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THE COST OF AIR POLLUTION IN LAGOS

Lelia Croitoru, Jiyoun Christina Chang and Andrew Kelly



NOVEMBER 2019

TASK TEAM LEADER: JOSEPH AKPOKODJE



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with Abimbola Adeboboye, Rose Alani, Iguniwari Ekeu-Wei, Jia Jun Lee and John Allen Rogers

Task Team Leader: Joseph Akpokodje

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1818 H Street NW
Washington DC 20433
Telephone: 202-473-1000
Internet: www.worldbank.org
Email: feedback@worldbank.org

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FOREWORD



Africa is home to some of the world's fastest growing cities. These cities are booming: they have job opportunities, infrastructure, and educational systems. But many are breathing polluted air. Every year, air pollution takes thousands of lives, particularly young children, and has negative impact on people's health. It devastates the poor. How long can this continue?

This report sheds light on the impact of air pollution in Lagos, one of the fastest growing megacities in the world. Using available ground-level monitored data and the most recent valuation techniques, the report shows that air pollution causes 11,200 deaths every year. Investing in actions to improve air quality would generate invaluable lifesaving benefits. Lagos is growing fast - there is no time to lose.

Maria Sarraf

Practice Manager

Environment, Natural Resources and Blue Economy, West Africa Region

World Bank



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EXECUTIVE SUMMARY

Ambient air pollution is a major contributor to mortality and morbidity. Fine particulate matter (PM_{2.5}) is especially harmful to human health. Globally, exposure to ambient PM_{2.5} caused 2.9 million premature deaths in 2017, or about 9 percent of total deaths in the world. In West Africa region, it was responsible for about 80,000 premature deaths¹ in the same year. The problem is particularly acute in Nigeria, which had the highest number of premature deaths due to ambient PM_{2.5} in the region; and especially in Lagos, the country's commercial capital and one of the world's fastest growing megacities. Despite growing concern about air pollution in Lagos, there is currently no reliable estimate of the impact of ambient air pollution, nor a comprehensive air pollution control plan. This report addresses this gap by providing an estimate of the impact of ambient PM_{2.5} on health, an analysis of the main pollution sources, and a set of possible options to control air pollution in Lagos.

Economic cost of air pollution. Currently, there are no operational air quality monitoring stations in Lagos. Available air quality data are largely based on short-term and irregular measurements, using air samplers. Only a few studies monitored PM_{2.5} over longer periods (e.g. one year) in a few representative locations of the city. Using these data and the exposed population in each location, this report quantifies the annual average PM_{2.5} concentration at about 68 µg/m³—which is in the same range with that of other very polluted megacities, such as Beijing and Cairo. It then estimates the health cost of air pollution at **US\$2.1 billion (Naira 631 billion)** in 2018.² This corresponds to about 1.3 percent of Lagos State's GDP.³ Exposure to ambient PM_{2.5} is responsible for about **11,200 premature deaths**⁴—the highest number in West Africa,⁵ making ambient air pollution **a very pressing challenge**. Children under five are the most affected group—primarily due to lower respiratory infections—accounting for about 60 percent of the total PM_{2.5}-related deaths.⁶ Special attention should be targeted to this age group when designing programs for reducing health impacts from air pollution.

1 Moreover, exposure to household air pollution from solid fuels was responsible for an additional 172,000 premature deaths in 2017 (<https://vizhub.healthdata.org/gbd-compare/>).

2 It is in the same range as the cost of ambient air pollution in Greater Cairo, estimated at US\$2.6 billion, or 1.35 percent of the country's GDP in 2017 (World Bank 2019a).

3 Based on Lagos State' GDP estimated at US\$157.7 billion for 2018 by the Lagos Bureau of Statistics (<https://lagosstate.gov.ng/about-lagos/>)

4 A portion of this estimate accounts for deaths due to the joint effect of exposure to both ambient and household air pollution (WHO 2018).

5 It is substantially higher than in many other West African capitals such as Abidjan, Cotonou, Dakar and Lomé.

6 This result is consistent with the 2017 GBD study, which found that children under five account for a similar proportion in the total ambient PM_{2.5}-related deaths at the national level in Nigeria.

Pollution sources. Road transport, industrial emissions, and power generation are major contributors to air pollution in Lagos. Although a refined source apportionment study is needed to quantify the contribution of each source, road transport stands out as a key source of PM_{2.5}, primarily due to: high vehicle density (227 vehicles/km/day), use of old emission technologies (most cars are older than 15 years), high sulfur content in imported diesel and gasoline fuel (3,000 ppm in diesel and 1,000 ppm in gasoline), and limited transportation options in the city (there are only 1.3 km/million people of intra-city rail, far less than in other megacities).

Pollution control options. Based on the experience of other developing countries, options that could be investigated to reduce emissions in the main polluting sectors in Lagos relate to:

- » *road transport*, e.g. incentives for purchasing cleaner passenger vehicles, vehicle inspections, retrofitting the most polluting vehicles, shift to public transport, adoption of cleaner fuel, etc. Some of these measures are already underway: for example, standards for fuels were lowered to 50 ppm for diesel and 150 ppm for gasoline in 2017. However, these changes are still awaiting Government approval and implementation.
- » *industry and power*, e.g. implementation of best available technologies in the most polluting industries; use of solar cells with battery storage for power generation.
- » *other sectors*, e.g. waste, agriculture, construction and shipping.

The options identified above include measures that have been successfully implemented in different countries to curtail air pollution. However, the choice of measures

should be based on the cost of implementing them and the associated benefits in terms of reducing air pollution, which further depend on the context of Lagos. It is clear from the outset that no single action can solve the air pollution challenges faced by the city. An evidence-based air pollution control plan, that considers actions across the most polluting sectors, is required and envisaged by the Lagos PMEHA/AQM project.

Priority areas for future work. This study is based on a comprehensive review of existing air quality monitoring, health information and sectoral data in Lagos; and intervention options that have successfully reduced air pollution in other developing countries. However, available information in many of these areas are limited. To refine these results, priority areas for future work are presented below, most of which are expected to be delivered by the Lagos Pollution Management and Environmental Health/Air Quality Monitoring (PMEHA/AQM) project:

- » conduct long-term monitoring of ambient PM_{2.5} in several locations, representative for major activities in the city (e.g. transport, industry, landfills), applying international best practices.
- » centralize health data (e.g. mortality and morbidity by cause and age) at the city level.
- » develop and validate an inventory of air pollutant emissions in Lagos.
- » conduct refined source apportionment works that quantify and localize the contribution of each major source of pollution to the PM_{2.5} concentration in the city.
- » identify a suitable set of air pollution control options, based on their economic, technical and institutional feasibility in Lagos.
- » examine the impact of household air pollution on health in Lagos.



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CHAPTER 1

OVERVIEW OF AMBIENT AIR POLLUTION IN LAGOS

Cities are nowadays at the center of economic activities, and urbanization is an unavoidable path to development (Folberth et al. 2015). However, high rates of urbanization and industrial development contribute to increasing pollutant emissions in the atmosphere. Air pollution has devastating effects particularly in the world's growing megacities⁷ (Gurjar et al. 2008; Mage et al. 1996); these effects are more pronounced in the megacities of developing countries (Komolafe et al. 2014). This chapter discusses the problem of ambient air pollution in Nigeria, with special focus on ambient fine particulate pollution in Lagos.

1.1. INTRODUCTION

Ambient air pollution is a major contributor to human mortality and morbidity (Cohen et al. 2005). World Health Organization (WHO) identified four pollutants for which there is strong evidence of health effects on humans: particulate matter (PM), ozone (O₃), sulfur dioxide (SO₂), and nitrogen dioxide (NO₂) (WHO 2005). Among them, PM has received significant attention in recent years due to its adverse impact on health. It is the most relevant indicator for urban air quality (Cohen et al. 2005). In particular, long-term exposure to fine particulate matter (PM_{2.5})—particulate matter with aerodynamic diameter of less than 2.5 micrometers, is especially harmful to health, as it can pass the barriers of the lung and enter the blood stream, causing premature deaths as well as respiratory and cardiovascular diseases (Brook et al. 2010)⁸. Therefore, this report focuses primarily on PM_{2.5}.

Globally, ambient PM_{2.5} pollution caused 2.9 million premature deaths, or about 9 percent of total global deaths in 2017 (GBD 2017 Risk Factor Collaborators 2018). In West Africa region, it was responsible for about 80,000 premature deaths in the same year. The problem is particularly acute in Nigeria, the country with the *highest*

⁷ Megacities are urban agglomerations having over 10 million inhabitants (<https://population.un.org/wup/>).

