IMPACTAR TOOL: VALUING AIR QUALITY HEALTH IMPACTS OF URBAN BUS FLEET CHANGES IN BRAZIL

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SUMMARY

Air pollution is recognized as one of the greatest challenges of our time. Besides being an important contributor to climate change, several epidemiological studies indicate the association between air pollution and mortality (fatal diseases) and morbidity (nonfatal diseases). These impacts have implicit (unobservable) costs, such as hospitalization expenditures and productivity losses. The assessment and valuation of air pollution impacts is essential to make observable the implicit costs (or savings) of certain choices of economic agents (population, companies, and governments) that can increase or reduce air pollution levels. In Brazil, the transport sector accounts for the largest share of outdoor air pollution emissions, impacting the number of hospitalizations, deaths, and public and private expenditures, among other consequences.

Within the Brazilian transport sector, public urban bus fleets, dominated by diesel-powered technologies, contribute significantly to high levels of air pollution, especially particulate matter (PM). Transitioning urban bus fleets from less efficient in terms of pollutant emissions to cleaner technologies, however, can present high investment costs because the up-front purchase price of more developed technologies is often higher compared to less efficient ones. This can discourage the improvement of a city's bus fleet. In order to promote a more accurate benefit-cost analysis of fleet renewal projects, it is crucial to measure the direct and indirect costs of premature mortalities, morbidities, workforce loss, and the associated monetary loss due to fatal and nonfatal diseases associated with variations in air pollution levels.

CONTENTS

WRI Technical Notes document the research or analytical methodology underpinning research publications, interactive applications, and other tools.

This is the second version of this publication. The previous version contained an error in the values of the PM fixed conversion measures (PM FCM) for Belo Horizonte (MG) and Rio de Janeiro (RJ). The numbers have been corrected for this version.

This technical note presents the Valuation tool for air quality health impacts of urban bus fleet changes in Brazil (ImpactAr), a tool that aims to assess the impacts of urban air pollution on health and economy. It evaluates these health impacts and the associated monetary costs of changes in emissions levels linked to modifications in urban bus fleets in four Brazilian cities: São Paulo, Rio de Janeiro, Belo Horizonte, and Niterói. Focused on public managers—but also available for politicians, private sector operators, academics and researchers—it works as a support tool for the decision-making process, demonstrating the potential costs and returns of air pollution externality connected with investments in different transport technologies. This tool is the first step in measuring the implicit costs and benefits of changes in urban transport fleets in terms of different effects on PM_{10} and $PM_{2.5}$ emissions and concentration levels and their impacts on fatal and nonfatal diseases. The ImpactAr tool was developed with the financial support of the Children's Investment Fund Foundation (CIFF).

1. INTRODUCTION

Atmospheric air pollution is the contamination of the external or internal environment by any chemical, physical, or biological agent that modifies the natural characteristics of the atmosphere (air quality). Outdoor air pollution originates from natural and anthropogenic sources.[1] The most prominent polluting anthropogenic sources include fuel combustion for transport, power generation, heating, and industry (WHO 2018).

Among the main pollutants, particulate matter (PM) is commonly used as an indicator for air pollution because it affects more people than any other pollutant (WHO 2018). PM is a mixture of solid and liquid particles of organic and inorganic substances suspended in the air, including sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust, and water. PM varies in size, composition, and origin. Whereas particles with a diameter of 10 micrometers or less ($\leq PM_{10}$) can penetrate and lodge deep inside the lungs, the even more health-damaging particles are those with a diameter of 2.5 micrometers or less ($\leq PM_{2.5}$) (WHO 2018). According to epidemiologists, air pollution represents a risk factor; this means it is not the direct cause of individual deaths (Roy and Braathen 2017), diseases, or injuries, but it significantly increases the likelihood of an individual dying or developing disease (WHO 2016).

In most of Brazil's urban areas, which contain about 84 percent of the national population (IBGE 2010), vehicles are the main source of pollutants emitted into the atmosphere (Miranda et al. 2012). Within the country's transport sector, the major contributor to PM emissions are heavy vehicles moved by diesel—mainly trucks and buses (MMA 2014).[2]

According to national studies,[3] in terms of health impacts, outdoor air pollution in the main metropolitan regions and state capitals of the country is linked to about 20,500 annual deaths caused by cardiovascular and respiratory diseases (Miraglia and Gouveia 2014) and is responsible for 5.2 percent of hospital admissions for respiratory causes among children and 8.3 percent among elderly, totaling 4,581 respiratory admissions per year (Marcilio and Gouveia 2007). Other studies strongly suggest an association between the country's air pollution and fatal and nonfatal cases

of cancer, restrictions on fetal development, and changes in the human male-to-female ratio, among others (Hettfleisch et. al. 2017; Miraglia et. al 2013; Yanagi et al. 2012). From a financial point of view, air pollution in the country leads to about 130,000 cases of work absences and a cost of US$6,472,686 in terms of hospitalization expenditures and absences at work every year (Rodrigues-Silva et al. 2012). All of these impacts heavily affect the population's quality of life and pressure the local public budgets.

In this scenario, urban bus fleets in most Brazilian cities continue to be outdated and less efficient in terms of PM emissions when compared to cleaner technologies available throughout the world. Low-emissions buses account for only 0.003 percent of the national urban bus fleet (NTU 2020). This can be partially explained by the fact that fleet transitions to cleaner technologies, such as electric buses, may present high investment costs because the initial purchase price of these technologies is often higher than less efficient ones (Sclar et al. 2019). Additionally, the policies, regulations, and incentives to improve a fleet are determined at the federal government level, but the health costs of air pollution particularly impact municipal budgets, reducing the incentives to a faster fleet upgrading.

How can managers overcome these obstacles and provide municipalities with cleaner bus technologies in terms of air pollution emissions, resulting in fewer fatal and nonfatal diseases, lower associated costs, and increased quality of life for all Brazilians? The first step is to include the measurement of emissions variations and their implicit health costs into investment evaluation—which are not often considered—allowing managers to perform a more accurate benefit-cost analysis of projects aimed at achieving cleaner urban bus fleets.

With this goal, WRI Brasil has developed the Valuation tool for air quality health impacts of urban bus fleet changes in Brazil (ImpactAr). The tool measures the health impacts and the associated monetary costs of changes in emissions levels linked to modifications in urban bus fleet technologies in the cities of São Paulo, Rio de Janeiro, Belo Horizonte, and Niterói. The measurement and analysis of the impacts are made for a 1-year period (short-run analysis) and a 30-year period (long-run analysis), aiming to inform users of the short-run and the long-run cumulative effects of air pollution.

The ImpactAr tool covers the impacts of $PM_{2.5}$, one of the most harmful pollutants to human health, as well as PM_{10}. The tool also provides, among other financial and economic results, the measurement of hospitalization costs in both the public and private health care systems. These monetary outcomes, interpreted as savings or costs, are compared to municipal macroeconomic variables, such as the annual municipal gross domestic product (GDPm) and annual public health budget, providing a reference of cost magnitude for users.[4]

Ultimately, ImpactAr serves as a support tool for decision-makers, indicating the implicit costs and returns of public investments related to air pollution in four Brazilian cities. It provides relevant information about air pollution health impacts and their consequences for the economy, which are useful information to complement the project's benefit-cost analysis and other studies.

This technical note is divided into seven sections: (i) an introduction; (ii) the methodology, with clarifications on the model embedded in the ImpactAr tool; (iii) the ImpactAr tool structure; (iv) the data sources used to build the tool; (v) the limitations and uncertainties; (vi) the pilot test analysis; and (vii) concluding remarks.

2. METHODOLOGY

In this section, we explain the key concepts used in this technical note and describe the framework for analyzing the ImpactAr tool, the methodological choices, and the data applied in the development of the tool.[5]

2.1 Key Concepts

Bottom-up approach: In the case of air pollution assessment, a methodology that measures air pollution emissions and atmospheric concentrations by analyzing the specific sources of emissions. It is the opposite of the top-down approach, according to which the concentration levels of pollutants are first analyzed, and the sources of the emissions are estimated later on.

Concentration-response coefficients (C-Rs): Coefficients that indicate the magnitude of response of morbidity and mortality cases related to a variation in air pollution concentration levels (Marcilio and Gouveia 2007). They are derived from epidemiological studies.

Economic costs: The state-of-the-art literature on the monetization of air pollution impacts presents two typologies of costs: financial costs and economic costs. Economic costs measure changes in people's welfare as a consequence of air pollution. They are not related to tangible services and products (such as the cost of medical appointments), but they are based on individual perceptions and valuations, which cannot be considered financial measures. Such costs represent the assessments on the amount of value that, for individuals, is lost due to air pollution. This can be the cost of suffering caused by diseases linked to air pollution.

Emissions and concentration levels of pollutants: Emissions are a measure of mass (tons) of pollutants emitted by one or more sources. In the ImpactAr tool, they represent the mass of $PM_{2.5}$ and PM_{10} produced by the urban bus fleets in each city. Concentration levels express the volume of pollutants in a specific area (micrograms per cubic meter, $\mu g/m^3$). It can differ according to temperature, humidity, wind, and other factors. Consequently, although cities can present the same emissions levels, concentration levels can vary greatly according to local conditions.

Emissions factor: According to the U.S. Environmental Protection Agency (EPA), "An emissions factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant" (industry, motorized vehicle, etc.) (EPA n.d.). In the case of the ImpactAr tool, it consists of a mass of pollutant emitted by buses when consuming fuel to travel for a determined distance (measuring unit: grams of pollutant per liter of diesel, g/L).

Epidemiology: The field of study that deals with the causes and distribution of diseases and other related phenomena. Examples of epidemiological studies include issues such as the relation between smoking and lung cancer, obesity and stroke, and the causes of psychiatric disorders, among others.

Externality: Economists employ this term to refer to the impacts coming from the activities of one entity that change the welfare of another entity (Rosen and Gayer 2008), without the latter's consent. Externalities can be positive (e.g., vaccinations) or negative (e.g., passive smoking). For this technical note, air pollution and all of its impacts on health and economy are considered a negative externality coming from the transport sector—more specifically, coming from the public urban bus fleet.

Financial costs: Financial costs are related to monetized, market-based costs. In relation to air pollution, these can be the costs of hospitalization and medical expenses caused by diseases attributable to pollutants.

Health endpoint: The type of fatal and nonfatal diseases caused by air pollution. In the case of the ImpactAr tool, health endpoints include fatal and nonfatal cardiovascular and respiratory diseases according to Chapters I and J, respectively, of the 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10).

PM fixed conversion measure (FCM): This is the estimated factor used to convert a variation of PM emissions levels into variations of PM concentration levels for each city. FCMs were obtained through numerical experiments with the Brazilian Developments on the Regional Atmospheric Modeling System (BRAMS 5.2),[6] which identified the existence of a fixed pattern in the conversion between emissions variations and concentrations variations for each city (for further discussion, please see Section 2.3, Methodology Description, and Section 5, Limitations and Uncertainties, of this technical note).

Value of statistical life (VSL): The monetization of the welfare/economic cost caused by mortality. It represents the aggregate of the individual willingness to pay (WTP) for a marginal reduction in the risk of dying from air pollution. It should be noted that this is not a judgment or an evaluation of the measure of one's life; it measures the amount that individuals would be willing to pay, considering not only impacts on their income but also on their well-being, to marginally reduce their risk of dying due to air pollution.

2.2 Framework for Analysis

The impact of air pollution on health and economy is not direct. Before affecting a population's health and creating related costs, pollutants go through a chain of environmental, epidemiological, financial, and economic stages (Figure 1). A motorized vehicle, through its fuel combustion, brakes, tires, and road surface wear emits pollutants, among them PM. PM emissions react with atmospheric conditions (meteorological conditions, physical obstacles, etc.), resulting in a concentration level of PM in a determined region. A set of the population is exposed to this concentration of pollutants in the determined region and so, by increasing the likelihood of individuals suffering illnesses and deaths, cases of morbidity and mortality linked to PM are verified among the population. Finally, the premature deaths and illnesses result in monetary costs.
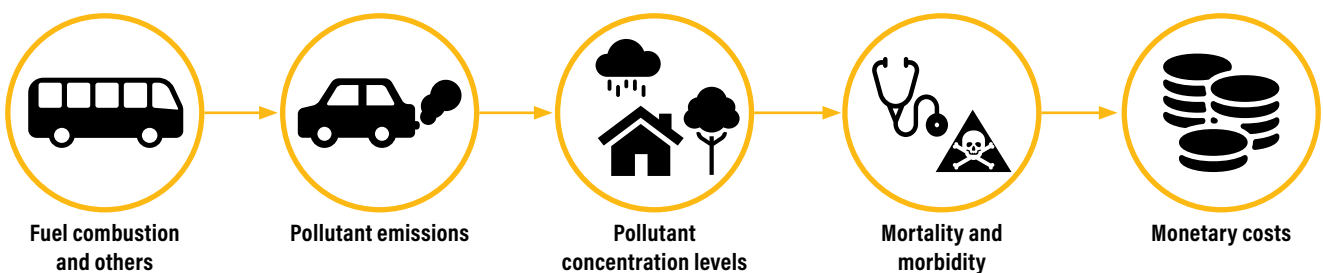
Measuring the health and related financial and economic impacts of air pollution requires the reproduction of this chain process. The ImpactAr tool systematizes the stages presented in Figure 1 based on the impact pathway approach (IPA) formulated by the ExternE Project.[7] This approach consists of a bottom-up approach that proposes the measurement of environmental benefits and costs caused by changes in air pollution levels through a pathway from source emissions to monetary expressions of benefits and costs (ExternE n.d.). The calculation involves two sets of components:

Data points: Data estimates that inform the results of the impacts in each stage of the IPA. For example, total annual variation in PM_{10} concentration levels and total annual number of avoided deaths due to cardiovascular diseases. They are represented by the boxes in Figure 2.

Linking functions: Algebraic functions that connect and convert the different stages of the IPA, allowing the assessment between distinctive types of data. They are represented by the yellow arrows in Figure 2.

