supposedly this would also be the case for Rabat, if the existing monitoring station was operational.

  As part of setting up the monitoring stations the project will assist in suggesting technical solutions for publishing the data on the relevant websites. This could incur additional costs for the authorities in terms of the technical design and other IT related services and it is recommended that the technical expertise is hired inhouse on a permanent basis for sustainability purposes. It is foreseen that the publication of data could be up and running shortly after the completion of the project.

7.3.3 Recommendations for implementing a monitoring network at city scale

As a follow-up to the monitoring campaigns performed in pilot areas of the selected cities, this section presents an approach to implement an air quality monitoring network at the scales of cities. Information concerning related costs are also provided. The successive steps proposed are the following:

- **Step 1: Selection of areas of interest**
  At first, in order to determine the number and implementation structure of future fixed monitoring sites, it is essential to identify several areas with different characteristics that can impact air quality, such as:
  - Population density;
  - Roads and traffic: such as transport corridors, narrow/wide streets, bus stations, and congested traffic zones;
  - Habitat type: including residential or commercial buildings, middle-class homes, and slums.
  - Local sources: such as industries, activities (e.g., cooking by street vendors), and waste burning;
  - Topography: for example, c how terrain and geography impact pollution levels are affected by features such as inversions and sea breezes.

[105] http://www.marocmeteo.ma/

Once several areas have been identified, attention should be focused on the most important ones, such as main transport corridors and high population density areas. Ideally, 4 or 5 neighborhoods should be identified.

- **Step 2: Air pollution diagnostic (preliminary campaign)**
  The objective of this second step is to assess air pollution in these areas by organizing temporary air quality measurement campaigns using:
  - Low-cost compact stations based on micro-sensing technologies. Half of the monitoring stations can be placed near transport corridors and the other half can be placed in densely populated areas. Typically, two air quality stations can be deployed during one week at 2 locations. In subsequent weeks, the sampling locations can be changed in order to quantify the pollution levels at 10 to 20 sampling locations. Another possibility is to organize mobile monitoring campaigns by walking slowly along a predetermined path in the identified neighborhoods with the air quality monitor and a GPS unit.
  - Co-located passive sampling tubes to measure NO_2 and SO_2. It is appropriate to distribute the samples in a regular mesh framework, with mesh interval spacing of several miles. Roads near high population centers should be given special attention and sampling resolution should be increased. The sampling period should be done for one or two weeks, and if possible, multiple seasons should be observed.
    For example: 10 sampling tubes can be used per neighborhood (5 with a regular mesh spacing and 5 along the main roads) during one week in one season and again for a second week in a later season. To lower the costs, it is possible to use half as many SO_2 devices compared to NO_2 devices. For example, 40 NO_2 and 20 SO_2 devices should be co-located during one week. It is estimated that it will take two people one day to set up 60 passive sampling tubes and one day to deposit them.

  An air quality compact station for several gases and particulate matter costs 1500 to 5000 USD, and one passive sampling device (including analysis cost) is 40 to 150 USD each. Thus, for a campaign using two air quality compact stations (3000 – 10,000 USD) and 60 passive sampling devices (approximately 4000 USD), total investment cost is less than 15,000 USD.

- **Step 3: Analysis of the results**
  The detailed analysis of the results from these preliminary campaigns will elucidate the following information:
  - Concentration levels for targeted pollutants;
  - Hot-spots zones, i.e. areas close to major roads, industries, and waste landfills;
  - The areas that are both densely populated and highly polluted;
  - The areas that are not particularly highly polluted but may be of interest (e.g., business centers, universities, hospitals, and parks);
  - Identification of areas and pollutants that require additional measurements.

- **Step 4: Implementation of permanent air quality stations**
  Based on the previous step, the optimal location of future fixed monitoring sites will be better understood. Their number and location are dependent on scientific and technical criteria, but also on administrative, political, and financial considerations. Installation of a comprehensive air quality survey is generally expensive, which is why cost optimization should be evaluated and performed. The following list presents the main considerations and results from a cost optimization analysis:
  - To install 1 to 3 permanent stations equipped with reference methods, the employees in charge will need to be trained in sampler maintenance and data quality assurance.
  - Additional low-cost monitoring networks with compact and mobile air quality devices (such as CAIRNET stations used in this AfDB project) will be developed in several areas of interest that were highlighted during the preliminary campaign. It is interesting to note that the

development of a Global Platform on Air Quality and Health framework will be aided by current UNEP actions to design an affordable national air quality monitoring network based on UNEP Air Quality Units for measuring particulates, key pollutants such as sulphur dioxide, nitrous oxide, and ozone (1500 USD/unit). Location and temperature can also be measured and there are supplemental calibration units that have an additional set of sensors for humidity.

Investment costs and operating costs for reference monitoring stations are quite expensive, therefore, we recommend to implementing 1 to 3 reference stations (depending on the size of the city) that use less expensive monitoring devices as presented in step 2 (above).

The table below indicates approximate costs for the reference equipment:

Table 7-1: Detailed costs for a reference station

Reference equipment	Costs
Nitrogen dioxide, carbon monoxide, sulfur dioxide	Approximately 15,000 USD each
Particulate matter PM10 or PM2.5	35 – 40,000 USD each
Equipped shelter	20,000 USD
Annual costs of an equipped shelter (gas, electrical power, climatization, communication etc.)	Approximately10,000 USD

Thus, the total cost for 2 permanent reference stations complemented by 10 compact stations should be approximately 350,000 USD + 20,000 USD annual costs.

In term of human resources, air pollution controls require solid technical and scientific skills and understanding. Conventional reference analyzers must be regularly calibrated; system calibration and maintenance must be performed at least twice a year. Ozone analyzers must be checked using a portable ozone generator and NO_x, SO_2, and CO analysers are checked using certified gas cylinders.

An operator will spend 4 – 8 hours a week per site for maintenance and servicing, including:

- Filters and charcoal replacement,
- Sample pumps verification,
- Teflon sample probe and line cleaning,
- Software updating.

However, the largest variable in personnel requirements is the amount of time needed to troubleshoot the system in the event of system failure.

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9. APPENDICES