⁸ Because of its significant impact on health, recent global flagship reports on health and air pollution by the World Bank, WHO and Organization for Economic Co-operation and Development (OECD) focused on PM_{2.5} (OECD Development Centre 2016).

number of premature deaths in the region due to ambient PM_{2.5} pollution (49,100). Overall, the rate of premature mortality due to ambient PM_{2.5} pollution in Nigeria (23.8 premature deaths per 100,000 people) is well above the average for the West Africa region (18.4 premature deaths per 100,000 people).⁹

Lagos is the commercial and economic hub of Nigeria. It is also one of the world's fastest growing megacities, expected to become the largest city by 2100¹⁰ (Hoornweg and Pope 2016). It generated 25 percent of the country's Gross Domestic Product (GDP) in 2015, and 70 percent of the country's industrial and commercial activities (Owoade et al. 2013; PwC 2015). Fast urbanization and industrialization have exposed the majority of population to high levels of air pollution, with negative impacts on human lives (Olowoporoku, Longhurst, and Barnes 2012) and on changing climatic conditions (Komolafe et al. 2014). The following sections briefly review the available studies on ambient PM_{2.5} concentration in Lagos.

1.2. AMBIENT PARTICULATE MATTER POLLUTION IN LAGOS

Currently, there are no operational air quality monitoring stations in Lagos¹¹. Available PM_{2.5} data are largely based on short-term and irregular measurements, using air samplers (e.g., Gent stack filter unit samplers). Table 1 presents an overview of the most recent data on PM_{2.5} concentrations in Lagos. It includes results of ground-level measurements conducted by the Government (e.g. Lagos State Environmental Protection Agency, LASEPA) and other entities (e.g. University of Lagos), and satellite-

derived data. The table shows that PM_{2.5} concentration varies from 12 µg/m³ to 85 µg/m³, depending on the location, season, time frame and year of sampling.

It should be noted that most studies using *ground-level measurements* collected data for less than three months. However, Nigeria's climate has pronounced wet and dry seasons, resulting in seasonal variations in ambient PM_{2.5} concentration due to differences in pollutant dispersion and deposition (Petkova et al. 2013). In addition, some studies collected data at the most polluted sites during the emissions peak time. For example, uMoya Nilu Consulting (2016) measured PM_{2.5} concentration for seven days during peak time in a few hotspots in Lagos, showing concentrations that range between 2 µg/m³ and 1770 µg/m³. While these studies may reflect instances of extreme pollution events, data collected for such a limited period and at the extreme condition do not adequately represent the current status of the PM_{2.5} pollution in Lagos.

In addition, Etchie et al. (2018) provided an assessment based on satellite-derived data for Lagos State. However, satellite information at the local level can be reliable only after calibration with ground-level data, which was not conducted by the authors.

The above paragraphs suggest that **most of the existing efforts do not reflect reliably the average annual PM_{2.5} concentration in Lagos**. Chapter 2 estimates the average population weighted PM_{2.5} concentration at 68 µg/m³, based on the most recent publication found with long-term monitoring (Ezeh et al. 2018). This should be considered as a *preliminary* estimate that needs to be updated in the future, based on long-term monitoring efforts.

9 See IHME website, <https://vizhub.healthdata.org/gbd-compare/>. In addition, a recent study indicated Nigeria as the country with the highest increase in the mean annual PM_{2.5} concentration (above 30 µg/m³) between 1990–2015, after Bangladesh (World Bank 2019). The study compared changes in the mean annual PM_{2.5} for 42 low- and middle-income countries.

10 Although there are many ways to measure the growth of a city, Hoornweg and Pope (2016) refer to population growth.

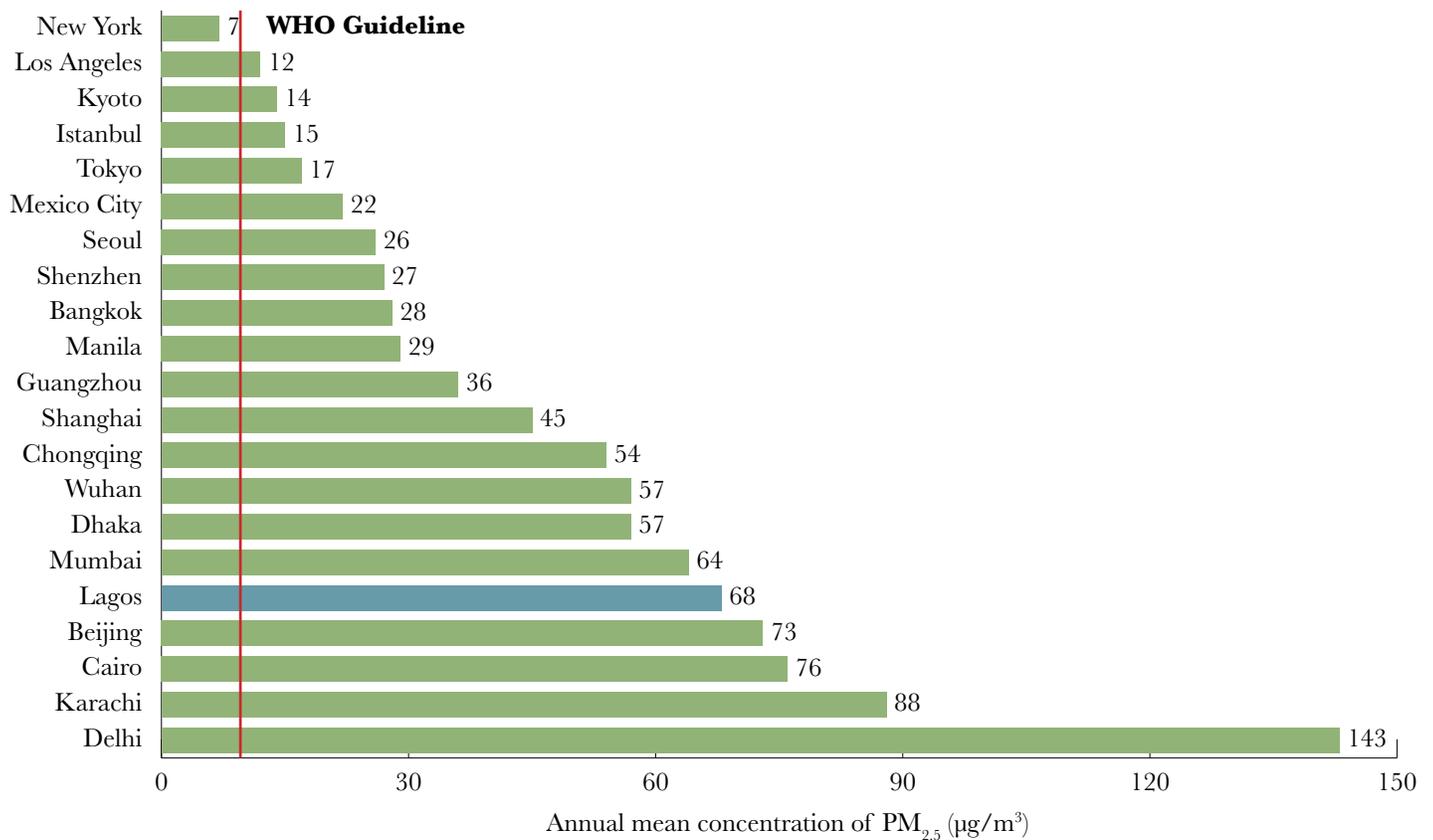
11 The Nigerian Meteorological Agency (NiMET)-owned air quality monitoring station in Lagos is currently not operational due to power unavailability, poor maintenance and lack of human, technical and financial resources to sustain the monitoring program.