In the ImpactAr tool, the set of data points and linking functions that are encompassed in the pathway are organized in a sequence of three stages, which starts with the technical solution for the urban bus fleet's renewal (for instance, the number of buses replaced for each technology):

Figure 1 | **The Pollutant Chain of Impacts**

Fuel combustion and others → Pollutant emissions → Pollutant concentration levels → Mortality and morbidity → Monetary costs

Source: WRI authors.

1. **Environmental Stage:** This provides the annual variations in emissions and concentration levels of $PM_{2.5}$ and PM_{10} as a result of the differences between the current fleet (scenario 0) and the projected fleet (scenario 1) features.

2. **Epidemiological Stage:** By assessing the number of people and general epidemiological cases of cardiovascular and respiratory diseases in one city, this stage isolates the impacts of the annual concentration variations of $PM_{2.5}$ and PM_{10} levels on the number of hospitalizations and deaths caused by cardiovascular and respiratory diseases.

3. **Financial and Economic Stage:** This stage monetizes nonfatal and fatal respiratory and cardiovascular diseases isolated in the epidemiological stage through the cost of illness (COI) methodology, which measures the financial costs of nonfatal cases, and through the VSL, which measures the economic costs of fatal cases.

Figure 2 illustrates the steps of the methodology embedded in the tool. We can list five data points—represented by the boxes in Figure 2—and four linking functions applied to each data point to obtain new outcome units—represented by the yellow arrows.

2.3 Methodology Description

The methodology and data applied to build the ImpactAr tool were based on the most recent Brazilian empirical literature on the measurement of air pollution impacts on health and economy in the country. Before the development of the tool, a three-stage literature review was carried out by the World Resources Institute (WRI) staff, starting from research on the main academic search platforms, followed by research of publications from leading researchers and institutions, and closing with a workshop with the main Brazilian specialists and institutions for validation of the literature review. This process resulted in 67 studies from which the impacts to be analyzed and methodologies applied were chosen.[8]

The ImpactAr tool comprises the methodologies and data presented in the Brazilian empirical literature, arranged according to the IPA chain process. Among others, it includes the analysis of deaths and illnesses caused by cardiovascular and respiratory diseases in the Epidemiological Stage, and it uses the COI and VSL methodologies in the Financial and Economic Stage.

The ImpactAr tool focuses on the pollutants PM_{10} and $PM_{2.5}$ for the following reasons:

Figure 2 | **Methodology Steps Used in the ImpactAr Tool**
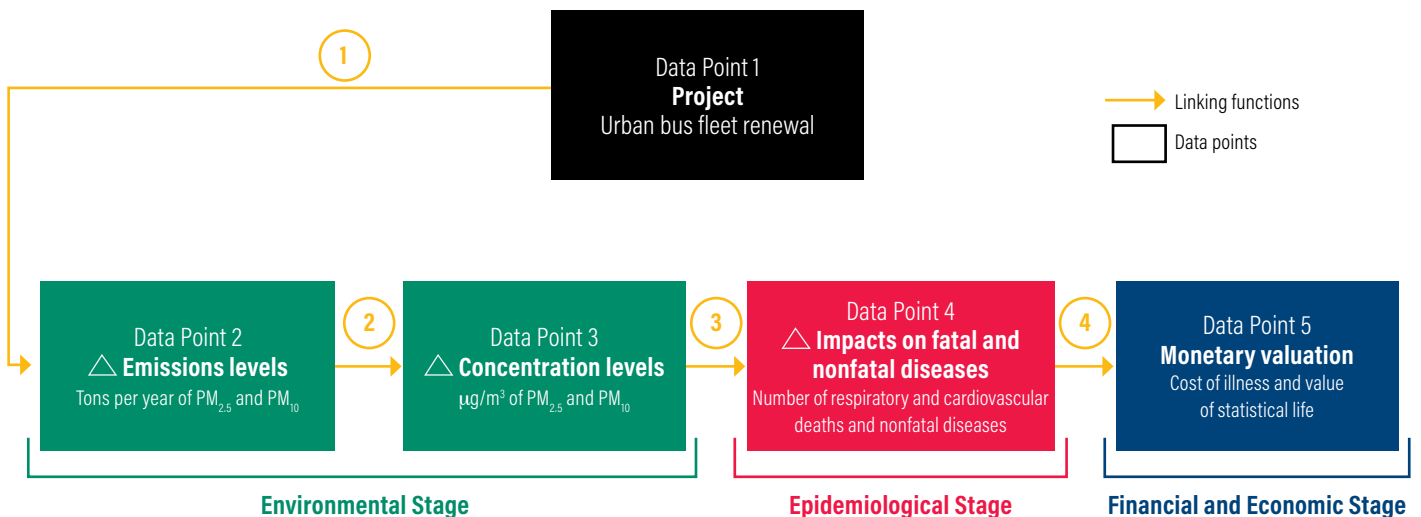
Source: WRI authors.

- PM imposes the most serious threat to human health compared to other pollutants (WHO 2018).
- Brazilian epidemiological literature, using a consolidated measurement methodology, identifies PM as responsible for a high number of health and economic impacts.
- PM_{10} and $PM_{2.5}$ present different sources of emissions from the road transport activities[9] (Hooftman et al. 2016) and distinct health incidence on the development of respiratory and cardiovascular cases[10] (Abe and Miraglia 2016; Silva et al. 2017).
- The transport sector is a major contributor of outdoor air pollution and the largest emitter of PM in Brazil (MMA 2014).

This version of the tool only fits four Brazilian cities: São Paulo, Rio de Janeiro, Belo Horizonte, and Niterói. The first three cities were chosen because they are the most important cities with which WRI Brasil works, and they contain three of the largest vehicle fleets in the country, representing 8 percent, 3 percent, and 2 percent of the national share, respectively.[11] When summed, they represent about 15 percent of the country's fleet. Although Niterói has a relatively less expressive fleet in relation to the other cities—about 0.3 percent of the national fleet—the city was added due to its previous partnership with WRI Brasil in the field of electric bus impact measurement.

Unfortunately, as we expect to include more cities in the tool in the future, it will not be possible to include all Brazilian municipalities due to the size of the input data and the time required to do so. In this sense, we recommend potential users and people interested in assessing air pollution impacts due to bus fleet change projects in their cities use this technical note and the tool itself as a blueprint or a guide to build their own tool. We strongly encourage people to contact the authors in such cases, so we can help with any possible doubts and questions that may not be covered by this technical note.

A more detailed look at data points, linking functions (both presented in Figure 2), and the methodology selected to measure air pollution changes and impacts is provided below.

2.3.1 Project

Data point 1, technical solution: A public project aiming to renew a city's current public bus fleet. Data required is entered twice: first for the baseline or current fleet (scenario 0), and then for the projected fleet (scenario 1). The ImpactAr tool requires the following input data: (i) the number of buses per technology,[12] (ii)

the bus technology, and (iii) the average annual travel distance per bus in kilometers (km). Optional input data include emissions factors (g/L) and average fuel consumption per technology in liters or kilowatt-hours per 100 km (L or kWh/100 km). If the user does not possess such information, the model will provide data by default.[13]

2.3.2 Environmental Stage

Linking function 1, from technical solution to variation on annual emissions levels: Both scenario 0 fleet and scenario 1 fleet annual emissions levels (tons per year) are measured according to the formula

$$\text{Annual PM emissions} = N \times d \times CC \times e_x \quad (1)$$

where N is the number of buses per technology, d is the average annual traveled distance per bus (km), CC is the annual fuel consumption per technology (L or kWh/100 km) and e_x is the emissions factor of PM per technology (g/L).

This formula is applied to each technology reported. It only provides annual PM emissions, without distinctions between the PM diameters, due to the methodology used to measure the PM FCMs (for further information, please see linking function 2 below). In this sense, a ratio, obtained from the Handbook Emission Factors for Road Transport, model version 3.3, is adopted to assess PM emissions of less than 10 μg (PM_{10}) and PM emissions smaller than 2.5 μg ($PM_{2.5}$).[14] The ratio applied is $PM_{2.5}/PM_{10} = 0.7$. This ratio was equally applied for all four cities as, during numerical experiments to determine concentration levels, we used a regional round covering the four cities.[15]

It is worth noting that $PM_{2.5}$ and PM_{10} emissions and concentration variations, as well as impacts, cannot be summed because PM_{10} particulates include $PM_{2.5}$ particulates. In this sense, all the results are showed separately, once for PM_{10} and once for $PM_{2.5}$.

Data point 2, variation on annual emissions levels: This is the difference between annual $PM_{2.5}$ and PM_{10} emissions of the current/scenario 0 fleet and annual $PM_{2.5}$ and PM_{10} emissions of the projected/scenario 1 fleet. This represents the total annual emissions variations that the technical solution would bring, if implemented. These can be represented as

$$\Delta E_{PM_{2.5}} = \text{annual } PM_{2.5} \text{ emissions of scenario 1} - \text{annual } PM_{2.5} \text{ emissions of scenario 0} \quad (2)$$

$$\Delta E_{PM_{10}} = \text{annual } PM_{10} \text{ emissions of scenario 1} - \text{annual } PM_{10} \text{ emissions of scenario 0} \quad (3)$$

where $\Delta E_{PM2.5}$ represents the total annual variation on PM$_{2.5}$ emissions levels due to the technical solution, and ΔE_{PM10} represents the total annual variation on PM$_{10}$ emissions levels due to the technical solution.

Linking function 2, from annual variations on emissions levels to annual variations on concentration levels: Concentration levels can vary greatly according to temperature, humidity, and wind, among other factors; therefore, they vary according to geographic location. To obtain the annual variations in concentration levels for each city, the WRI team carried out numerical experiments with the BRAMS 5.2, using the Coupled Chemistry Aerosol-Tracer Transport model (CCATT), analyzing the dispersion of the pollutants from the emissions data available from public transport scenarios. This modeling system (CCATT-BRAMS) is considered to be state of the art because simultaneous (online) predictions of weather and atmospheric composition are available in real time (meteorology integrated with dispersion/chemistry).

A control experiment (baseline) and three scenarios modified by different technology configurations were simulated for the urban bus fleets in São Paulo, Rio de Janeiro, Belo Horizonte, and Niterói for weather conditions in June 2018 in the Southeast region of Brazil. The emissions scenarios were simulated in grid points with 25 km of spatial resolution and 80 meters (m) of thickness in the first vertical layer over the urban area of the cities, using a methodology proposed by Alonso et al. (2010). The simulations were configured to evaluate the regional dispersion of pollutants PM$_{2.5}$ and PM$_{10}$, associated only with the activity of the bus fleet and using meteorological initial and boundary conditions from the global model of the Center for Weather Forecast and Climatic Studies (Centro de Previsão do Tempo e Estudos Climáticos, CPTEC) and the National Institute for Space Research (Instituto Nacional de Pesquisas Espaciais, INPE).

From such simulations, a linear pattern in the conversion between the emissions variations and concentrations was identified, providing a conversion factor for each city.[16] The PM FCM for São Paulo is 0.00143; for Rio de Janeiro, 0.00195; for Belo Horizonte, 0.00078; and for Niterói, 0.0001407. Total annual variation on PM$_{2.5}$ emissions levels and total annual variation on PM$_{10}$ emissions levels are multiplied by this factor. Hence,

$$\Delta E_{PM2.5} \times FCM = \Delta C_{PM2.5} \quad (4)$$

$$\Delta E_{PM10} \times FCM = \Delta C_{PM10} \quad (5)$$

where $\Delta E_{PM2.5}$ represents the total annual variation on PM$_{2.5}$ emissions levels due to the technical solution, ΔE_{PM10} represents the total annual variation on PM$_{10}$ emissions levels due to the technical solution, FCM is the PM FCM for each city, $\Delta C_{PM2.5}$ represents the total annual variation on PM$_{2.5}$ concentration levels due to the technical solution, and ΔC_{PM10} represents the total annual variation on PM$_{10}$ concentration levels due to the technical solution.

Data point 2, annual variation on concentration levels: This represents the total annual variation in concentration levels of PM$_{2.5}$ and PM$_{10}$ that the technical solution would bring, if implemented (represented as $\Delta C_{PM2.5}$ and ΔC_{PM10} in Equations 4 and 5).

2.3.3 Epidemiological Stage

Linking function 3, from annual variations in concentration levels to annual variations in the number of fatal and nonfatal diseases: Linking function 3 consists of the conversion of the total annual variation in concentration levels of PM$_{10}$ and PM$_{2.5}$ into annual variations in the number of hospitalizations (nonfatal cases) and deaths (fatal cases) attributable to air pollution.[17]

Given the specificities of the state-of-the-art Brazilian epidemiological studies that measure air pollution health impacts,[18] exponential functions were applied to measure health impacts in the ImpactAr tool. Such types of functions are widely used to measure air pollution impacts because they are able to account for nonlinear relations among variations in pollutant concentrations and their health impacts, seasonality trends, and lags between the increase in pollution and the occurrence of the health event, among others (Conceição et al. 2001). The following epidemiological equation is used (André et al. 2017; Rothman and Greenland 1998):

$$AE = [EXP^{(\beta * \Delta CPMx)} - 1] \times TE \quad (6)$$

where AE is the annual attributed events of fatal and nonfatal diseases due to the annual variation in concentration levels of PM$_{10}$ and PM$_{2.5}$, β represents the C-R, ΔC_{PMx} represents the total annual variation in PM$_{2.5}$ or PM$_{10}$ concentration levels due to the technical solution implemented, and TE is the total annual events of fatal and nonfatal respiratory or cardiovascular diseases, covered by the public and private health systems.[19]

To capture the relation between the mean increase (or decrease) in pollutant concentration and the corresponding mean increase (or decrease) in the number of health events, epidemiologists make use of C-Rs (β). In the Brazilian literature on air pollution impact assessment, several ecological time-series studies provide such coefficients for different populations, pollutants, health impacts, and age ranges. The C-Rs (β) retrieved to build the ImpactAr tool come from the Brazilian empirical literature, specifically from seven articles, which are listed in Table 1. All the attributable events measured in the tool follow exactly the criteria of age range, health endpoint, and pollutant of each C-R, defined by the authors of the epidemiological studies.