TABLE 1: PM_{2.5} CONCENTRATION IN LAGOS CITY

Type of location	Name of location	PM _{2.5} concentration (monitored, µg/m ³)	Mean PM _{2.5} concentration (µg/m ³)	Author	Measurement schedule (c)
GROUND-LEVEL MEASUREMENTS					
Residential	C.M.S. Grammar School, Bariga	28			
Heavy traffic	Amuwo-Odofin Mini Water Works	31	27	Owoade et al. (2013)	Data collected twice every fortnight during February–October 2010, between 7 am–7 pm.
Marine	Law School, Victoria Island	25			
Industrial	Oba Akran Road, Ikeja	26			
High density residential	n.a.	35		Obioh et al. (2013)	Data collected for one day in each site, during September–October 2009. The sampling time covered 2 hours during mornings (6–11 am), afternoons (12–3 pm) and evenings (4–9 pm).
Low density residential	n.a.	12	23		
Industrial	n.a.	30			
Commercial	n.a.	14			
Industrial	Ikeja; Amuwo Odofin; Kirikiri; Ikorodu.	62			
Residential	M.K.O. Abiola Gardens, Ikeja; Alaka Estate, Surulere; Oloje Street, Matori; VGC, Lekki.	42		LASEPA (2014)	Data collected during March – April 2014, two weeks per month.
Highways	Ojota, Gani Fawehinmi Park; Oshodi; Lekki Toll Gate; Ikorodu Central Junction.	55	53		
Industrial	Ikeja	77	68 (a)	Ezech et al. (2018)	Data collected during daytime, two days a week during December 2010–November 2011.
High density residential	Mushin	85			
Low density residential	Ikoyi	41			
Transport	Transport sector locations and residential areas of the Mainland Local Government Area	69	52	Obanya, Nnamdi and Togunde (2018)	Fifty two samples collected during September–November 2017. Exposure duration for sampling was 2 hours per site.
Residential		35			
Industrial, commercial, residential, dumpsite, heavy traffic, high population density	Apapa, Idumota, Odogunyan, Olusosun, Okobaba, Pen Cinema, Nigerian Conservation Foundation (NCF) Lekki	Sec note (b)	Sec note (b)	uMoya Nilu Consulting (2016)	Seven-day sampling during peak times for 3 hours (6–9 am and 4–7 pm) between 11 and 18 December 2015.
Transport	University of Lagos (UNILAG)	66	66	Communication with UNILAG (Dr. Rose Alani)	Data collected during November 2018–March 2019, based on continuous sampling for 4 days in November, 10 days in December, 11 days in January, 16 days in February and 6 days in March.
SATELLITE DATA					
Local Government Authorities of Lagos	Agege, Ajeromi-Ifelodun, Amuwo-Odofin, Apapa, Eti-Osa, Ikeja, Lagos Island, Lagos Mainland, Mushin, Oshodi Isolo, Surulele.	24–32	27	Erchie et al. (2018)	Based on satellite data derived from van Donkelaar et al. 2016 for 2015.

Notes: (a) The mean PM_{2.5} concentration is a population-weighted average, based on GIS mapping. (b) The report provided only the minimum and maximum PM_{2.5} concentrations recorded at each monitoring site, for example: in Apapa, between 16–280 µg/m³ in the mornings; and between 22–274 µg/m³ in the evenings. It does not provide all the recorded observations, which are necessary to calculate a meaningful average. n.a. = not available. (c) If not specified, information on the average time of sampling and timing of the day is not available.

FIGURE 1: ANNUAL MEAN CONCENTRATION OF PM_{2.5} IN DIFFERENT MEGACITIES



Sources: Chapter 2 for the concentration in Lagos. WHO 2016 and 2018 for the concentration in the other cities.

Despite inherent limitations, this estimate—and all the other results reported in Table 1—indicate that ambient PM_{2.5} concentration in Lagos exceeds the guideline set by the WHO for the annual mean PM_{2.5} concentration of 10 µg/m³ (WHO 2005)¹². Figure 1 presents the average annual PM_{2.5} concentrations in several megacities over the world. The estimated value places Lagos close to the most polluted megacities in the world e.g., Beijing and Cairo.

Overall, available PM_{2.5} data are based on sparse and short-term sampling efforts. Reasons for insufficient

monitoring include: limited equipment for sustained air quality monitoring; inadequate institutional, human and financial capacity; absence of stringent air quality standards at the national and state levels; lack of appropriate guidelines on air quality monitoring practices; lack of monitoring enforcement; and limited incentives to address these problems. To improve the quality of existing PM_{2.5} concentration data, monitoring equipment and long-term monitoring using best practices are highly needed in several locations representative for major activities in the city, e.g. transport, industry, power generation and landfills.

¹² WHO also specifies that no threshold has been identified below which no damage to health is observed, and therefore, recommends to aim at achieving the lowest concentration of PM possible (WHO 2005). In addition, the GBD 2017 Risk Factor Collaborators (2018) identify the theoretical minimum risk exposure level between 2.4 µg/m³ and 5.9 µg/m³ for both household and ambient PM.

CHAPTER 2

THE COST OF AIR POLLUTION IN LAGOS

This chapter estimates in monetary terms the impacts of ambient $PM_{2.5}$ on health in Lagos city. Lagos State covers 20 local government authorities (LGAs), with a population estimated at 25.6 million in 2018¹³. The analysis *targets only Lagos city*, which covers only 17 LGAs, with 24.4 million people¹⁴. As the study was conducted during a short period of time (October 2018—March 2019), it is based only on secondary data.

2.1. COST OF AIR POLLUTION

Exposure to ambient $PM_{2.5}$ is responsible for *premature mortality*, primarily due to respiratory and heart diseases; and *morbidity*, due to problems such as chronic bronchitis, hospital admissions, work loss days, restricted activity days, and acute lower respiratory infections in children (Hunt et al. 2016; World Bank 2016). We estimate the cost related to these outcomes in four steps, presented below.

1. **Select data on the $PM_{2.5}$ concentration.** Based on the overview of the $PM_{2.5}$ concentration presented in Chapter 1, only two studies provide data monitored over relatively long periods of time: twice every fortnight for nine months, from February to October 2010, by Owoade et al. (2013); and two days a week for one year, from December 2010 to November 2011, by Ezech et al. (2018). As Ezech et al. (2018) monitored $PM_{2.5}$ concentration more frequently over a longer period of time, we use their results to estimate the population-weighted $PM_{2.5}$ concentration for Lagos city in the following step.
2. **Estimate the population-weighted $PM_{2.5}$ concentration.** This is conducted by using data on:
 - » $PM_{2.5}$ concentration measured at three monitoring stations: Ikeja ($77 \mu\text{g}/\text{m}^3$), Mushin ($85 \mu\text{g}/\text{m}^3$) and Ikoyi ($41 \mu\text{g}/\text{m}^3$) (Table 1).

¹³ Based on records derived from the 2006 population census and further projections carried out by Lagos Bureau of Statistics.

¹⁴ It covers all LGAs except Badagry (555,200 people), Epe (472,300 people) and Ibeju-Lekki (145,300 people).

- » Proportion of the population exposed to air pollution around each of the above monitoring stations, estimated by World Bank staff, using Geographic Information System (GIS)¹⁵: Ikeja (18 percent), Mushin (46 percent) and Ikoyi (36 percent).

Based on the above, the average population-weighted PM_{2.5} concentration is estimated at¹⁶ 68 µg/m³. Considering that most PM_{2.5} monitoring efforts in Lagos have been conducted sporadically and over short periods of time, it is not possible to compare this estimate with a recent long-term ground-level measurement. However, it should be noted that the Department of Chemistry of the University of Lagos started PM_{2.5} monitoring in November 2018; data collected till the time of writing this report (March 2019) show an average PM_{2.5} concentration of 66 µg/m³ (Communication with Dr. Rose Alani, Department of Chemistry, University of Lagos). Although a direct comparison between the two estimates is difficult—due to the difference in the monitoring period and specific locations of the measurement—they suggest that the estimated 68 µg/m³ is a reasonable (preliminary) approximation of the average PM_{2.5} concentration in Lagos.

3. **Quantify the health impacts of exposure to PM_{2.5}.** Several epidemiological studies revealed strong correlations between long-term exposure to PM_{2.5} and premature mortality (Apte et al. 2015; Cohen et al. 2017): ischemic heart disease; stroke¹⁷; chronic obstructive pulmonary disease; tracheal, bronchus and lung cancer; and diabetes mellitus type 2¹⁸; and to lower respiratory infections in all ages (GBD 2017 Risk Factor Collaborators 2018).

15 The estimation was conducted using the GIS, based on the following method: (i) mapping the monitoring sites, using the coordinates of the locations from GoogleMaps; (ii) spatially join the population value that intersect the location of each site; (iii) calculate the share of population at site versus the total population of the city; (iv) derive the population exposed at each site using the share and population values.

16 It should be noted that the 2019 State of Global Air report indicates a population-weighted average of 72 µg/m³ for 2017 in Nigeria (HEI 2019).

17 This includes ischemic stroke, intracerebral hemorrhage and subarachnoid hemorrhage (<http://ghdx.healthdata.org/gbd-results-tool>).

18 Evidence suggests that exposure to PM_{2.5} can be linked to type 2 diabetes through altered lung function, vascular inflammation, and insulin sensitivity (Rajagopalan and Brook 2012).

We estimate the number of deaths attributable to air pollution (PM_{2.5}) using data on: (i) mortality¹⁹ by disease and age group, based on the 2017 Global Burden of Disease study (IHME, 2017); (ii) proportion of deaths due to PM_{2.5} calculated by using specific relative risk factors, which are available by disease, age and PM_{2.5} concentration²⁰.

The results show that exposure to ambient PM_{2.5} is responsible for about **11,200 premature deaths** in 2018²¹. Lower respiratory infections are the leading cause of PM_{2.5}-related mortality; children under five are the most affected group, accounting for about 60 percent of total deaths (Figure 2). This result is consistent with the 2017 GBD study at the national level in Nigeria, which found that children under five account for a similar proportion in the total ambient PM_{2.5}-related deaths.²² It is important to note that under five mortality due to lower respiratory infections (all causes combined) in Nigeria is the second highest in the world (153,100 cases), after India (185,400 cases)²³.