Table 1 | **Concentration-Response Coefficient (β) Details and Sources**

β	AGE RANGE	AREA	HEALTH ENDPOINT	POLLUTANT	C-R	SOURCE
β_1	Children (<5)	Mortality	Respiratory diseases	PM_{10}	0.0011821980	Marcilio and Gouveia 2007
β_2	Children (<5)	Morbidity	Respiratory diseases	PM_{10}	0.0010138430	Gouveia et. al. 2017
β_3	Elderly (≥60)	Mortality	Respiratory diseases	PM_{10}	0.0013212330	Costa et al. 2017
β_4	Elderly (≥60)	Mortality	Cardiovascular diseases	PM_{10}	0.000010000	Costa et al. 2017
β_5	Elderly (≥65)	Morbidity	Respiratory diseases	PM_{10}	0.001960024	Marcilio and Gouveia 2007
β_6	Elderly (>39)	Morbidity	Cardiovascular diseases	PM_{10}	0.000999983	Gouveia et al. 2017
β_7	All ages	Mortality	Respiratory diseases	$PM_{2.5}$	0.0010148330	Fajersztajn et al. 2017
β_8	Children (<12)	Morbidity	Respiratory diseases	$PM_{2.5}$	0.008925820	Nascimento et al. 2016
β_9	Elderly (≥45)	Mortality	Cardiovascular diseases	$PM_{2.5}$	0.0010544210	Rodrigues et al. 2017
β_{10}	Elderly (>64)	Morbidity	Respiratory diseases	$PM_{2.5}$	0.0042101180	Ignotti et al. 2010
β_{11}	Elderly (≥45)	Morbidity	Cardiovascular diseases	$PM_{2.5}$	0.002254400	Rodrigues et al. 2017

Source: WRI authors.

At first, it may seem counterintuitive to assume that impacts on specific age ranges are representative of the population's health impacts as a whole. Nevertheless, due to the nonlinear nature of the relation between pollutant variations and health impact variations, children and the elderly are the segments of the population that experience much higher-than-average personal health impacts caused by air pollution. By assessing the impacts of this risk group, we are able to provide a more sensitive basis for the detection of any increase in disease (National Research Council 1988).

Exposure refers to a "pollutant concentration at a particular place and time, and the presence of a person at that place and time."[a] It can vary according to (i) the magnitude of the concentration level, (ii) the duration of the exposure to the pollutant, and (iii) the frequency of exposure to the pollutant.[b] This entails that, within a city, exposure levels, and therefore health impacts, differ greatly according to the person's mobility trends and living area. The ImpactAr tool does not measure different levels of exposure among the population in each city due to the lack of data regarding georeferenced information on PM concentration levels in different areas of the analyzed cities and specific features of the population's mobility in those areas. Instead, our model uses the total number of fatal and nonfatal cardiovascular and respiratory diseases in each city as a baseline. To obtain such numbers for a 30-year analysis, a projection of population, morbidity rate, and mortality rate, considering the concentration-response coefficient criteria of age range and health endpoints, was measured.

The population projections were calculated on the basis of population forecast estimates from local government studies combined with polynomial interpolation in the years for which data were missing. Mortality and morbidity rates were projected from data retrieved from the Department of Information Technology of the National Public Health System (Departamento de Informática do Sistema Único de Saúde, DATASUS). For fatal disease forecasts, we used cross-sectional DATASUS data on the number of deaths, and for nonfatal diseases we used cross-sectional DATASUS data on hospitalizations—both from 2000 to 2017. To maintain the reasonableness of the behavior of fatal and nonfatal cases until 2050 (30-year analysis), we set the 2050 value as the best result in these health indicators (the minimum value reached) in the data provided by DATASUS (2000–17). Our main assumption is that, over the years, the overall health of the population will improve, reaching the best result already reached—and therefore the lowest number—of fatal and nonfatal cardiovascular and respiratory diseases.

The projections were made through direct linear extrapolation, according to the following model:[c]

$$\ln(m_{x,t}) = a_x + b_x t + \varepsilon_{x,t}$$

where $m_{x,t}$ is the mortality/morbidity rate of interest, for age x, in year t; a_x means the mortality/morbidity constant for age; b_x denotes the age-specific multiplied by time t; $\varepsilon_{x,t}$ is the residual error. It is fundamentally a log-linear model, with the mortality/morbidity rate as the dependent variable and the year, as well as a constant, as an explanatory variable.

In possession of the population forecasts, we applied the projected mortality and morbidity rates of respiratory and cardiovascular diseases to obtain the absolute number of occurrences. The number of deaths provided by DATASUS covered both occurrences in the public health system as well as in the private health system. For hospitalizations, however, data provided only covered hospitalizations in the public health system. Therefore, in order to find hospitalizations in the private health system, we applied the method of André et al. (2012) as follows:

$$N_{ps} = N_{public} \left(\frac{1}{1\text{-}PI} \right) - 1$$

where N_{ps} is the number of hospital admissions in the private system, N_{public} is the number of hospital admissions in the public system, and PI is the proportion of the population with access to private health insurance.

Note: There are several methods for projecting mortality/morbidity. Direct linear extrapolation is not meant to be accurate but rather to point to trends. This method is traditionally used in this kind of study (Stoeldraijer et al. 2013). Methods that include additional information or an extra dimension to the data (e.g., cohort) "will automatically lead to a more subjective model. . . . Models which capture age, period, and cohort effects in mortality will provide a better model fit than age-period models, given that a cohort effect exists in the mortality data. . . . However, there is no guarantee that models with a better fit will produce better forecasts" (Stoeldraijer et al. 2013, 344–45).

Sources: a. National Research Council 1988, 208; b. National Research Council 1988; c. Booth and Tickle 2008; Stoeldraijer et al. 2013.

Data point 4, annual variations on the number of fatal and nonfatal diseases: This represents the health impacts linked to the technical solution chosen. It provides the changes in the number of hospitalizations and deaths due to respiratory and cardiovascular diseases as a consequence of the annual variation in $PM_{2.5}$ and PM_{10} concentrations. Annual variations in the number of fatal and nonfatal cases are provided for 1 year and 30 years.

2.3.4 Financial and Economic Stage

Linking function 4, from annual variations on the number of fatal and nonfatal diseases to monetary valuation: The monetization of the changes in the numbers of fatal and nonfatal diseases applied in the tool was divided between morbidity costs and mortality costs. For the former, we have opted to monetize the cost of nonfatal diseases attributable to air pollution through the financial approach, as the Brazilian literature used the well-grounded COI methodology.[20] For the latter, we chose to use a measure of economic cost that is not often verified in the Brazilian literature—namely, the VSL. Yet however

controversial the VSL may be, it aims to measure nonmarket costs related to suffering and loss of well-being, broadening the spectrum of costs covered by the ImpactAr tool.

a. **Morbidity costs**: According to the COI methodology, the financial impacts of hospitalizations consist of the sum of two types of costs:

Direct cost of disease: This represents the total costs of hospitalizations. It is measured using the average cost of hospitalizations in 2018 provided by the Department of Information Technology of the National Public Health System (Departamento de Informática do Sistema Único de Saúde, DATASUS) for each age range and health endpoint of the C-Rs and the annual attributed events of nonfatal diseases due to the variation on concentration levels. As DATASUS only provides the average cost of hospitalizations in the public health system, we assumed that the average cost of hospitalizations in the private system is three times higher in relation to public ones, as estimated by André et al. (2012). The total direct cost according to each age range and health endpoint is given by

$$TDC=AC \times AD \ (7)$$

where *TDC* is the total annual direct cost of nonfatal diseases, *AC* is the average cost of each hospitalization for each age and health endpoint, and *AD* is the annual attributed nonfatal diseases due to the variation on concentration levels.

Indirect cost of disease: This represents the cost of work absences due to hospitalizations. It is measured for each age range and health endpoint of the C-Rs, and it uses the average stay of hospital admissions in 2018 provided by DATASUS (we assumed that the average stay of hospitalizations in the private system is the same as in the public system); individual daily per capita earnings of all sources in 2015 (2018R$) per city, which were measured by dividing by 30 the average monthly earning of all sources in 2015 provided by the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística, IBGE); and the number of the annual attributable events of nonfatal diseases due to the annual variation on concentration levels. This can be summarized by the formula

$$TIC=AS \times DI \times AD \ (8)$$

where *TIC* represents the total annual indirect cost of disease, *AS* is the average stay of hospital admissions for each age range and health endpoint of C-Rs, *DI* is the individual daily income per capita of all sources per city, and *AD* is the annual attributed nonfatal diseases due to the variation on concentration levels.

Besides the indirect cost of morbidity, the ImpactAr tool also provides the number of workdays lost due to hospitalizations. Although we analyze the impacts in nonworking-age ranges, we assume that someone active, both in the formal and informal job market, will be absent from work to take care of the ill, as proposed by Ortiz-Durán and Rojas-Roa (2013).

Finally, the total financial cost of morbidity impacts, or the COI, calculated by the tool is given by the equation

$$COI=TDC+TIC \ (9)$$

where *COI* is the cost of illness, *TDC* is the total annual direct cost of nonfatal diseases, and *TIC* represents the total annual indirect cost of disease.

b. **Mortality costs**: Mortality costs were measured by multiplying the number of deaths by the VSL for Brazil in 2018, as presented in Equation 10:

$$MC=ND \times VSL \ (10)$$

where *MC* is the total cost of mortality, *ND* is the annual number of deaths, and *VSL* is the value of statistical life for Brazil.

Brazil does not present an extensive literature[21] that measures the VSL for air pollution through revealed preference or state preference methods.[22] We have opted to adopt the unit value transfer method to obtain the VSL value, according to which we transfer data from previous studies of stated preference or revealed preference from one context to another, with adjustment for specific variables. The methodology applied has been widely used by the Organisation for Economic Co-operation and Development (OECD) (OECD 2012, 2014; Roy 2016; Roy and Braathen 2017; WHO/Europe and OECD 2015). Specifically, for the ImpactAr tool, we adopted the methodology proposed by an OECD study (Roy and Braathen 2017) that targeted the countries of Brazil, Russia, Indonesia, India, China, and South Africa (BRIICS). The value transferred was the 2005 VSL for OECD countries, US$3 million (2005$) (OECD 2012).

According to the formula we applied, we adjusted the value for the difference in per capita income, income per capita growth from 2005 and 2018, and inflation from 2005 and 2018 (Roy and Braathen 2017):

$$VSL_{BRASIL,2018} = VSL_{OECD,2005} \times \left(\frac{Y_{BRASIL,2005}}{Y_{OECD,2005}}\right)^b \times (1 + \%\Delta P + \%\Delta Y)^b \quad (11)$$

where $VSL_{BRASIL,2018}$ is the value of statistical life for Brazil in 2018; $VSL_{OECD,2005}$ is the base value for OECD countries in 2005; $Y_{BRASIL,2005}$ is the GDP per capita in terms of purchasing power parity at 2018 prices for Brazil in 2005; $Y_{OECD,2005}$ is the per capita GDP in terms of purchasing power parity at 2018 prices for OECD countries in 2005; b is the income elasticity of VSL (considered to be 1, as proposed by Roy and Braathen [2017, 17]); $\%\Delta P$ represents the price inflation in Brazil between 2005 and 2018, as estimated by the consumer price rate; and $\%\Delta Y$ is the real income growth between 2005 and 2018 for the country. All the economic indicators were retrieved from the OECD online database.

Data point 5, monetary valuation: This represents the monetization of the variations in health impacts found in the Epidemiological Stage. For costs related to changes in morbidity impacts—namely, variations in the number of hospitalizations—we used the COI methodology, which can be interpreted as the financial savings/costs of health treatment and income avoided/generated due to the total decrease/increase on $PM_{2.5}$ and PM_{10} annual concentration levels. For costs associated with mortality, in their turn, the VSL was used. In simple terms, the VSL is an estimate of how much people are willing to pay to reduce their risk of death, taking into account issues such as suffering and discomfort. Therefore, this cost represents more than the financial impacts of mortality, aiming to evaluate the impact on welfare losses due to a fatality.

Monetary values are measured in Brazilian reals (R$) at 2018 prices and a discount rate of 6.75 percent per year was used for the 30-year analysis (February 2018, Brazilian basic interest rate, called the Special System for Settlement and Custody [Sistema Especial de Liquidação e de Custódia (SELIC)] rate). The concept behind the use of the discount rate for projections is intended to deal with future inflation, making future costs comparable to current 2018 Brazilian prices (2018R$).

3. IMPACTAR TOOL STRUCTURE

The presented methodology was used to build an interactive spreadsheet tool using Microsoft Excel 2013. The tool presents a cover, with a brief model description and menu, and a user guide, with details on each spreadsheet's functions (Figures 3 and 4).

Figure 3 | **Interface of the ImpactAr Tool Cover**

Source: ImpactAr tool.

Figure 4 | **Interface of the ImpactAr Tool User Guide**

⊞ **USER GUIDE**

This tool contains the following spreadsheets:

OPT_INPUTS

- In this spreadsheet, the user can either choose to change the following data or to use the model values by default: (i) emissions factor per technology (g/L) and (ii) average fuel consumption per technology (L or kWh/100km).

1_PROJECT

- It contains the input information regarding the public project aimed at the renewal of the current urban bus fleet.
- Data required includes (i) the city where the project will be implemented, (ii) number of buses, (iii) type of technology (e.g., Euro V), and (iv) the annual traveled distance (km).
- All information above is filled in twice: once for the current fleet and once for the projected fleet.
- If you do not possess the information required for the current and/or projected fleet, you can add the annual particulate matter (PM) emissions or concentration changes you wish.

2_ENVIRONMENTAL STAGE

- It provides $PM_{2.5}$ and PM_{10} emissions and concentration levels of the current fleet and of the projected fleet.
- Emissions data is given in tons/year and concentration data is given in $\mu g/m^3$.

3_EPIDEMIOLOGICAL STAGE

- Variations in the numbers of epidemiological cases are provided as a consequence of the changes in the concentration levels of $PM_{2.5}$ and PM_{10}.
- Epidemiological data consists of cases of fatal diseases and cases of nonfatal diseases.
- The analysis of epidemiological impacts covers a period of 30 years.
- All epidemiological data provided refers to the impact in 1 year (short-run analysis) and the cumulative impact of 30 years (long-run analysis) due to the change in the urban bus fleet.

4_FINANCIAL AND ECONOMIC STAGE

- Morbidity costs (nonfatal diseases) and mortality costs (fatal diseases) are provided as a consequence of variations in the number of epidemiological cases due to changes in the concentration levels of $PM_{2.5}$ and PM_{10}.
- Morbidity costs can be divided into direct costs, which represent hospitalization expenditures, and indirect costs, which represent the costs due to absences at work.
- Whereas morbidity costs represent financial costs, that is, costs incurred by the municipality or by the population, mortality costs are of economic nature, aimed at measuring the less tangible matters, such as suffering and loss of leisure.
- All financial and economic data provided refers to the impact in 1 year (short-run analysis) and the cumulative impact of 30 years (long-run analysis) due to the change in the urban bus fleet.

5_MAIN RESULTS

- It provides the main results—environmental, epidemiological, and economic-financial—that the changes in the concentration levels of $PM_{2.5}$ and PM_{10} would produce.
- It also offers a comparative analysis between economic and financial results provided by the model and economic indicators from the municipality, such as the municipal GDP, municipal annual health expenditure, and average cost of hospitalizations in the municipality. This analysis covers 1 year (short-run analysis) and 30 years (long-run analysis).

6_LONG-RUN ANALYSIS

- It provides graphs with the evolution of morbidity and mortality cases and their respective costs over the period of 30 years (long-run analysis), with data numbers provided every 5 years.

❖ WRI BRASIL

Source: ImpactAr tool.

After these two first sections, the tool presents another seven spreadsheets. The first corresponds to an optional input section, the second to a required input section, and the following five spreadsheets consist of sections for reports and results. Each one contains specific types of data; Table 2 provides a summary.

Table 2 | ImpactAr: Tool Contents and Structure

ORDERING	SHEET REFERENCE NAME	MAIN CONTENTS
Sheet 1	**Optional Inputs**	This is an optional input sheet that enables users to change the PM emissions factor and average fuel consumption per technology of buses. The values available in the model by default are provided in the only table of the spreadsheet, in the gray cells. Note that users should only fill the optional value in the orange cells of the table if they have the data required. Otherwise, the user should keep the orange cells with N/A value, as the model will provide data by default.
Sheet 2	**Project**	The user enters the data for the fleet's renewal project, including data on the city's current bus fleet or any baseline fleet (scenario 0) and data on the city's projected bus fleet (scenario 1). If the user does not possess fleet data to enter, she/he can input any value of annual emissions or concentration levels of $PM_{2.5}$ or PM_{10} in the "Environmental Input Data" subsection and the tool will measure the epidemiological, financial, and economic impacts in the following spreadsheets. In this case, the values entered will represent annual variations on air pollution levels linked to the transport sector. This means that the tool will assume that air pollution levels for scenario 1 represent the values inputted by the user, and the air pollution levels for scenario 0 will be equal to zero.
Sheet 3	**Environmental Stage**	It provides the annual emissions and concentration levels of $PM_{2.5}$ and PM_{10} both for the current and the projected fleet. If the user provides data directly through the "Environmental Input Data" subsection of the "Project Stage," he or she can go directly to the next spreadsheet, "Epidemiological Stage."
Sheet 4	**Epidemiological Stage**	It provides the numbers of epidemiological cases (hospitalizations and deaths) attributable to the difference between the annual concentration levels of $PM_{2.5}$ and PM_{10} linked to the current fleet (scenario 0) and the annual concentration levels of $PM_{2.5}$ and PM_{10} linked to the projected fleet (scenario 1). It also offers the number of work absences due to hospitalizations. Values are provided for 1 year (short-run analysis) and 30 years (long-run analysis). If the user provides data directly through the "Environmental Input Data" subsection of the "Project Stage", the number of fatal and nonfatal diseases provided by ImpactAr represents an estimation of health endpoints due to the annual variation on emissions and concentration levels inputted.
Sheet 5	**Financial and Economic Stage**	Morbidity costs (nonfatal diseases) and mortality costs (fatal diseases) are provided as a consequence of the changes in the annual concentration levels of $PM_{2.5}$ and PM_{10} caused by the fleet's renewal. Values are provided for 1 year (short-run analysis) and 30 years (long-run analysis). If the user provides data directly through the "Environmental Input Data" subsection of the "Project Stage", the financial and economic costs of fatal and nonfatal diseases represent an estimation of the costs associated with the epidemiological cases due to the annual variation in emissions and concentration levels inputted.
Sheet 6	**Main Results**	It provides the main results—environmental, epidemiological, and financial-economic—that the changes in PM_{10} and $PM_{2.5}$ annual concentration levels originated by the fleet's renewal or by the direct air quality inputs of the user (in the "Environmental Input Data" subsection of the "Project Stage") would produce. It also offers a comparative analysis between economic and financial results and economic indicators of the municipality, such as the municipal GDP, municipal annual health expenditure, municipal annual hospital expenditure, and average cost of hospitalizations in the municipality. Values are provided for 1 year (short-run analysis) and 30 years (long-run analysis).
Sheet 7	**Long-Run Analysis**	It provides graphics with the evolution of morbidity and mortality cases and their respective costs over the period of 30 years, with data numbers provided every 5 years.

Notes: GDP = gross domestic product; PM = particulate matter.
Source: WRI authors.

As specified, the sixth and seventh spreadsheets (Main Results and Long-Run Analysis) are not part of the stages presented in Figure 2, but they provide a summary of main results and economic comparisons. The interfaces of all the other spreadsheets mentioned in Table 2 are presented in Appendix A.

Besides the 9 spreadsheets presented above (Cover, User Guide, Optional Inputs, Project, Environmental Stage, Epidemiological Stage, Financial and Economic Stage, Main Results, and Long-Run Analysis), the tool

has 10 additional support spreadsheets that cannot be visualized or modified by the user. These sections contain all default data used as well as the calculations and databases of health, financial, and economic impacts measured by the tool.

4. DATA SOURCES

All external data sources used to build the ImpactAr tool are summarized in Table 3, with specifications on their locations.

Table 3 | **Data Source Specifications**

DATA	SOURCES	SPREADSHEET
Emissions factor per technology (g/L)	Ministry of the Environment[a] São Paulo Transportation (São Paulo Transporte)[b]	DEFAULT_DATA_ ENVIRONMENTAL
Average fuel consumption per technology (L or kWh/100 km)	Operation experience—reported to the World Resources Institute—from a large Brazilian city. The name of the city will not be provided as to avoid relevant information disclosure. For average electric consumption, we added the average of the operation data of nine Padrón electric buses of a pilot carried out in Santiago, Chile.	DEFAULT_DATA_ ENVIRONMENTAL
Broad National Consumer Price Index (Índice Nacional de Preços ao Consumidor Amplo, IPCA)	Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística; IBGE)[c]	DEFAULT_DATA_ ENVIRONMENTAL
Particulate matter fixed conversion measures (FCM) for emissions-concentration	Obtained through simulations in the Coupled Chemistry Aerosol-Tracer Transport model to the Brazilian Developments on the Regional Atmospheric Modeling System (CCATT-BRAMS) model.	DEFAULT_DATA_ ENVIRONMENTAL
Municipal gross domestic product—2015 (2018R$)	IBGE[d]	DEFAULT_DATA_ ENVIRONMENTAL
Annual municipal health expenditure in 2018 (2018R$)	São Paulo: 2018 data from the Municipal City Hall (Prefeitura do Município de São Paulo)[e] Rio de Janeiro: 2018 data from the Municipal City Hall (Prefeitura da Cidade do Rio de Janeiro)[f] Belo Horizonte: 2018 data from Municipal City Hall (Prefeitura Municipal de Belo Horizonte)[g] Niterói: 2018 data from the Municipal City Hall (Prefeitura Municipal de Niterói)	DEFAULT_DATA_ ENVIRONMENTAL
Average cost of hospitalizations from all causes in 2018 (2018R$)	Department of Information Technology of the National Public Health System (Departamento de Informática do Sistema Único de Saúde; DATASUS)	DEFAULT_DATA_ ENVIRONMENTAL
Average hospital expenditure in 2018 from all causes per city (2018R$)	DATASUS	DEFAULT_DATA_ ENVIRONMENTAL
Resident population per city and age ranges (table)	DATASUS (2011–12: IBGE population estimates submitted to the Federal Audit Court (Tribunal de Contas da União, TCU), stratified by age and sex by MS/SGEP/DATASUS)[h]	DEFAULT_DATA_ EPIDEMIOLOGICAL

DATA	SOURCES	SPREADSHEET
Private health insurance coverage per city in August 2018 (%) (table)	National Agency of Supplementary Health (Agência Nacional de Saúde Suplementar, ANS)	DEFAULT_DATA_ EPIDEMIOLOGICAL
Average stay of hospitalizations in 2018 (table)	DATASUS	DEFAULT_DATA_FIN_ AND_ECO
Value of statistical life for Brazil in 2018 (2018R$)	Value obtained by transferring the value of statistical life to OECD countries in 2005, as proposed by Roy and Braathen (2017)	DEFAULT_DATA_ FIN_ AND_ECO
Discount rate	Brazilian basic interest rate in February 2018 (SELIC rate) per the Brazilian Central Bank (Banco Central do Brasil)[i]	DEFAULT_DATA_ FIN_ AND_ECO
Average individual monthly income of all sources per city in 2015 (2018R$)	IBGE Automatic Recovery System (Sistema IBGE de Recuperação Automática, SIDRA)[j]	DEFAULT_DATA_ FIN_ AND_ECO
Average cost of PUBLIC hospitalization in 2018 (2018R$)	DATASUS	DEFAULT_DATA_ FIN_ AND_ECO
Average cost of PRIVATE hospitalization in 2018 (2018R$)	The average cost of hospitalizations in the private system was considered to be three times higher in relation to public ones, as proposed by André et al. (2012)	DEFAULT_DATA_ FIN_ AND_ECO
Population forecasts for São Paulo	Foundation for the State System of Statistical Data Analysis (Fundação Sistema Estadual de Análise de Dados Estatísticos, SEADE)[k]	DEFAULT_DATA_ POPPROJ
Population forecasts for Belo Horizonte	João Pinheiro Foundation (Fundação João Pinheiro) population studies	DEFAULT_DATA_ POPPROJ
Population forecasts for Rio de Janeiro	Pereira Passos Institute (Instituto Pereira Passos)	DEFAULT_DATA_ POPPROJ
Population forecasts for Niterói	Municipal Secretary of Urbanism and Mobility (Secretário Municipal de Urbanismo e Mobilidade)[l]	DEFAULT_DATA_ POPPROJ

Notes: g/L = grams of pollutant per liter of diesel; L or kWh/100 km = liters or kilowatt-hours per 100 kilometers; SELIC = Sistema Especial de Liquidação e de Custódia.
Sources: a. MMA 2011; b. SPTrans 2012; c. IBGE n.d.b; d. IBGE 2017; e. Prefeitura do Município de São Paulo 2018a; f. Prefeitura da Cidade do Rio de Janeiro 2018; g. Prefeitura Municipal de Belo Horizonte 2018; h. IBGE n.d.a; i. BCB 2018; j. IBGE 2015; k. Fundação SEADE 2017; l. SMU 2015.

5. LIMITATIONS AND UNCERTAINTIES

Although the ImpactAr tool offers a robust model to measure air pollution impacts, limitations and uncertainties are inexorable, but identifying them will help users better interpret the results. We have segregated the main limitations according to the stages presented in Section 2, Methodology, additionally including an overall limitations analysis.

Environmental Stage limitations: The main issue that may raise controversy in this stage is related to the methodology applied to convert PM emissions into PM concentration levels. This conversion is based on a fixed conversion factor for each city, which may mislead the user to believe that the different variables that influence concentration levels were not considered. The PM FCMs, however, incorporate aspects inherent to the atmospheric simulation for the period (June 2018) and region analyzed (Southeast Brazil) in the BRAMS 5.2 modeling system, such as wind influence, atmospheric boundary layer behavior, soil-atmosphere interaction, and mesoscale and synoptic scale phenomena.

The emissions scenarios for a 25 percent, 50 percent, 75 percent, and 100 percent change in the bus fleet of each city were interpolated on a gridded domain (25 km) over an urban area of the cities using a methodology proposed by Alonso et al. (2010), native in PREP-CHEM-SRC. The emissions preprocessing tool (Freitas et al. 2011) is a comprehensive tool for preparing emissions fields of trace gases and aerosols for use in atmospheric chemistry transport models.

Although FCMs carry limitations—such as meteorological boundary conditions of one month, coarse-grid resolution, and some model limitations like atmospheric parameterizations—they are a useful option for ImpactAr tool users because this methodology does not require expertise in atmospheric modeling. Furthermore, the FCMs are sensitive only to bus fleet emissions scenarios, and the inclusion of additional meteorological boundary conditions like Representative Concentration Pathway (RCP) scenarios,[23] for example, would bring more uncertainty to the simulations of PM concentration. The grid points with 25 km of spatial resolution and 80 m of thickness in the first vertical layer were chosen due to the computational resource associated with the timetable for the delivery of the tool. One future improvement of the tool is to include simulation with higher grid-point resolutions, which has a tendency of increasing the concentration levels measured.

Epidemiological Stage limitations: All dose-response coefficients retrieved measure the short-term effect of PM on health (usually on the same day of the exposure, up to seven days past). The epidemiological evidence indicates that the long-term effects of air pollution also negatively affect people's health (Beelen et al. 2014; Pope 2007). The Brazilian literature, however, does not present an extensive list of such studies. In order to consider a long-term analysis, the ImpactAr tool sums the impacts of air pollution measured by short-run dose-response coefficients for the 30-year analysis. Furthermore, we have retrieved the coefficients from specific studies. In the future, we intend to carry out averaging estimates by meta-analytic approaches to obtain the dose-response coefficients from a larger number of studies.