4. **Estimate the value of health impacts due to exposure to PM_{2.5}.** We estimate in monetary terms the impacts of PM_{2.5} on health as follows:
 - » The cost of *mortality* is estimated based on the Value of Statistical Life (VSL), which reflects people's willingness to pay to reduce their risk of death.

19 Similar to other countries, mortality data by age and disease in Lagos city are not readily available. In the absence of these data, the estimation uses national-level information, which are adjusted based on the ratio between the population in Lagos and that at the national level. The base information at the national level was derived from IHME database (<http://ghdx.healthdata.org/gbd-results-tool>)

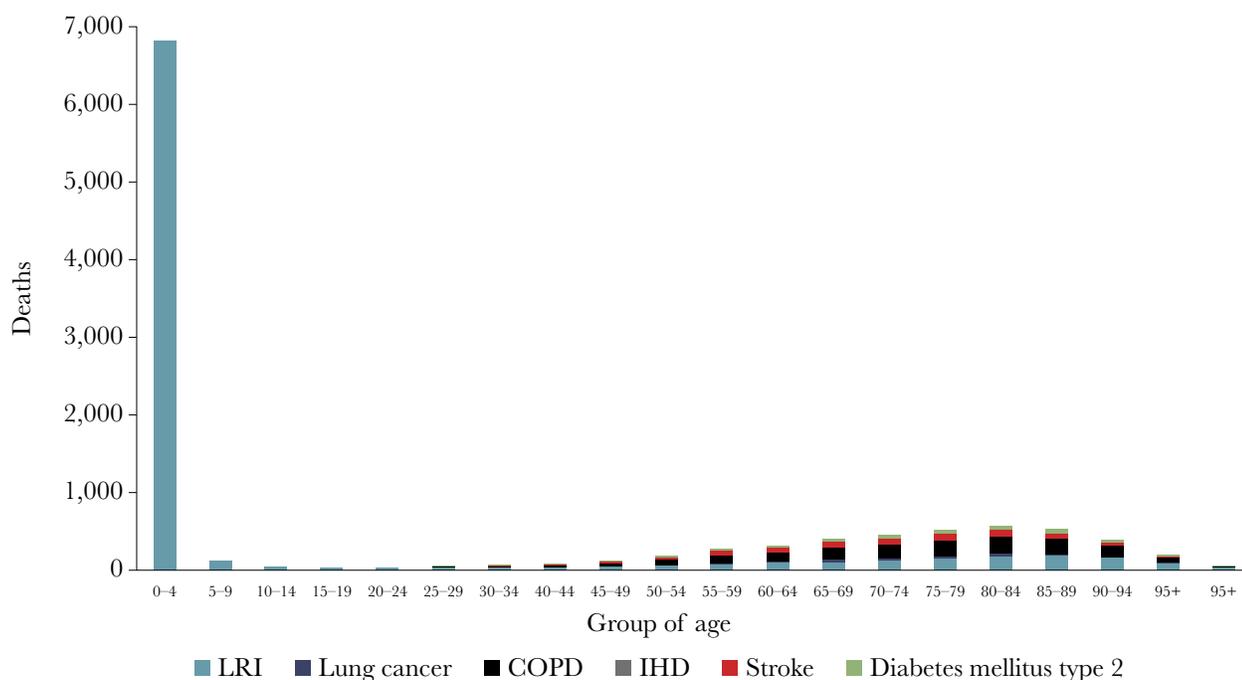
20 For more details, see GBD 2017 Risk Factor Collaborators (2018).

21 It should be noted that a portion of this estimate accounts for deaths due to the joint effect of exposure to both ambient and household air pollution (WHO 2018). Adjusting the estimate to capture only the impact of ambient air pollution would require the quantification of the number of people exposed to both household and ambient air pollution; in-depth knowledge about the causes of household air pollution; and data on household PM_{2.5} concentration in the affected areas. As this report did not focus on household air pollution, this adjustment was not made.

22 The number of deaths due to ambient PM_{2.5} in Nigeria was estimated at 49,100 for 2017, of which children under five accounted for 29,900, or 61 percent of the total (<http://ghdx.healthdata.org/gbd-results-tool>).

23 Data refer to 2017, based on IHME, <https://vizhub.healthdata.org/gbd-compare/>.

FIGURE 2: MORTALITY DUE TO PM_{2.5} EXPOSURE, BY AGE GROUP



Source: Authors, based on data from IHME (2018) and GBD 2017 Risk factors collaborators (2018)

Notes: IHD = ischemic heart disease; LRI = lower respiratory infections; COPD = chronic obstructive pulmonary diseases.

We use a VSL for Nigeria of about²⁴ US\$167,400, based on benefits transfer of a base value from a meta-analysis conducted in OECD countries (World Bank 2016). Accordingly, the cost of mortality is estimated at **US\$1.9 billion**.

- » The cost of *morbidity* includes resource costs (i.e. financial costs for avoiding or treating pollution-associated illnesses), opportunity costs (i.e. indirect costs from the loss of time for work and leisure), and disutility costs (i.e. cost of pain, suffering, or discomfort). The literature assessing causal relationships between exposure to PM_{2.5} and morbidity is much more limited than that for mortality (Hunt et al. 2016).

So far, no commonly accepted method has been developed to value the overall cost of morbidity due to air pollution (OECD 2014). However, results of studies conducted in several OECD countries indicate that morbidity costs account for a small percentage of mortality costs (Hunt et al. 2016; Narain and Sall 2016; OECD 2014). On this basis, OECD proposed a 10 percent markup of mortality cost to account for morbidity (Hunt et al. 2016). Using this assumption also for Lagos, the cost of morbidity is estimated at about **US\$0.2 billion**.

Based on the above, the cost of mortality and morbidity due to air pollution from PM_{2.5} exposure is estimated at **US\$2.1 billion**, or 0.5 percent of the country’s GDP in 2018²⁵. This corresponds to about **1.3 percent of the Lagos State’ GDP** in 2018.²⁶

24 Other estimates for the VSL in Nigeria are US\$485,000 by Viscusi and Masterman (2017), and US\$489,000 by Yaduma, Kortelainen, and Wossink (2013). This report uses a different estimate (US\$167,400), based on a base value derived from a meta-analysis of values from several OECD countries, rather than just for one country (United States).

25 This is based on a GDP of US\$397.3 billion in Nigeria (current prices, 2018). (<https://data.worldbank.org/>).

26 Based on a GDP for Lagos State estimated at US\$157.7 billion for 2018 by the Lagos Bureau of Statistics (<https://lagosstate.gov.ng/about-lagos/>, accessed in October 2019).

2.2. DISCUSSION

To the authors' knowledge, this is the first study estimating the health cost of air pollution in Lagos city, based on ground-level monitored data. Previous studies valuing the cost of air pollution in Nigeria are also worth noting. For example, Etchie et al. (2018) estimated the health cost of air pollution in all Nigerian states, based on satellite-derived $PM_{2.5}$ data; the result for Lagos State was substantially lower than that of the present study (US\$1.1 billion vs. US\$2 billion), primarily due to the use of a lower $PM_{2.5}$ concentration data and a slightly different methodology²⁷. Yaduma et al. (2013) estimated the economic cost of PM_{10} pollution at the national level at US\$33.5 billion in 2006, using an earlier methodology (Ostro 1994), not comparable to that employed in the present study (GBD 2017 Risk Factor Collaborators 2018).

It is interesting to put the results of the present study in a broader regional context. Table 2 presents results of recent studies that estimated the cost of ambient air pollution in Dakar (Senegal), Cotonou (Benin), Lomé (Togo), Abidjan (Côte d'Ivoire) and Cairo (Egypt) (Croitoru, Miranda and Sarraf 2019; World Bank 2018). Among the West African cities, air pollution is a particularly pressing challenge in Lagos, the city with the highest number of $PM_{2.5}$ -related deaths, both in absolute (11,200 deaths) and relative terms (46 deaths per 100,000 people). It is slightly lower than in Cairo, which has a higher level of ambient $PM_{2.5}$ concentration.

Every effort was made to calculate meaningful estimates of the impact of air pollution, based on reliable information. Nonetheless, the analysis remains subject to some data and methodological *limitations*. Data constraints include use of old information on ground-level $PM_{2.5}$ concentration, which refer to 2010–2011; and of estimates of mortality by disease and age from global statistics (IHME). Methodological limitations are related to the use

²⁷ The difference between the two estimates is due to: (i) use of ground-level $PM_{2.5}$ measurements in the present study, averaging to 68 $\mu\text{g}/\text{m}^3$, compared to the use of satellite-derived $PM_{2.5}$ data, averaging 27 $\mu\text{g}/\text{m}^3$ by Etchie et al. (2018); (ii) use of an updated methodology in the present study (based on GBD 2017; see GBD 2017 Risk factor collaborators, 2018), compared to the previous one (based on GBD 2015; see Cohen et al. 2017); (iii) use of different estimates of the VSL.