Among the epidemiological field, we analyze only a small yet significant portion of consequences caused by air pollution. Studies already suggest the impacts of air pollution on birth gender (Lichtenfels et al. 2007) and fetal development (Hettfleisch et al. 2017). Another limitation is related to the fact that the ImpactAr tool does not consider different sets of exposure among the population in each city. Air pollution does not affect the population evenly, and there is evidence that suggests that low-income groups tend to experience higher exposures to pollutants (Fairburn et al. 2019; Martins et al. 2004; Rivas et al. 2017) and, therefore, higher impacts on health.

Financial and Economic Stage limitations: As previously mentioned, we have obtained the VSL for Brazil, which measures mortality costs, through the unit transfer methodology. Unfortunately, the unit transfer methodology only acknowledges income and inflation differences between OECD countries (original value transferred) and Brazil. Other differences, which significantly affect the VSL value, include life expectancy and income elasticity, among others.[24]

Furthermore, the tool acknowledges future inflation for the long-run analysis (30 years) through a discount rate, but income growth is not included in the analysis, as we believe the different methodologies used to calculate it could raise strong controversy. This has the potential to underestimate the financial and economic results, as the income is kept at 2018 levels.

Overall limitations: Our tool only fits four Brazilian cities: São Paulo, Rio de Janeiro, Belo Horizonte, and Niterói. Due to the methodology used and the size of the input data required to add more cities, such as new PM FCMs and the number of deaths and hospitalizations

per city from DATASUS, we opted to focus on the set of the most important cities in the country in which WRI Brasil works. As the ImpactAr tool is calibrated for these municipalities and is not automatically updated, the use of it to simulate impacts on other Brazilians cities is not recommended. Also, the adoption of ImpactAr for non-Brazilian cities is particularly discouraged because almost all epidemiological parameters embedded in it were retrieved from Brazilian studies.[25]

And last, we acknowledge the need for caution when using ImpactAr tool results. It is important to note that we use a chain process of calculus to measure PM_{10} and $PM_{2.5}$ impacts, meaning that we can assert that the final results carry the aggregate errors of each stage's calculation—namely, environmental, epidemiological, and financial and economic. Unfortunately, we are unable to evaluate whether these uncertainties would potentially increase or diminish the results provided by the tool. Hence, the quantitative outputs provided by the ImpactAr tool must be interpreted as estimates that indicate the existence of the impacts, costs, and their respective magnitude in the analyzed cities; they are not an expression of the exact values of epidemiological cases and costs related to the fleet's renewal in terms of $PM_{2.5}$ and PM_{10} variations.

Bearing the previous limitations and uncertainties in mind, however, the ImpactAr tool comprises a robust model for measuring air pollution impacts, developed using the state-of-the-art methodologies and most credible databases currently applied among the academic field. The consequences of changes in air pollution levels on health and economy are continuously addressed by empirical studies, and, in this sense, the ImpactAr tool provides an important insight to address such matters in the context of these Brazilian cities.

6. PILOT TEST ANALYSIS

The aim of this section is to provide the reader with a better understanding of the tool's outputs by performing a simulation of an urban bus fleet renewal project for the city of São Paulo. This city is the largest city in Brazil in terms of population and economic activity. With 12.2 million inhabitants, São Paulo accounts for 5.8 percent of Brazil's population, and it is responsible for 11 percent of the national GDP.[26] It also has the biggest vehicle fleet of the country, reaching 8 percent of total national fleet[27] with around 9 million vehicles (Detran SP 2019). In this scenario, air pollution is an evident externality in the city, and transport is its main cause.

In January 2018, the municipality implemented a long-term target to reduce the greenhouse gas (GHG) emissions and air pollutants generated by its collective transport fleet in 20 years.[28] The law settled specific targets of reduction for different air pollutants and GHGs, for instance, PM, carbon dioxide (CO_2), and nitrogen oxides (NO_x). Particularly for PM, the law stipulates a minimum decrease of 95 percent in 20 years from the validity of the law (2038) compared to the 2016 levels (Prefeitura do Município de São Paulo 2018b, subsection IV of article 50).

The simulation in the ImpactAr tool is based on the described target for PM reductions in São Paulo. As the target is based on the percentage of emissions reduction, rather than on a profile change in the fleet technology, WRI Brasil determined ad hoc the number of buses of each technology that achieves the 95 percent of reduction in PM emissions, maintaining the total number of buses. The constructed scenario focused on a large increase in the electric fleet, a modest rise in the trolleybus fleet,[29] and a large reduction in the most pollutant type of technology, Euro III and Euro V.

The current fleet (scenario 0) and the projected fleet (scenario 1) data inputs for the test are described in Tables 4 and 5.

Table 4 | **Scenario 0 (Current Fleet) Inputs: Location in the ImpactAr Tool—Project Stage Spreadsheet**

CURRENT FLEET			
TYPE OF BUS	TECHNOLOGY	NUMBER OF BUSES	ANNUAL TRAVELED DISTANCE (KM)
Bus 1	Euro III	7,739	63,102
Bus 2	Euro V	6,756	63,102
Bus 3	Trolleybus	201	63,102
Bus 4	Euro VI	0	0
Bus 5	Euro VI	0	0

Source: WRI authors.

Table 5 | **Scenario 1 (Projected Fleet) Inputs: Location in the ImpactAr Tool—Project Stage Spreadsheet**

PROJECTED FLEET			
TYPE OF BUS	**TECHNOLOGY**	**NUMBER OF BUSES**	**ANNUAL TRAVELED DISTANCE (KM)**
Bus 1	Euro III	330	63,102
Bus 2	Euro V	566	63,102
Bus 3	Trolleybus	250	63,102
Bus 4	Electric	13,550	63,102
Bus 5	Euro VI	0	0

Source: WRI authors.

It is worth noting that the simulation used the values of the emissions factor and the average fuel consumption provided in the tool by default.

6.1 Test Results

Considering only the impacts of $PM_{2.5,}$ the pollutant with the largest impacts on human health, the implementation of the 95 percent of PM reduction target in São Paulo has the potential to avoid about 122 cases of illness and 5 deaths in the first year, reaching around 4,122 cases of sickness and 184 deaths in 30 years.[30] In terms of working days lost due to hospitalizations, in 1 year, about 826 work absences would be avoided, whereas in 30 years this number rises to 29,383 work absences avoided. These impacts represent a potential savings of about R$7 million regarding the morbidity costs and R$391 million regarding the mortality costs, both in the long run.

These and other estimates are presented in Table 6 and are analyzed in more detail in the following subsections.

Table 6 | **Main Results of Pilot Test Analysis: Location in the ImpactAr Tool—Main Results Spreadsheet**

STAGE	SUBSTAGE	$PM_{2.5}$		PM_{10}	
		1 YEAR	**30 YEARS**	**1 YEAR**	**30 YEARS**
ENVIRONMENTAL	**Emissions** (tons/year)	-97.7		-139.6	
	Concentration ($\mu g/m^3$)	-0.1397		-0.1996	
EPIDEMIOLOGICAL	**Morbidity cases** Number of disease cases	-122	-4,122	-51	-1,875
	Mortality cases Number of fatalities	-5	-184	-3	-115
	Working days lost due to hospitalization stays	-826	-29,383	-402	-15,008
FINANCIAL AND ECONOMIC	**Morbidity costs** Cost of illness (R$)	-403,455.11	-7,013,262.75	-215,108.93	-3,772,350.13
	Mortality costs Value of statistical life (R$)	-22,846,531.01	-391,237,883.36	-11,870,574.35	-228,565,113.10

Source: WRI authors.

6.1.1 Environmental Results

Table 7 and Figures 5 and 6 show the reduction in emissions and concentration levels in one year due to the technical solution implemented. Units are measured in tons for emissions levels and μg/m³ for concentration levels. The proposed fleet's renewal would result in a drop in emissions of about 140 tons of PM_{10} and 98 tons of $PM_{2.5}$ compared to the levels of 2016, which represents approximately a 95 percent reduction as proposed in municipal law 16.802/2018. Changes in concentration levels would reduce around 0.2000μg/m³ and 0.140μg/m³, for PM_{10} and $PM_{2.5}$, respectively.

Table 7 | **Main Environmental Results: Location in the ImpactAr Tool—Environmental Stage Spreadsheet**

	POLLUTANT	CURRENT FLEET (SCENARIO 0)	PROJECTED FLEET (SCENARIO 1)	VARIATION	VARIATION (%)
Emissions (tons/year)	$PM_{2.5}$	102.84	5.1	-97.69	95
	PM_{10}	146.91	7.4	-139.55	95
Concentration (μg/m³)	$PM_{2.5}$	0.1471	0.0074	-0.1397	95
	PM_{10}	0.2101	0.0105	-0.1996	95

Source: WRI authors.

Figure 5 | **Emissions Reductions: Location in the ImpactAr Tool—Environmental Stage Spreadsheet**

Annual emissions variations (tons/year)

-97.69

-139.55

PM2.5   PM10
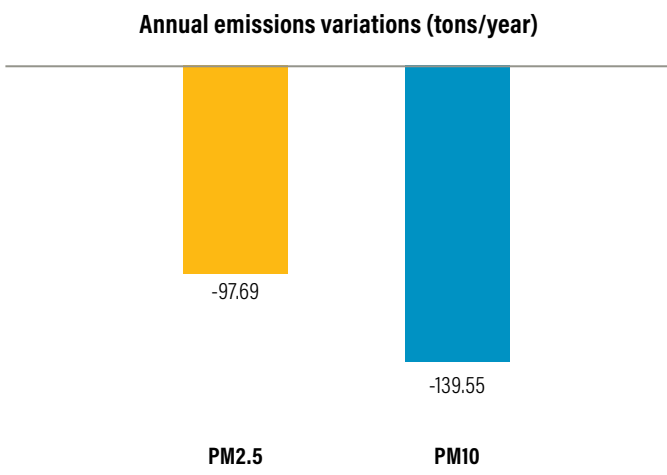
Source: ImpactAr tool.

Figure 6 | **Concentration Reduction: Location in the ImpactAr Tool—Environmental Stage Spreadsheet**

Annual concentration variation (μg/m³)

-0.140

-0.200

PM2.5   PM10
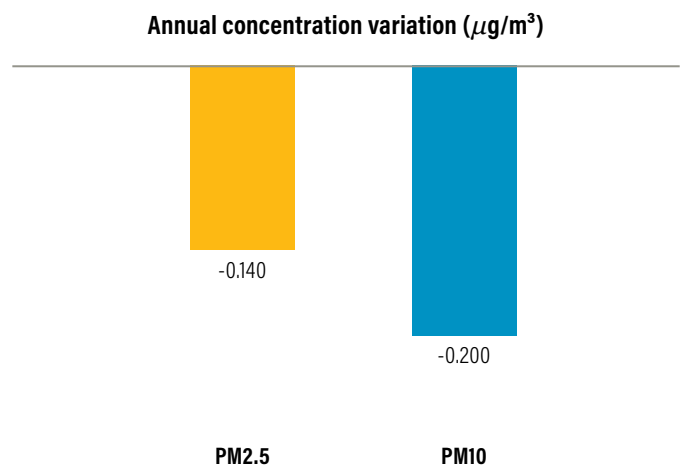
Source: ImpactAr tool.

6.1.2 Epidemiological Results

Table 8 and Figures 7, 8, 9, and 10 present the numbers of morbidity and mortality cases avoided according to the long-run and short-run analyses of the ImpactAr tool, measured for each pollutant and type of disease. The reductions in PM_{10} and $PM_{2.5}$ emissions are reflected in the number of mortality and morbidity cases related to air pollution. For total cumulative effects provided by the long-run analysis (30 years), reductions in $PM_{2.5}$ concentration levels would avoid approximately 4,122 hospitalizations, whereas reductions in PM_{10} concentration levels would avoid about 1,875. As for mortality outcomes, 184 cases would be avoided due to the drops in $PM_{2.5}$ levels and 115 cases due to the drops in PM_{10} levels, both for the 30-year analysis.

Table 8 | **Main Epidemiological Results: Location in the ImpactAr Tool—Epidemiological Stage Spreadsheet**

VARIATION OF FATAL AND NONFATAL CASES					
TYPE OF HEALTH IMPACT	POLLUTANT	PERIOD (YEARS)	CARDIOVASCULAR DISEASE	RESPIRATORY DISEASE	TOTAL
MORBIDITY	$PM_{2.5}$	1	-44	-77	-121
		30	-1,684	-2,438	-4,122
	PM_{10}	1	-30	-22	-52
		30	-1,067	-809	-1,875
MORTALITY	$PM_{2.5}$	1	-4	-1	-5
		30	-140	-43	-184
	PM_{10}	1	0	-3	-3
		30	-2	-113	-115

Source: WRI authors.

Figure 7 | **Avoided Morbidity in One Year: Location in the ImpactAr Tool—Epidemiological Stage Spreadsheet**

Morbidity cases in 1 year
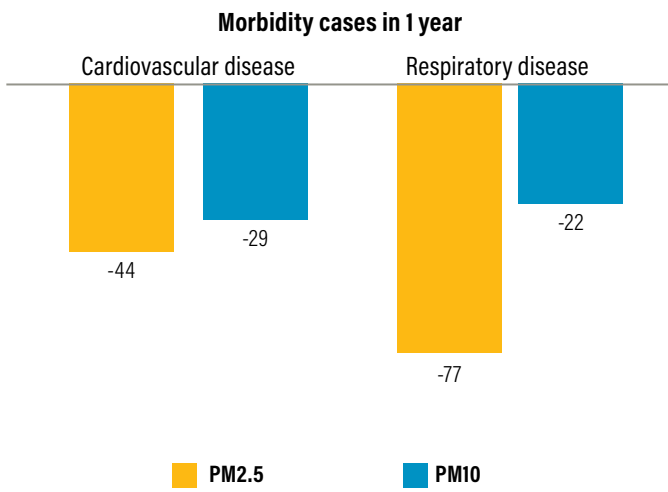
Source: ImpactAr tool.

Figure 8 | **Avoided Morbidity in 30 years: Location in the ImpactAr Tool—Epidemiological Stage Spreadsheet**

Morbidity cases in 30 years
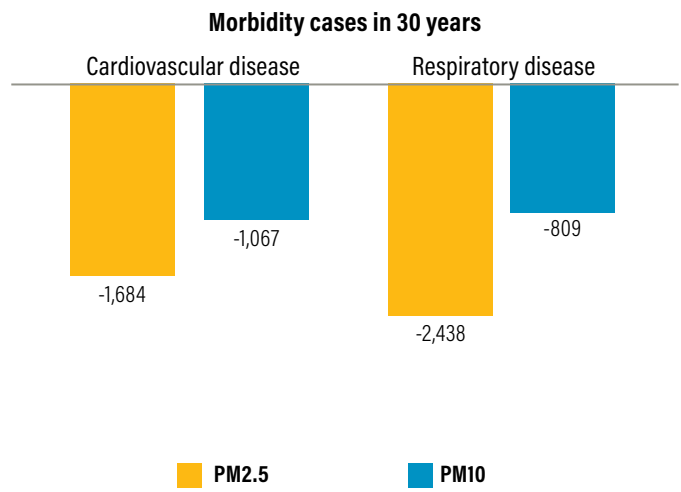
Source: ImpactAr tool.

The numbers of avoided fatalities were significantly lower than those for avoided hospitalizations. This result was already expected because C-Rs had already shown that the impact of changes in concentration levels was much higher for nonfatal diseases than for fatal diseases. For both mortality and morbidity, $PM_{2.5}$ impacts were significantly larger when compared to PM_{10} figures.

Figure 9 | **Avoided Mortality Cases in One Year: Location in the ImpactAr Tool—Epidemiological Stage Spreadsheet**

Variation of mortality cases - 1 year
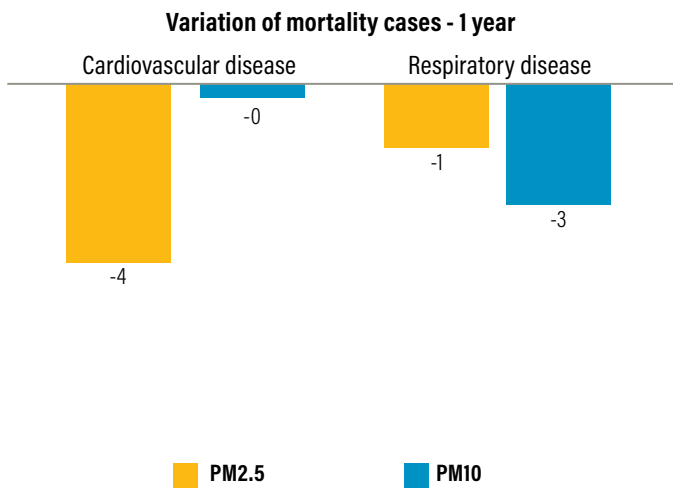
Source: ImpactAr tool.

Figure 10 | **Avoided Mortality Cases in 30 Years: Location in the ImpactAr Tool—Epidemiological Stage Spreadsheet**

Variation of mortality cases - 30 years
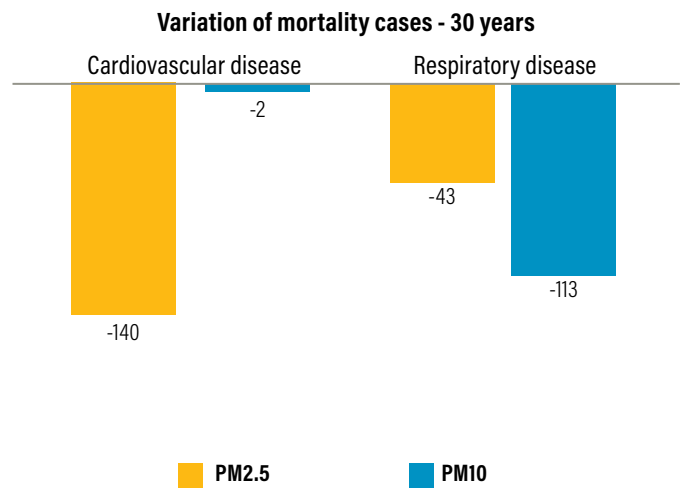
Source: ImpactAr tool.

6.1.3 Financial and Economic Results

Tables 9 and 10 show the costs avoided related to the variation in the numbers of mortality and morbidity cases linked to the fleet's renewal. It is worth noting that mortality costs are of an economic nature, whereas morbidity costs are of a financial nature. This happens due to the different methodology of measuring: mortality costs are calculated through the VSL, and morbidity costs are measured through the COI methodology.

Table 9 | **Total Cost of Morbidity: Location in the ImpactAr Tool—Financial and Economic Stage Spreadsheet**

			TOTAL VARIATION OF MORBIDITY COSTS		
	POLLUTANT	PERIOD (YEARS)	CARDIOVASCULAR DISEASES (R$)	RESPIRATORY DISEASES (R$)	TOTAL (R$)
MORBIDITY	$PM_{2.5}$	1	-241,559.33	-161,895.78	-403,455.11
		30	-4,339,170.57	-2,674,092.19	-7,013,262.75
	PM_{10}	1	-156,662.27	-58,446.66	-215,108.93
		30	-2,718,564.27	-1,053,785.87	-3,772,350.13

Source: WRI authors.

Table 10 | Total Cost of Mortality: Location in the ImpactAr Tool—Financial and Economic Stage Spreadsheet

VARIATION ON TOTAL MORTALITY COSTS					
	POLLUTANT	**PERIOD (YEARS)**	**CARDIOVASCULAR DISEASES (R$)**	**RESPIRATORY DISEASES (R$)**	**TOTAL (R$)**
MORTALITY	$PM_{2.5}$	1	-17,023,127.57	-5,823,403.45	-22,846,531.01
		30	-296,653,715.16	-94,584,168.20	-391,237,883.36
	PM_{10}	1	-207,966.44	-11,662,607.92	-11,870,574.35
		30	-3,827,538.49	-224,737,574.61	-228,565,113.10

Source: WRI authors.

Figures 11 and 12 summarize savings in terms of hospitalization costs and income losses as a result of the decrease in the number of nonfatal diseases. Again, analyses cover the impacts of PM_{10} and $PM_{2.5}$, short-run and long-run analyses for each health endpoint. As expected, cardiovascular diseases presented the larger share of the costs avoided. The cumulative effects of avoided costs in 30 years totaled R$7,013,262.75 for $PM_{2.5}$ and R$3,772,350.13 for PM_{10}. According to the short-run analysis (1 year), $PM_{2.5}$ reductions would avoid costs of around R$403,455.11, and PM_{10} reductions would avoid costs of around R$215,108.93.

Figure 11 | Avoided Morbidity Costs in One Year: Location in the ImpactAr Tool—Financial and Economic Stage Spreadsheet

Variation on total morbidity costs in 1 year (R$)

PM2.5   PM10

-58,446.66
- 161,895.78
-156,662.27
- 241,559.33

■ Cardiovascular disease ■ Respiratory disease
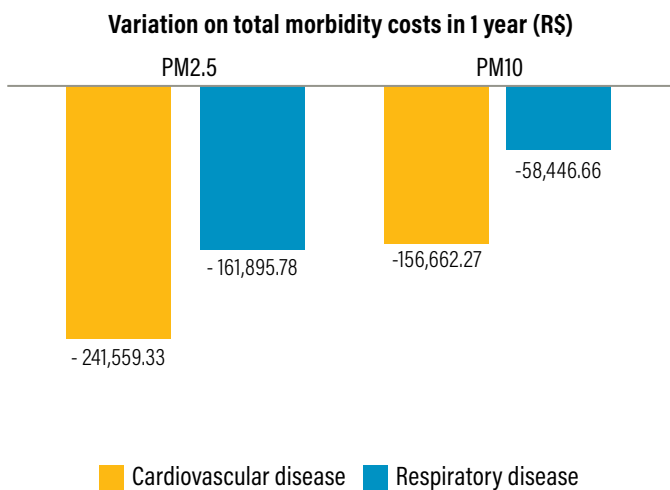
Source: ImpactAr tool.

Figure 12 | Avoided Morbidity Costs in 30 Years: Location in the ImpactAr Tool—Financial and Economic Stage Spreadsheet

Variation on total morbidity costs in 30 years (R$)

PM2.5   PM10

-1,053,785.87
-2,674,092.19
- 2,718,564.27
- 4,339,170.57

■ Cardiovascular disease ■ Respiratory disease
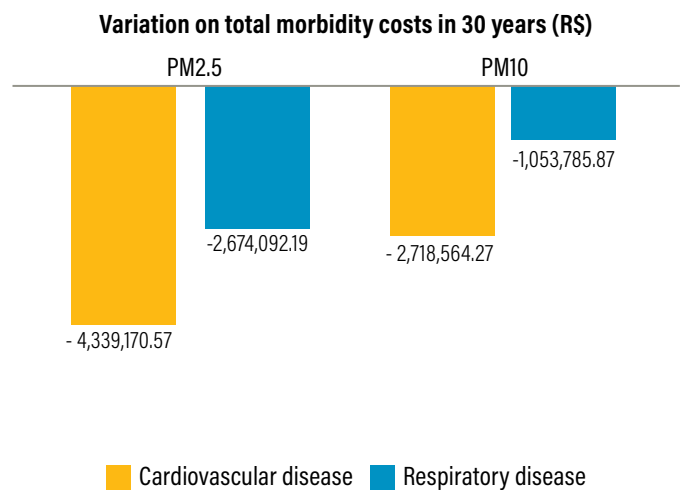
Source: ImpactAr tool.

The mortality economic costs avoided represented the largest figures in the Financial and Economic Stage of the results provided by the ImpactAr tool. This can be explained by the intended variables covered by the methodology. The idea is to provide a measure, in terms of Brazilian reals, of the welfare losses avoided due to variations in air pollution levels. The values, however, do not have an accountant nature and therefore cannot be addressed as financial costs.

Figures 13 and 14 illustrate the mortality costs avoided as a result of the technical solution adopted for São Paulo's urban bus fleet. The total avoided economic/welfare losses related to mortality reached approximately R$391,237,883.36 for $PM_{2.5}$ reductions and R$228,565,113.10 for PM_{10} reductions in 30 years.

Figure 13 | **Avoided Mortality Costs in One Year: Location in the ImpactAr Tool—Financial and Economic Spreadsheet**

Variation on total mortality costs in 1 year (R$)
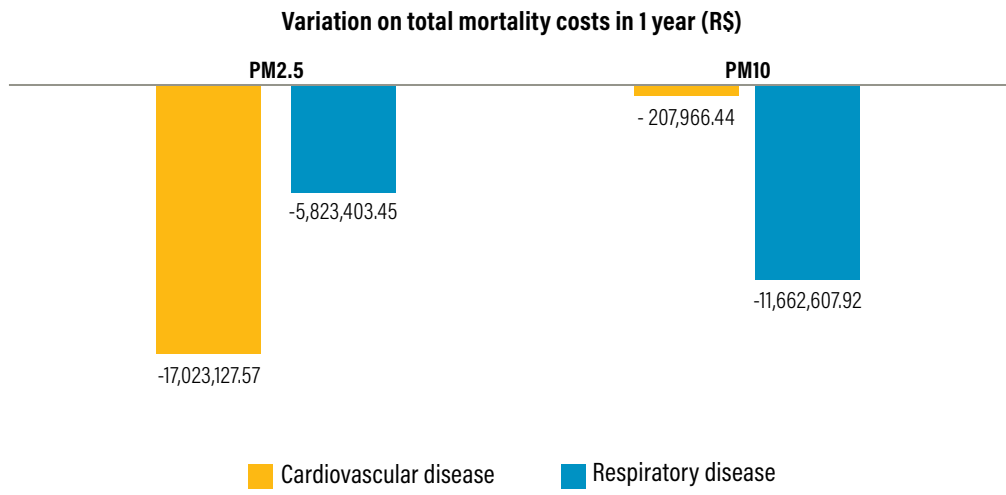
Source: ImpactAr tool.

Figure 14 | **Avoided Mortality Costs in 30 Years: Location in the ImpactAr Tool—Financial and Economic Spreadsheet**

Variation on mortality cost in 30 years (R$)
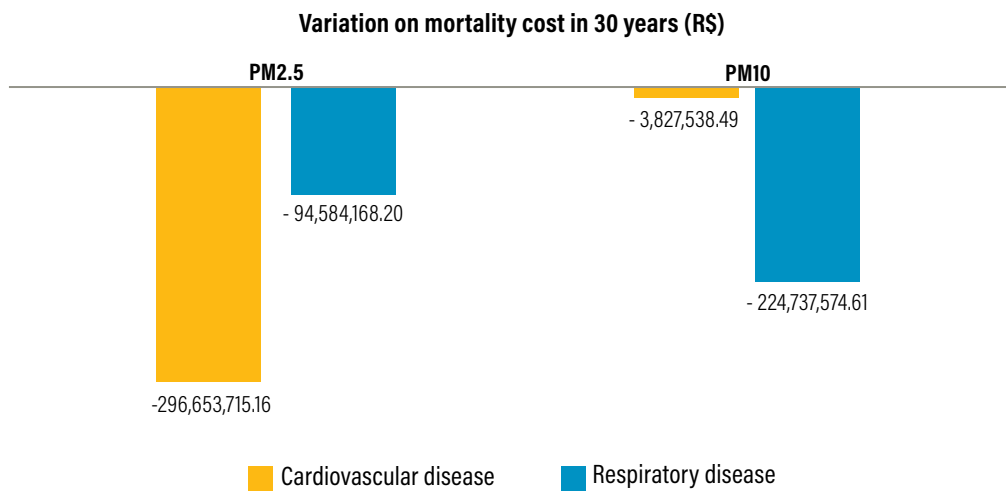
Source: ImpactAr tool.