TABLE 2: IMPACT OF AIR POLLUTION IN SELECT COASTAL CITIES OF AFRICA

Losses	$PM_{2.5}$ ($\mu\text{g}/\text{m}^3$)	Deaths due to air pollution	Deaths/ 100,000 people
Dakar	21	270	25
Cotonou	32	200	32
Lomé	32	490	31
Abidjan	32	1,500	35
Lagos	68	11,200	46
Cairo	76	12,600	73

Sources: Authors for Lagos; World Bank 2019a for Cairo; Croitoru, Miranda and Sarraf (2019) for other cities. A portion of these estimates represents deaths due to the joint effect of exposure to ambient and household air pollution.

of the VSL concept to estimate mortality. Although the concept has been commonly used (Viscusi and Masterman, 2017), its application is still subject to challenges, e.g., (i) in countries where primary surveys have been conducted, its application often generated a wide variety of results, depending on the approach used, type of survey, etc.; (ii) in countries with no primary surveys, the VSL has been usually obtained through benefits transfer of a value from a different country. The latter is the case of the present study, where the VSL has been obtained through benefits transfer of a base value from OECD countries, following the guidelines of World Bank (2016). Thus, it should be noted that the result is a very conservative estimate of the VSL, which does not capture the real value of life.

Overall, this analysis points to the following key messages:

- » Exposure to ambient $PM_{2.5}$ has significant health impacts in Lagos, costing society about **US\$2.1 billion**, or **Naira 631 billion**²⁸ in 2018. This is a conservative estimate, based on $PM_{2.5}$ data monitored during 2010–2011; ever since, economic development and traffic growth have most likely led to increased atmospheric pollution. Even though conservative, the estimate is still much higher than that of other coastal cities in West Africa, calling for urgent action to improve air quality in Lagos.

²⁸ Using an exchange rate of US\$1 = Naira 306, reported by the International Monetary Fund for 2018 (data.worldbank.org, accessed October 2019).

- » Exposure to $PM_{2.5}$ caused about **11,200 premature deaths**. Children under five were the most affected group, accounting for about 60 percent of total deaths. This alarming result is consistent with the 2017 GBD study, which found that children under five account for a similar proportion in the total ambient $PM_{2.5}$ -related deaths at the national level in Nigeria.
- » This analysis was conducted by using limited and relatively old²⁹ available data on ground-level $PM_{2.5}$

concentration and by adjusting national level information on mortality by disease and age from IHME statistics. **Longer-term monitoring of $PM_{2.5}$** and **better centralization of health data** at the city level are needed for future refinement of this analysis and for designing policies to improve air quality. These are among the core objectives of the Lagos PMEH/AQM project, which is direly needed in Nigeria, and particularly in Lagos.

²⁹ The data used are related to 2010–2011.



Photo Credit: Richard J Greenman / Alamy Stock Photo

CHAPTER 3

SOURCES OF AIR POLLUTION

Understanding sources of pollutants and their contribution to air pollution is the first step to design effective strategies for cleaner air. PM is a complex pollutant that consists of *primary* particles (directly emitted) and *secondary* particles (formed in the atmosphere from precursors) (Zhang et al. 2017). These particles can be derived from natural (e.g., sea spray and wildfires) and anthropogenic sources (e.g., industrial or agriculture activities and fossil fuel combustion).

There are multiple sources of PM_{2.5} pollution in Lagos. These include road transport (Ibitayo 2012), heavy energy dependence on inefficient diesel and gasoline generators (~50 percent of total energy demand) due to unreliable power supply (Cervigni, Rogers, and Dvorak 2013; Oseni 2016), poor waste management (open dumpsite and illegal burning of waste) (Adegboye 2018), ongoing construction to build infrastructure (Adama 2018) and use of polluting fuel and stoves for household cooking (Ozoh et al. 2018). This chapter summarizes the findings of the **available** PM_{2.5} source apportionment studies in Lagos, and analyzes the situation of road transport, as a key source of ambient air pollution in the city.

3.1. REVIEW OF SOURCE APPORTIONMENT STUDIES IN LAGOS

Only a few studies on PM_{2.5} source apportionment based on long-term monitoring were found for Lagos. An air quality monitoring study conducted by Lagos Metropolitan Area Transport Authority (LAMATA) used positive matrix factorization (PMF) analysis to identify the sources of PM_{2.5}. The results indicated that road transport was the major cause of pollution in the city in 2007: vehicular emissions accounted for 43 percent of total PM, followed by sea salt particles (26 percent) and metallic smelting companies (9 percent) (LAMATA 2008, 2016).

Owoade et al. (2013) conducted principal component factor analysis (PCA) based on data collected from February to October in 2010 in four locations. The authors found

that: vehicular traffic was the major contributor to the $PM_{2.5}$ concentration in three locations, representative for residential (C.M.S. Grammar School, Bariga), heavy traffic (Amuwo-Odofin Mini Water Works) and marine areas (Law School, Victoria Island); while industry—followed by traffic—was the largest contributor to $PM_{2.5}$ concentration in an industrial area (Oba Akran Road, Ikeja).

More recently, Ezeh et al. (2018) conducted PMF using $PM_{2.5}$ data collected from December 2010 to November 2011 at three locations representative for low density residential zones (Ikoyi), high density residential zones (Mushin) and industrial areas (Ikeja). The authors concluded that the major source of $PM_{2.5}$ pollution in Lagos was petroleum oil combustion, accounting for 70 percent of the overall $PM_{2.5}$ mass load; this was explained through the cumulative impact of emissions from vehicular traffic and use of petrol-driven electric generators.

The methods used in the above studies—PMF and PCA—are receptor-oriented models that apportion the sources based on observation at the monitoring sites. Compared to other receptor-oriented models (e.g., chemical mass balance), these methods do not require prior knowledge of the sources and of the source profiles (Hopke 2016). A common issue of these approaches is that the resulting components or factors may represent mixtures of several emission sources rather than independent sources (Viana et al. 2008). Thus, finding the optimal number of components to fit the datasets is key to using these methods for source apportionment. Yet, the above publications do not discuss other details on selecting the number of components, the goodness of model fits, or uncertainties. Thus, a refined source apportionment study based on long-term monitoring data is needed to quantify the contribution of each source to the $PM_{2.5}$ pollution in Lagos.

Overall, these results suggest that *road transport, along with industrial emissions and power generation, were the largest contributors to $PM_{2.5}$ pollution in Lagos* during the period considered in the above studies. However, it is important to note that: (i) road transport accounts for over 90 percent of total consumption of petroleum products in Nigeria (IEA 2018); (ii) Lagos accounts for more than 90 percent of vehicle registrations in the country (Nigeria National Bureau of Statistics 2018b). This suggests that *road transport is by itself*

a key source of air pollution in Lagos. An analysis of the road transport situation is presented below.

3.2. ROAD TRANSPORT

Lagos has the shortest public transport rail system of many megacities (Salau 2018). Lagos' 24 km of rail amounts to only 1.3 km per million people—far less than many other megacities (Figure 3). Cairo, the city with the next shortest rail length per capita, has 8.2 km/million people³⁰. This large gap indicates limited transportation options in Lagos, forcing most people rely on personal vehicles, state-owned and privately-operated commercial buses and minibuses, tricycles, and motorcycles for transportation. Lagos is known as a city of vehicles. A project to extend Lagos' rail system was initiated in 2008, but the completion of construction has been repeatedly delayed (Salau 2018). Once the newly built rail system starts service, it will offer an alternative mass transit option with less exposure to air pollution (Cepeda et al. 2017).

High vehicle density has caused heavy traffic congestion and high fuel consumption in Lagos State. The number of vehicles in Lagos has almost quadrupled during the last decade, reaching 5 million per day on the road³¹. Vehicle records in Lagos indicate an average of about 227 vehicles per kilometer of road per day—considerably more than the national average of 11 vehicles per kilometer of road per day (Zaccheaus 2017). Lagos is notable for its perennial high traffic congestion, with most commuters spending at least three hours in traffic daily³². It was named the worst city for drivers in Africa and the third worst in the world, with 60 percent congestion and an average speed of only 17.2 km/hour³³. Poor road networks, traffic management, and driving habits, and the lack of parking facilities exacerbate traffic congestion problems (Ukpata and Etika 2012). The level of