6.1.4 Comparative Analysis

Considering the costs that would be avoided due to the reduction of $PM_{2.5}$ and PM_{10} emissions, the ImpactAr tool provided a comparative analysis with selected economic indicators for the municipality of São Paulo. It analyzed how much the monetary outcomes, as a consequence of the proposed change in the bus fleet, would represent in terms of the municipal GDP, municipal health and hospitalization expenditures in 2018, and how many public hospitalizations could be provided to the population, according to the financial savings. This information is presented in Table 11.

In one year, the total avoided COI (direct and indirect costs summed) is almost zero compared to the annual GDP and total health expenditure of São Paulo. However, the savings due to nonfatal diseases could provide São Paulo's population with an additional 145 hospitalizations, in the case of $PM_{2.5}$ reductions, and 77 in the case of PM_{10} reductions, considering the average unit price of public and private hospitalizations in 2018 from all causes in São

Paulo. Mortality costs, in turn, would represent around 0.02 percent and 0.01 percent of the municipal GDP, for $PM_{2.5}$ and PM_{10} in one year, respectively.

If we consider the cumulative impact of avoided costs for 30 years and compare it with the same annual indicators, the 30-year avoided cost of mortality could reach about 0.3 percent and 0.2 percent of São Paulo's GDP, for $PM_{2.5}$ and PM_{10}, respectively. Summing up the COI for 30 years, the values remain low, being about 0.005 percent for $PM_{2.5}$ and 0.003 percent for PM_{10} of municipal GDP. As for the relation of morbidity avoided costs and the municipal health and hospitalization expenditures of 2018, $PM_{2.5}$ associated costs represented, respectively, 0.07 percent and 0.84 percent, and PM_{10} associated costs around 0.04 percent and 0.45 percent. In terms of additional hospitalizations due to morbidity savings, the numbers reach 2,526 for $PM_{2.5}$ and 1,359 hospitalizations for PM_{10} that could be provided to the population.

Table 11 | **Comparative Analysis: Main Results Spreadsheet**

| PERIOD	SUBSTAGE	TOTAL COSTS VARIATION (R$)		TOTAL COSTS VARIATION/GDPm (%)		TOTAL COSTS VARIATION/ ANNUAL HEALTH EXPENDITURE (%)		TOTAL COSTS VARIATION/ ANNUAL HOSPITAL EXPENDITURE (%)		NUMBER OF HOSPITALIZATIONS DUE TO SAVINGS/ COST OF FLEET CHANGES	
		$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
1 year	Morbidity	-403,455.11	-215,108.93	0.00031222	0.0001665	0.0040	0.0021	0.048	0.025	145	77
	Mortality	-22,846,531.01	-11,870,574.35	0.01768015	0.0091862	*	*	*	*	*	*
30 years	Morbidity	-7,013,262.75	-3,772,350.13	0.0054273	0.0029193	0.0710	0.0382	0.839	0.451	2.526	1.359
	Mortality	-391,237,883.36	-228,565,113.10	0.30276556	0.1768787	*	*	*	*	*	*

Notes: GDPm = municipal gross domestic product.
*For the costs associated with mortality, the value of statistical life (VSL) methodology was used. VSL is an estimate of how much people are willing to pay to reduce the risk of death, taking into account issues such as suffering and discomfort. Therefore, this cost represents more than the financial impacts of mortality and cannot be compared with financial variables such as health expenditures.
Source: WRI authors.

7. FINAL REMARKS AND CONCLUSION

Air pollution currently imposes one of the most serious threats to a variety of dimensions of human life. Fighting against air pollution requires the engagement of decision-makers from different sectors, and the use of epidemiological, economic, and financial evidence provides a common ground for it (WHO/Europe and OECD 2015). As mentioned before, however, estimating the unobservable costs of air pollution impacts is not a trivial task, as it requires the use of several methodologies that are capable of both isolating the effects of pollutants on health and estimating the costs associated with these diseases.

Through the systematic organization of several existing methodologies applied in national empirical studies, the ImpactAr tool conveys the different stages of the chain process that pollutants go through in one tool. By allying scientific integrity and practicality, the tool is an attempt to provide Brazilian public municipal decision-makers, as well as politicians, private sector operators, academics, researchers, and the public in general, with (i) a robust tool that models air pollution impacts, (ii) easy access to the advanced methodologies, (iii) maximum ease of use and understanding of the results, and (iv) transparency about the methodology and data used in the process.

By using the ImpactAr tool, estimates on the existence and magnitude of the impacts on health and its related costs of PM caused by changes in the bus fleet can be measured for the cities of São Paulo, Rio de Janeiro, Belo Horizonte, and Niterói. The tool is a first step toward making observable the implicit costs of air pollution in Brazilian cities, after which a deeper research on a case-by-case basis should be carried out. The tool's results can broaden the benefit-cost analysis of transport projects made by their proponents by adding the potential nonobservable costs of air pollution.

It is important to bear in mind that, although the impacts related to human health are considered the most significant consequences of air pollution, the literature on the matter has strongly suggested that air pollution affects other areas of human life, such as urban vegetation (Amato-Lourenço et al. 2016), real estate values (Carriazo Osorio 2001), and cultural heritage (Watt et al. 2009). Furthermore, air pollution, and, more specifically, the short-lived climate forcers (SLCFs),[31] are also important contributors to climate change and key challenges because their reduction would have the potential to slow the climate change in the near term (UNEP 2011). Due to limited data and the incipient Brazilian empirical studies on these subjects, we opted not to include such areas, as we would significantly raise the uncertainty of the model, though it is important not to forget that, by broadening the areas of impact, the costs/benefits of a fleet's renewal would certainly increase.

Despite focusing on four Brazilian cities, the aim of the tool is not to be confined to them. In this sense, both ImpactAr and its technical note should be used as a blueprint for other cities to learn and develop their own version of the ImpactAr tool. We hope to broaden the scope of cities covered in the future and improve the calculations and methods embedded in the tool by allowing, for instance, the acknowledgment of more than one bus fleet change over time and the inclusion of PM FCMs originated from simulations with higher grid resolutions. The authors encourage users to provide feedback and recommendations so they can advance both the applicability as well as the accuracy of their results.
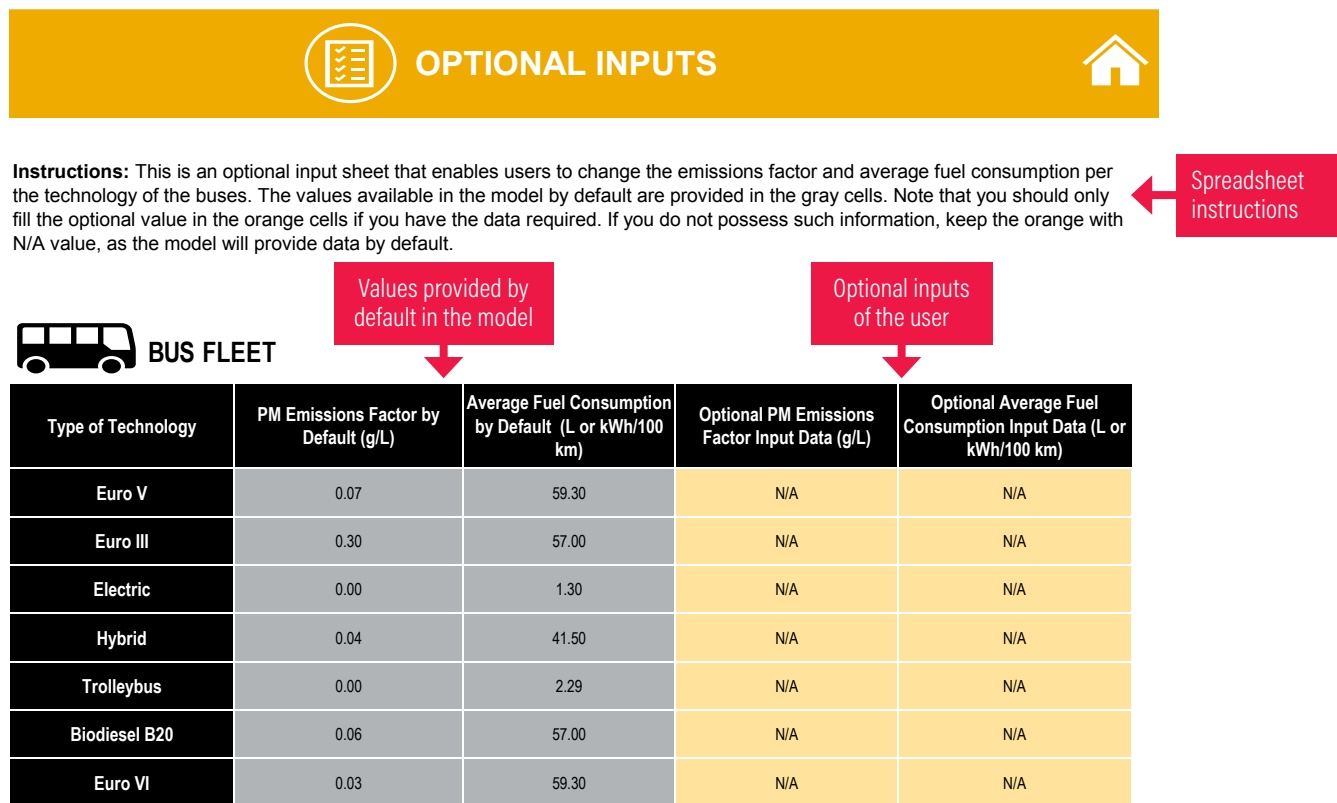
APPENDIX A – IMPACTAR TOOL USER GUIDE AND SPREADSHEET INTERFACES

This section presents a short user guide (along with the interfaces of specific spreadsheets in the ImpactAr tool[32]) to help users enter the required and/or optional data and to navigate the main outcomes of the tool. It is worth remembering that ImpactAr was built to maintain maximum ease of use and understanding of the results for users. By following the instructions below, users will be able to fully operate the tool.

A.1 Inserting Optional Data

After the first two spreadsheets—"Cover" and "User Guide" (presented in Section 3, ImpactAr Tool Structure)—the tool presents the "Optional Inputs" (OPT_INPUTS) spreadsheet (Figure A1). This optional input sheet contains a table that enables users to change the PM emissions factors (g/L) and average fuel consumptions (L or kWh/100 km) per the technology of the buses. The values available in the model by default are provided in the gray cells of the table. The optional value can be filled in the orange cells of the table only if the user possesses such data; otherwise, orange cells must be kept with N/A value, as the model will provide data by default.

Figure A1 | **Interface of the Optional Input Spreadsheet — OPT_INPUTS**

OPTIONAL INPUTS

Instructions: This is an optional input sheet that enables users to change the emissions factor and average fuel consumption per the technology of the buses. The values available in the model by default are provided in the gray cells. Note that you should only fill the optional value in the orange cells if you have the data required. If you do not possess such information, keep the orange with N/A value, as the model will provide data by default.

Spreadsheet instructions

Values provided by default in the model

Optional inputs of the user

BUS FLEET

Type of Technology	PM Emissions Factor by Default (g/L)	Average Fuel Consumption by Default (L or kWh/100 km)	Optional PM Emissions Factor Input Data (g/L)	Optional Average Fuel Consumption Input Data (L or kWh/100 km)
Euro V	0.07	59.30	N/A	N/A
Euro III	0.30	57.00	N/A	N/A
Electric	0.00	1.30	N/A	N/A
Hybrid	0.04	41.50	N/A	N/A
Trolleybus	0.00	2.29	N/A	N/A
Biodiesel B20	0.06	57.00	N/A	N/A
Euro VI	0.03	59.30	N/A	N/A

Source: ImpactAr tool.

A.2 Inserting Required Data

After the Optional Inputs spreadsheet is the "Project" (1_PROJECT) spreadsheet. This is the only required input section. To start the simulation, the user should follow the steps provided in this spreadsheet.

Step 1: Choose your city. The user must first select the city of interest: São Paulo, Rio de Janeiro, Belo Horizonte, or Niteroi—by filtering the cell. Please note that entering the correct city is paramount to getting the correct results because the databases used to calculate the impacts for each city vary significantly and, therefore, the outcomes as well.

Step 2: Do you have information regarding your current and projected fleet of buses and/or trucks? Before users are required to input information about the current and projected bus fleets, there is a cell asking whether they possess such data. If users possess the data, they are instructed to remain in the same spreadsheet and complete the following two tables with the data (see Step 3 below). If users do not possess the required information, they are instructed to press a cell, which leads them directly to the additional step in the same spreadsheet (see Additional Step).

Step 3: Fill in the data regarding your current and your projected fleet. Fleet data must be entered in the input worksheet (Project spreadsheet) twice: once for the city's current bus fleet and once for the city's projected (future) bus fleet. Data required include the
- number of buses (current and projected fleet);
- type of technology (current and projected fleet); and
- average annual travel distance (km) per bus (current and projected fleet).

Additional Step: Fill in environmental data. Note you should only fill these cells if you haven't filled the data required in Step 3, otherwise, keep the annual value of the table "Input Data" as "0." This step is only required for users who have not filled in the data about the urban bus fleet (both current and projected). Here, any value of annual emissions or concentration levels of $PM_{2.5}$ or PM_{10} can be inputted, and the tool will measure the epidemiological, financial, and economic impacts in the following spreadsheets. In this case, the values entered will represent annual variations on air pollution levels linked to the transport sector. This means that the tool will assume that air pollution levels for scenario 1 represent the values inputted by the user, and the air pollution levels for scenario 0 will be equal to zero.

It should be noted that if users enter the data in the Additional Step section, the inputs inserted for the measurement of the impacts of fleet renewal will not be considered. In this sense, users should always keep the annual value of the Input Data table in the Additional Step as "0" if they want to measure the impacts of fleet renewal.

In order to present the interface of the Project Stage, we have broken the spreadsheet into Figure A2, which presents the section of the spreadsheet with Steps 1, 2, and 3; and Figure A3, which presents the section of the spreadsheet with the Additional Step.