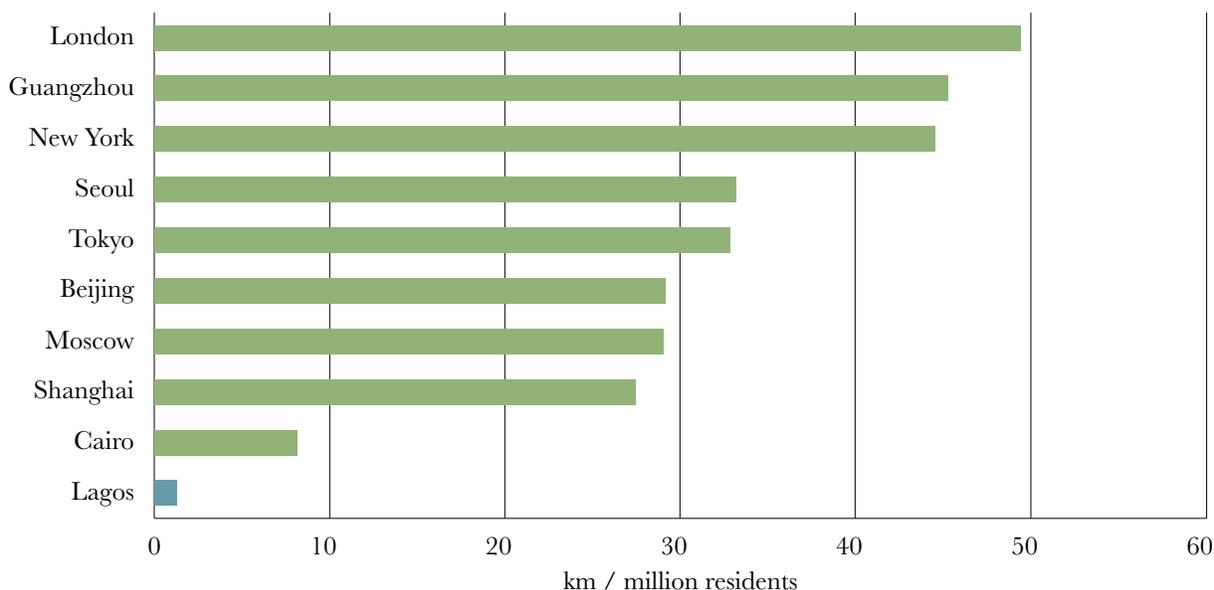
30 The boundary of cities in the population study and covered by the rail transportation network can be different. Therefore, this could be used just for the purpose of the reference.

31 The vehicles newly registered in Lagos was about 61 percent of total vehicle registration in Nigeria, the highest among all other states in the first quarter of 2018 (Nigeria National Bureau of Statistics 2018b).

32 <https://landlagos.com/blog/lagos-traffic-a-never-ending-tale/>

33 <https://www.forbes.com/sites/jimgorzelany/2017/09/27/the-worlds-best-and-worst-cities-for-drivers/#77cceddc42e9>

FIGURE 3: THE TOTAL LENGTH OF RAIL-BASED RAPID TRANSIT SYSTEM NETWORK PER MILLION PEOPLE IN SELECTED MEGACITIES



Source: Authors’ calculation based on: total length of rail-based rapid transit system from Metrobits (2012) and population from UN (2018).

traffic influences the degree of fuel consumption and the number of vehicles operating per unit area, thus contributing to local pollutant concentration (Gately et al. 2017). Lagos State is the largest consumer of petroleum products in Nigeria³⁴, accounting for about 31 percent of total diesel and 17 percent of total gasoline use in 2017 (Nigeria National Bureau of Statistics 2018a)³⁵.

Most vehicles operated in Lagos are believed to have old emission control technologies. Old vehicles can emit significantly more PM and black carbon than modern vehicles equipped with more efficient engines and recent emission control technologies (CAAAC 2006; Fiebig et al. 2014; Kholod and Evans 2016). Although the exact profile (e.g., age and emission control technology) of the existing fleets is not known, it is believed that most vehicles in Lagos are not equipped with the most updated emission control technologies, as they are more than 15 years old (LAMATA, 2016)³⁶. Most vehicles in Lagos are

gasoline-operated³⁷, except heavy duty trucks (HDVs) and buses³⁸. Diesel-powered HDVs can be a major source of primary PM_{2.5} emissions, due to significantly higher emission factors for primary PM_{2.5} than gasoline vehicles. However, numerous gasoline vehicles and motorcycles are also contributing to PM_{2.5} emissions in Lagos, since they are dominant sources of carbonaceous PM and secondary organic aerosol (Platt et al. 2017).

Nigeria imports diesel and gasoline fuel with high sulfur content. Reduced sulfur content in fuel combined with advanced emission control technologies can reduce vehicular PM emissions through several mechanisms: directly reducing sulfate particles, reducing secondary particle formation from sulfur dioxide (SO₂), and allowing installed emission control and catalyst system for other PM precursor emissions³⁹ to work properly

34 Road transportation accounts for 91 percent of total final consumption of petroleum products in Nigeria (IEA, 2018).

35 These numbers are substantially higher than those of the second major consuming states: Kano, with 7% of national gasoline consumption, and Ogun, with 9% of national diesel consumption.

36 Although Nigeria banned the import of passenger cars older than 15 years (Naré and Kamakaté 2017; United States Department of Commerce Interna-

tional Trade Administration Office of Transportation and Machinery 2015), the current vehicle registration system does not collect data on the age of the registered cars..

37 According to vehicle survey conducted by Cervigni, Rogers, and Dvorak (2013).

38 Based on the calculation using the World Bank’s Energy Forecasting Framework and Emissions Consensus tool (EFFECT) and the vehicle survey conducted by Cervigni, Rogers, and Dvorak (2013).

39 such as nitrogen oxides (NOx) and organic compounds

(Blumberg, Walsh, and Pera 2003). Even though Nigeria is one of the largest crude oil producers in West Africa⁴⁰, it imports most of its refined petroleum products from other countries, such as the United States and European countries. While these countries have long banned the domestic use of high-sulfur (dirty) fuel because of air pollution concerns, many still export it. Currently, the maximum allowed sulfur is 3,000 parts per million (ppm) in imported diesel, and 1,000 ppm in imported gasoline (George 2018); these are substantially higher than that in European Union, of 10 ppm for both products (European Council 2009).

Efforts to revise fuel and emissions standards are underway.

In December 2018, the Economic Community of West African States (ECOWAS) Commission deliberated on the harmonization of fuel and vehicle standards at a technical workshop co-organized by UNEP. Participants agreed to set a maximum of 50 ppm sulfur in both imported gasoline and diesel starting on 1 January 2020 and a minimum vehicle emission standard of Euro IV/4 or equivalent for all new vehicle registrations (UNEP 2018). The proposed standards are awaiting endorsement by ECOWAS ministers in 2019. In addition, there is an ongoing project to construct a new refinery near Lagos to produce ultralow-sulfur fuel to meet the Euro V emission specification (De Beaupuy and Wallace 2019;

Miller 2018; Naré and Kamakaté 2017). The new clean fuel and vehicle standards together with the momentum in the industrial sector for future domestic supply of clean fuels, should reduce the PM_{2.5} pollution and bring substantial health benefits in Lagos. Reduction of PM pollution by introducing vehicle emission technology and fuel sulfur standards has been reported in several cities including London (Ellison, Greaves and Hensher 2013) and Los Angeles (Hasheminassab et al. 2014). However, successful implementation of such standards requires tremendous efforts and enforcement backed by strong political will, as shown by previous experience⁴¹ in Nigeria. Also well-designed programs should be coupled together to incentivize consumers and industrial stakeholders shifting to use of clean fuels and vehicles.

Overall, road transport, industrial emissions and power generation are major contributors to air pollution in Lagos. Although a refined source apportionment study is needed to quantify the contribution of each source to the pollution level, road transport stands out as a key source of PM_{2.5}, primarily due to high vehicle density, use of old emission technologies, high sulfur content in diesel and gasoline fuel, and limited transportation options in the city. The following chapter reviews possible options to tackle pollution from major sources in Lagos.

40 Nigeria produced more than 24 percent of Africa's crude oil in 2016 (IEA 2018).

41 For example, in 2015, Nigeria announced that it would tighten its regulations on vehicle emission technology from the Euro2/II standard, which had been adopted in 2012, to the Euro 3/III standard for light-duty vehicle (Loveday 2011; Naré and Kamakaté 2017). However, it is not clear whether this standard has been implemented. In addition, as part of a United Nations Environment Programme (UNEP) campaign, the country had committed to ban the imports of high-sulfur diesel by July 2017, by lowering the maximum allowed sulfur in imported diesel from 3,000 parts per million (ppm) to 50 ppm (UNEP 2016). The Nigerian National Petroleum Corporation NPC announced that it would also cut the sulfur level in gasoline to 300 ppm by October 2018, which is already overdue, and 150 ppm by October 2019 (Opara 2018).



Photo Credit: Novarc Images / Alamy Stock Photo



Photo Credit: Jordi Clave Garsot / Alamy Stock Photo

CHAPTER 4

OPTIONS FOR AIR POLLUTION CONTROL

The previous chapters have indicated that ambient air pollution is very costly to Lagos' society and that the main sources of PM_{2.5} emissions originate from road transport, industrial activity, and power generation. This chapter provides an overview of several air pollution control options that could be explored to reduce air pollution in Lagos.⁴² These options are *neither exhaustive*⁴³, *nor prescriptive*; their net benefits or cost-effectiveness to Lagos requires **further investigation**, which is expected from Lagos PME/ AQM project outputs—e.g., source apportionment work, cost-effectiveness analysis and policy modelling.

4.1. ROAD TRANSPORT

This section examines several options to reduce air pollution from road transport, based on the experience of other developing countries. It should be noted that a detailed assessment of the current and evolving nature of the vehicle fleet is needed to identify the most suitable options for Nigeria. Moreover, some options can be effective only when implemented simultaneously, e.g., importing low emission vehicles would help reduce air pollution only if coupled with adoption of cleaner fuels.

FUEL QUALITY

Upstream control of fuel quality can have a rapid impact on associated combustion emissions (Yue et al. 2015). Using fuels with lower sulfur content can contribute to lower PM emissions. Efforts in this area are already underway: the Nigerian Industrial Standard (NIS) for fuels were revised in 2017 for diesel (50 ppm), gasoline (150 ppm), and kerosene (150 ppm). However, these changes are still awaiting Government approval and implementation.

⁴² Recently, the Government of Nigeria published a report which discusses emissions, sources and impacts of PM_{2.5} based on an analysis using Long Range Energy Alternative Planning System-Integrated Benefit Calculator (Government of Nigeria, 2018).

⁴³ For example, this chapter does not touch upon measures to reduce indoor air pollution (such as switching stoves to cleaner fuels and better technology).

PASSENGER VEHICLES

Cleaner passenger fleet. The majority of cars traded in Nigeria are used cars with old emission control technologies, and some 60 percent of used car sales occur in Lagos (PwC 2016).⁴⁴ Encouraging the import of lower emission vehicles (e.g. vehicles with more advanced Euro standard emission control technology⁴⁵) could help reduce pollution levels if coupled with use of lower sulfur fuel. This could be achieved through a variety of methods that influence vehicle purchase choices. For example, in 2011, Mauritius introduced a revenue neutral tax structure that placed a high tax on older, inefficient vehicles, then earmarked those funds to a refund for purchases of newer, more efficient vehicles. While this tax intervention focused on carbon emissions, a similar scheme could be designed to encourage the purchase of vehicles fitting a set of preferred characteristics (e.g. low PM_{2.5} or NO_x emissions).

Vehicle inspections. While encouraging the import of cleaner vehicles is important, improving the performance of existing vehicles in Lagos is also essential for air quality. Lagos' Vehicle Inspection Service (VIS)⁴⁶ is currently undertaking emission tests for vehicles registration and renewals. Inspections of vehicle emission controls, with links to potential scrappage or retrofit programs, could lead to a cleaner road transport fleet in Lagos. Depending on the emission levels, vehicle technology and age, and cost-effectiveness criteria, some vehicles should be scrapped, while others should be repaired:

- » *Scrappage programs.* A few countries have successfully used scrappage programs for heavy duty vehicles (HDVs) and light duty vehicles (LDVs), including

44 In addition, the quality of imported cars is often low (e.g. crashed vehicles, flooded vehicles, vehicles with emission controls removed); in that regard, strengthening vehicle inspections and developing African vehicle standards have a role to play.

45 See further information at https://ec.europa.eu/growth/sectors/automotive/environment-protection/emissions_en

46 The Lagos State Government has established the Lagos Computerized Vehicle Inspection Service (LACVIS): <http://www.lacvis.com.ng>. LACVIS conducts road worthiness tests that assess braking, steering, chassis and chassis alignment, emission testing, lightning system, headlights and so on. The test currently uses gas analyzers and smoke testers for emission testing—see <https://www.lacvis.com.ng/quality/our-equipments/>, and reports on the website suggest that approximately 800,000 tests have been conducted at the time of writing.

China's national and local scrappage programs, Mexico's Federal Road Transport Modernization Program, and Chile's Truck Swapping program (Heger and Sarraf 2018)⁴⁷.

- » *Priority retrofits.* Retro-fitting pollution control equipment such as Diesel Oxidation Catalyst (DOC) and Diesel Particulate Filters (DPFs) to existing vehicles can be an effective way to reduce emissions (Yan, Bond, and Streets 2014). DOCs require a maximum of 500-ppm sulfur in diesel, and DPFs require a maximum of 50-ppm to function effectively. As this approach is relatively expensive⁴⁸, targeting only the most polluting vehicles in the fleet is justifiable⁴⁹. Such a programme should consider the age of the vehicle, the period it will continue to function, and the number of years the devices are expected to be effective. Several retrofit programs have been implemented in developing countries, such as in Mexico and Chile. The program in Santiago de Chile fitted DPFs to over 2000 buses during 2005–2011, and is expected to fit all buses in the fleet by the end of 2019 (Swiss Agency for Development and Cooperation SDC 2011).

PUBLIC TRANSPORT

Shift to public transport. Investing in public transport—e.g., through a larger fleet, new routes, enhanced comfort—improves the level of service and encourages increased use (Okokon et al. 2018). Shifting from use of single-occupancy vehicle to public transportation can reduce pollutant emissions by decreasing the number

47 It should be noted that scrappage programs are sometimes difficult to design and implement. A few main issues requiring careful attention include: ensuring that the most polluting vehicles are targeted, that public resources are not spent for vehicles that would have been scrapped anyway, that vehicle markets are not distorted.

48 DOCs cost about US\$1,000–2,000 and DPFs as much as US\$6,000–10,000.

49 Replacing older, more polluting vehicles entirely might be more cost-effective, given the many other benefits of newer vehicles, but may require further incentives to be financially feasible.

of vehicle miles traveled per capita⁵⁰. Such benefits can be further increased by improving logistics⁵¹, networks⁵², and management⁵³, and by replacing the current diesel-powered buses by more efficient models. The Lagos Bus Rapid Transit (BRT) is a positive initiative in this regard, as is the support to alternative mass transit modes, such as water taxis and ferries. LAMATA is considering a variety of approaches to encourage transport mode shifts to rail and water under the IFC-funded US\$50 million *Lagos City Infrastructure project*, and as under the proposed World Bank-funded US\$300 million *Lagos Urban Transport Project III*.

Cleaner and more efficient vehicles serving public transport include electrified or **compressed natural gas (CNG) buses**. In this regard, LAMATA has relevant initiatives whereby new terminals are being developed to support an expansion of the fleet and CNG buses. Where initial capital costs are a major barrier to growing the fleet, innovative approaches to financing could be explored (Miller et al. 2017). For example, Mexico City issued US\$50 million of green bonds in 2017 to fund improvements in public transit and expansion of the BRT system. Other approaches could include leasing buses from manufacturers, supported by State level guarantees.

Electric passenger cars are currently expensive relative to internal combustion engine vehicles, and require extensive and reliable charging infrastructure, making a transition to an electrified passenger car fleet a daunting prospect (Figenbaum 2017). In addition, coping with Nigeria's low power reliability would likely be the biggest challenge. However, with the cost of electric vehicles

declining rapidly, **electrification of certain captive fleets**⁵⁴ such as the bus fleet (primarily of high-emission diesel-powered HDVs) and ensuring charging at the most critical depots may be feasible and cost-effective. In this regard, LAMATA's initiative on the development of bus terminals that may ultimately be operated as charging stations for electrified mass transit modes would be a valuable support.

ALTERNATIVE MODES OF TRANSPORT

Non-motorized mode shifts. Improving air quality and safety across the transport network would encourage greater use of non-motorized modes of travel (e.g. cycling and walking). Investment in infrastructure to facilitate walking and cycling—principally safe paths and cycle routes—can, however, be expensive and challenging to merge within the existing infrastructure. Similarly, encouraging behavioral and cultural change can take considerable time and effort to achieve.

Ride sharing can help reduce pressure on the road traffic system, vehicle ownership, and associated emissions by displacing low-occupancy high-emitting journeys (Vanderschuren and Baufeldt 2018). This activity already exists in various forms in Lagos (e.g. Uber, Taxify, Lyft, Gokada). This could be further expanded as a way of curbing the increasing transport in the city.

CITY TRAFFIC MANAGEMENT

Enhanced monitoring and management of traffic, including licensing restrictions, low emission zones (LEZs), road pricing or congestion charging could reduce exposure to air pollution. In Beijing, as part of a response to the high levels of air pollution from road transport, there has been ongoing research and policy development to restrict urban traffic. One of the earlier initiatives was a high-profile alternating restriction on vehicles entering the city with odd or even number plates during the 2008 Olympics. More recently, to constrain the fleet size, the city has

50 Even though emission factors of current diesel-powered buses are higher than those of gasoline-powered cars, public transportation can reduce the need for many separate trips by private vehicles in dense urban areas, by replacing many separate emissions-producing vehicles with fewer transit vehicles that are generally emit less pollution per person (<https://www.transit.dot.gov/>).

51 Segregated lanes for BRT would allow large numbers of people to be carried through crowded areas at constant speeds, thus generating lower PM emissions thanks to fewer accelerations. Establishing high occupancy vehicles lanes is also worth exploring.

52 Restructuring public transport networks with densified nodes, would allow the same level of access with fewer vehicle kilometers.

53 Public transport vehicles can be managed as a fleet in a more controlled manner than the vehicle stock as a whole. This means that it might be possible to assure better maintenance of engines and emissions control equipment (and proper use of low-sulfur fuel) than for the fleet as a whole.

54 A captive fleet is a portion of the overall fleet that is controlled or managed by a given entity. Vehicles within a captive fleet are more readily managed and controlled.

capped the total number of cars registered through a lottery system for vehicle licenses, and has announced restrictions on the number of visits that cars registered outside Beijing can make⁵⁵. Other initiatives include the recent introduction of a LEZ that prevents HDVs from entering certain parts of Beijing⁵⁶. However, while management of urban traffic has a role to play, addressing the levels of transport activity and growth through non-motorized or public transit support should remain a priority (Kelly and Zhu 2016).

4.2. INDUSTRY AND POWER

Best Available Technologies (BAT). As indicated in chapter 3, earlier source apportionment work in Lagos recognized locations where industries are key sources of ambient PM_{2.5}. More refined work to identify major industry and power emission sources of relevance (e.g. cement, steel, power generation, refining, chemicals etc.) is expected from the Lagos PMEHA/AQM project. Based on that, specific cost-effective targeting of actions will further guide identification of BAT actions within these key industrial sources⁵⁷. For example, the World Bank's *Second Pollution Abatement Project* in Egypt (US\$20 million) financed BAT among the most polluting industries in Cairo, which reduced air pollution emissions from targeted industries by 91 percent during 2006–2015 (World Bank 2015).

Diesel and gasoline generators. Diesel and gasoline generators are regular sources of localized air pollution in Lagos (World Bank 2014). Several studies related to diesel generators in Nigeria suggest the need for inspection, maintenance, or upgrade of older generators, to curtail emissions (e.g. Adeniran et al. 2017). A *decommissioning program* could also be considered, but adequate and consistent alternative power sources must be available⁵⁸. Recent

55 <http://www.chinadaily.com.cn/a/201806/15/WS5b236853a310010f8f59d362.html>

56 www.lez-cc.info/en

57 The parallel work under the Lagos PMEHA/AQM project to develop the Lagos Bureau of Statistics (LBS) data with respect to emissions and abatement technologies from licensed industries within Lagos State will also be important in subsequently identifying and managing the additional potential for abatement from these facilities.

58 This measure has a clear linkage to broader energy policy and infrastructure in Lagos. The Lagos Independent Power Plants (IPPs) that currently provide energy to government institutions may have a role to play if they can be scaled-

research in Africa suggests that *solar photovoltaic cells* with a battery storage system can offer a cost-effective alternative to high polluting diesel-based systems for off-grid energy needs at varying scales (Madziga et al. 2018). In a similar vein, Lagos State Government has been investing in a number of smaller-scale independent power projects. These initiatives aim at providing more stable power to key state facilities and communities (e.g. the Island Power Project Expansion) and should reduce the reliance on the more polluting generators.

4.3. OTHER OPTIONS

Waste management is an ongoing challenge for Lagos State. The Lagos Bureau of Statistics (LBS) and the Lagos State Waste Management Authority (LAWMA) report a reliance on open dumpsites for waste management and the existence of illegal burning and dumping⁵⁹. Inadequate waste infrastructure can exacerbate air pollution due to the inability to control emissions. This was demonstrated when the Olusosun dumpsite in the Ojota area of Lagos caught fire in 2018⁶⁰. A few actions can be explored:

- » Alternative options for *advanced waste management* that offer potential for greater value recovery than landfills alone (Ayodele, Alao, and Ogunjuyigbe 2018). The options could include municipal solid waste incineration. The first such facility in sub-Saharan Africa opened in Addis Ababa in 2018 at a cost of over US\$110 million⁶¹.
- » *Improving existing waste management practices*, through regulation and actions related to packaging and sorting (Convery, McDonnell, and Ferreira 2007; Tencati et al. 2016). In Lagos, Wecyclers and Recycle Points have partnered with LAWMA to collect recyclable waste items (e.g. plastic bottles and bags, cans, paper and carton) directly from consumers,

up to power commercial and residential districts. A stable and secure energy supply to all residential and commercial operators should facilitate the decommissioning of 'backup' generators over time.

59 LAWMA has reported collection and disposal of approximately 1.7 million tonnes of waste in Lagos in 2016, of an estimated total waste generated of approximately 4.4 million in that same year (<http://www.lawma.gov.ng/>)

60 <https://guardian.ng/news/thick-smoke-as-another-fire-at-olusosun-dumpsite-envelopes-ojota/>

61 <https://www.unenvironment.org/news-and-stories/story/ethiopia-waste-energy-plant-first-africa>

providing much needed collection and sorting services (Jambeck et al. 2018). Extensions of existing LAWMA initiatives on waste recovery, recycling and special destruction of hazardous materials are relevant to an integrated pollution management program for Lagos.

- » Substantial quantities of waste are believed to be *illegally buried*⁶², *burned*, or *dumped*. Addressing these actions require investment in technologies, teams for monitoring and penalizing these activities, and provision of appropriate waste management infrastructure.

City management. Use of good practices can reduce the potentially negative impact of construction and maintenance activities on ambient air pollution. Such practices could include:

- » *Construction measures*, such as load management on trucks hauling debris and building materials to prevent overflowing; careful demolition practices for buildings; or increased use of prefabricated materials to reduce cutting on site.
- » *Road improvements*. Roads often have substantial litter, and are often bordered by unpaved sections, which can result in particles and pollution being resuspended and made respirable (Eliasson, Jonsson, and Holmer 2008; Kumar and Elumalai 2018). Road washing, sweeping and paving would reduce this effect. The Cleaner Lagos Initiative is a good example of efforts to maintain a visibly clean environment in the state.
- » *Tree planting*, while it would not reduce emissions, could limit particle dispersion by trapping emissions. It has been embraced by the Lagos State Government and undertaken by the Lagos State Parks and Gardens Agency in collaboration with LAWMA.

Agricultural measures. According to LBS, over 12 million poultry and 1 million pigs are kept within the state, and many animals are brought in for slaughter⁶³. Emis-

sions of NH₃ and N₂O from animal manure can be minimized by using appropriate methods to spread, altering the timing of spreading, and investing in alternate means of storing manure. Likewise, emissions from fertilizer use can be minimized through appropriate fertilizers, timing and methods of application.

Shipping and freight. Lagos is a major port area; a substantial number of ships use the Apapa and Tin Can ports⁶⁴. The proximity of so many large vessels and the associated freight traffic are likely to be relevant sources of air pollution for Lagos, as they are in many port cities around the globe (Fenton 2017). The applicability and cost-effectiveness for measures such as shore-side electrification should be explored, as research in Europe has indicated potential for its use (Winkel et al. 2016). International fuel standards for shipping, as well as fuel switching in proximity to port, could also offer public health benefits (Sofiev et al. 2018).

Other fiscal and information-led support actions can be used to help successful implementations of above options. *Environmental taxes and subsidies* can be powerful tools to influence incentives within the market place (Heine, Norregaard, and Parry 2012). For example, Nigeria heavily subsidizes imported refined petroleum products. While the subsidy supports the economy by making fuel more affordable, increased fossil fuel use also leads to pollution. Finding a balance whereby the subsidy is reduced for the importers and wholesalers, while poorer households receive targeted supports has been suggested as an alternative (Siddig et al. 2014) that may deliver better environmental and societal outcomes in Nigeria.

Information-led actions include: nudges and boosts (i.e. tools to stimulate positive behavioral change towards cleaner air), and awareness raising campaigns (e.g. dissemination of the information related to the Air Quality Index which is under preparation for Lagos).

Overall, the options identified above include measures that have been successfully implemented in other countries to curtail air pollution. However, the choice of meas-

62 Examples of suspected waste burning issues in Lagos include the burning of animal skins with tires in abattoirs, and the open burning of uncollected waste.

63 Lagos State Ministry of Agriculture reports over 800,000 cattle and over 500,000 sheep and 500,000 goats passing through Lagos' livestock control posts in 2016.

64 Nigerian port statistics indicate that over 33 million metric tons of cargo passed through these two ports in 2017.

ures depends on the cost of implementing them and the associated benefits in terms of reducing air pollution, which further depend on the context. It is clear from the outset that no single action can solve the air pollution

challenges faced by the city. An evidence-based air pollution control plan, that considers actions across the most polluting sectors is required and envisaged by the Lagos PMEH/AQM project.

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1818 H Street, NW
Washington, D.C. 20433 USA
Telephone: 202-473-1000
Internet: www.worldbank.org/environment