Figure A2 | Interface of the Project Stage Spreadsheet: Steps 1, 2, and 3—1_PROJECT

Instructions: This is a required input sheet. Please pay attention to each step. Gray cells are to be filtered, orange cells are to be filled, and green cells are optional inputs

FLEET INPUTS

Step 1: Choose your city

City
São Paulo

← Step 1

← Spreadsheet instructions

Step 2: Do you have information regarding your current and projected fleet of buses?

YES -> go to step 3		NO -> just press here

← Step 2

Step 3: Fill in the data regarding your current and your projected fleet ← Step 3

🚌 **BUS FLEET**

CURRENT FLEET - SCENARIO 0			
Type of bus	Technology	Number of buses	Average annual traveled distance per bus (km)
Bus 1	Euro III	7,739	63,102
Bus 2	Euro V	6,756	63,102
Bus 3	Trolleybus	201	63,102
Bus 4	Euro III	0	0
Bus 5	Euro III	0	0

PROJECTED FLEET - SCENARIO 1			
Type of bus	Technology	Number of buses	Average annual traveled distance per bus (km)
Bus 1	Euro III	330	63,102
Bus 2	Euro V	566	63,102
Bus 3	Trolleybus	250	63,102
Bus 4	Electric	13,550	63,102
Bus 5	Biodiesel B20	0	0

Source: ImpactAr tool.

Figure A3 | Interface of Project Stage Spreadsheet: Additional Step—1_PROJECT

Additional Step: *Note, you should only fill these cells if you haven't filled the data required in Step 3, otherwise, keep the annual value of the table "Input Data" as "0".*

If you do not possess fleet data to enter, you can input any value of annual emissions or concentration levels of PM$_{2.5}$ or PM$_{10}$ in this subsection, and the tool will measure the epidemiological, financial, and economic impacts in the following spreadsheets. In this case, the values entered will represent annual variations on air pollution levels. This means that the tool will assume that air pollution levels for scenario 1 represent the values inputted by the user, and the air pollution levels for scenario 0 will be equal to zero.

Input Data	
Pollutant	PM$_{2.5}$
Type of data	Concentration (µg/m³)
Annual value	0

← Table to input environmental data

Main Results from Input Data - *Annual Values*		
	Particulate matter 2.5 (PM$_{2.5}$)	Particulate matter 10 (PM$_{10}$)
Emissions (tons/year)	N/A	N/A
Concentration (µg/m³)	N/A	N/A

← Environmental results of the inputted data

← Additional Step instructions

Source: ImpactAr tool.

A.3 Analyzing the Results

After filling in either the information required for the fleet renewal or the environmental data, no new data will be required, and the user can navigate the results of the simulation's in the following five spreadsheets. Each spreadsheet or section contains a summary analysis of the main results per stage (environmental, epidemiological, and financial-economic) and a detailed section with specific outcomes. Different tables and different graphs that can be filtered are provided in each section and all analyses cover 1-year impacts (short-run analysis) and 30-year impacts (long-run analysis) of the variation of PM_{10} and $PM_{2.5}$ levels. **If the levels of $PM_{2.5}$ and PM_{10} emissions or concentration decrease (increase) as a result of the differences between the current and the projected fleet, all results will be given as negative (positive), meaning a reduction (growth) in emissions and concentration levels, epidemiological cases, and financial and economic costs. All the results will be given as negative if the user provided input information in the Additional Step section of the Project spreadsheet, as the tool will assume that air pollution levels for** scenario 1 represent the values inputted by the user, and the air pollution levels for scenario 0 will be equal to zero. Below you can find details on each spreadsheet's results section.

Analysis of the environmental results spreadsheet (2_ENVIRONMENTAL_STAGE). In the first part of this section, the user can analyze the main environmental results in terms of variations in concentration and emissions levels of $PM_{2.5}$ and PM_{10}. This data is presented in a table and two graphs that can be filtered. The spreadsheet also provides a second part with detailed results, showing total emissions and concentration levels by type of technology for both the current and projected fleets. This second part provides six tables and four graphs that can be filtered.

In order to present the interface of the Environmental Stage, we have broken the spreadsheet into Figure A4, which presents the section with the main environmental results, and Figure A5, which presents the section with the detailed environmental results.

Figure A4 | **Interface of the Environmental Stage Spreadsheet: Main Environmental Results—2_ENVIRONMENTAL_STAGE**
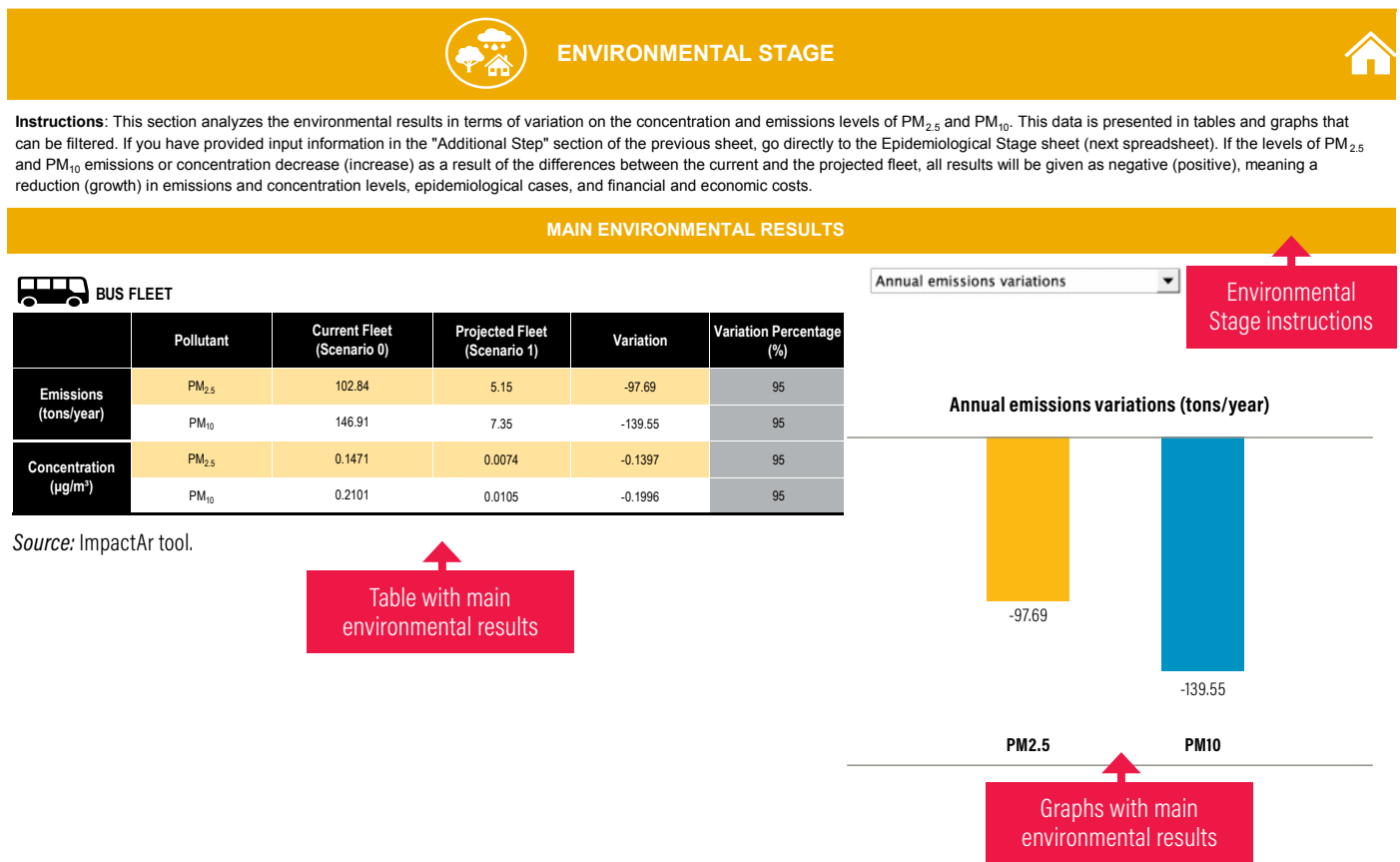
Source: ImpactAr tool.

Figure A5| **Interface of the Environmental Stage Spreadsheet: Detailed Environmental Results —
2_ENVIRONMENTAL_STAGE**

🚌 **BUS FLEET**

CURRENT FLEET/SCENARIO 0 EMISSIONS		
Type of bus	Annual emissions of particulate matter 2.5 (tons/year)	Annual emissions of particulate matter 10 (tons/year)
Bus 1	84.29	120.42
Bus 2	18.55	26.49
Bus 3	0.00	0.00
Bus 4	N/A	N/A
Bus 5	N/A	N/A
Total	102.84	146.91

PROJECTED FLEET/SCENARIO 1 EMISSIONS		
Type of bus	Annual emissions of particulate matter 2.5 (tons/year)	Annual emissions of particulate matter 10 (tons/year)
Bus 1	3.59	5.13
Bus 2	1.55	2.22
Bus 3	0.00	0.00
Bus 4	0.00	0.00
Bus 5	N/A	N/A
Total	5.15	7.35

ANNUAL EMISSIONS VARIATION		
	Δ PM$_{2,5}$ (tons/year)	Δ PM$_{10}$ (tons/year)
Total	-97.69	-139.55

Tables with detailed analysis of environmental results

CURRENT FLEET/ SCENARIO 0 CONCENTRATION LEVELS		
Type of bus	Annual concentration of particulate matter 2.5 (µg/m³)	Annual concentration of particulate matter 10 (µg/m³)
Total	0.1471	0.2101

PROJECTED FLEET/SCENARIO 1 CONCENTRATION LEVELS		
Type of bus	Annual concentration of particulate matter 2.5 (µg/m³)	Annual concentration of particulate matter 10 (µg/m³)
Total	0.0074	0.0105

ANNUAL CONCENTRATION LEVELS' VARIATION		
	Δ PM$_{2,5}$ (µg/m³)	Δ PM$_{10}$ (µg/m³)
Total	-0.1397	-0.1996

Current fleet concentration ▼

Current fleet concentration – Scenario 0 (μg/m³)

0.210

0.147

PM2.5   PM10
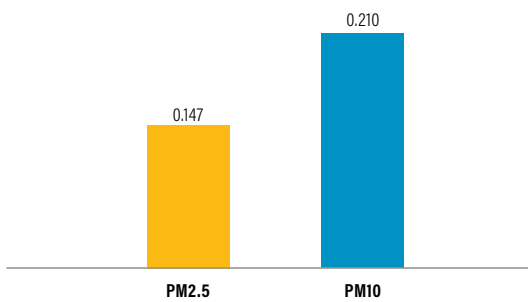
Graphs with detailed analysis of environmental results

Source: ImpactAr tool.

**Analysis of the epidemiological results spreadsheet
(3_EPIDEMIOLOGICAL_STAGE).** In the first part of this section, the user can analyze the main epidemiological results as a function of variations in PM$_{2.5}$ and PM$_{10}$ concentration levels. These results are separated by fatal and nonfatal cases of respiratory disease and cardiovascular disease, and by 1-year and 30-year analyses. This data is presented in a table and four graphs that can be filtered. The worksheet also provides a second part with detailed results, presenting the above epidemiological findings by age group and type of financial coverage of cases (public or private). This part also includes two tables with the total number of workdays lost due to hospitalizations and the total number of workdays lost per age range.

We have not provided a table of work absences per type of financial coverage because we assumed the average stay to be the same for public and private hospitalizations. This part provides four tables and 14 graphs that can be filtered.

In order to present the interface of the Epidemiological Stage, we have broken the spreadsheet into Figure A6, which presents the main epidemiological results; Figure A7, which shows the first part of the detailed epidemiological results sections; Figure A8, which presents the second part; and Figure A9, which shows the third and final part of the detailed epidemiological results section.

Figure A6 | Interface of the Epidemiological Stage Spreadsheet: Main Epidemiological Results—3_EPIDEMIOLOGICAL_STAGE

EPIDEMIOLOGICAL STAGE

Epidemiological Stage instructions

Instructions: This section analyzes the epidemiological results in terms of variation on the concentration and emissions levels of $PM_{2.5}$ and PM_{10}. This data is presented in tables and graphs that can be filtered. If the levels of $PM_{2.5}$ and PM_{10} emissions or concentration decrease (increase) as a result of the differences between the current and the projected fleet, all results will be given as negative (positive), meaning a reduction (growth) in emission and concentration levels, epidemiological cases, and financial and economic costs. All the results will be given as negative if the user provided input information in the "Additional Step" section of the "1_PROJECT" spreadsheet as the tool will assume that air pollution levels for scenario 1 represent the values inputted by the user, and the air pollution levels for scenario 0 will be equal to zero.

MAIN EPIDEMIOLOGICAL RESULTS

🚌 **BUS FLEET**

Variation on morbidity cases – 30 years

VARIATION FATAL AND NONFATAL CASES					
	Pollutant	Period (year)	Cardiovascular disease	Respiratory disease	Total
MORBIDITY	$PM_{2.5}$	1	-44	-77	-122
		30	-1,684	-2,438	-4,122
	PM_{10}	1	-30	-22	-52
		30	-1,067	-809	-1,875
MORTALITY	$PM_{2.5}$	1	-4	-1	-5
		30	-140	-43	-184
	PM_{10}	1	0	-3	-3
		30	-2	-113	-115

Source: ImpactAr tool.

Morbidity cases in 30 years

Table with main epidemiological results

Graphs with main epidemiological results

Figure A7 | Interface of the Epidemiological Stage Spreadsheet: First Part of the Detailed Epidemiological Results Section—3_EPIDEMIOLOGICAL_STAGE

DETAILED ANALYSIS OF EPIDEMIOLOGICAL RESULTS | **Analysis of nonfatal cases per age range** | **Analysis of nonfatal cases per type of health coverage**

Variation on total working days lo:

Variation of working days lost due to hospitalizations in 30 years per age range – PM_{10}

Quick button to go to the table with the analysis of the nonfatal cases per age range

Quick button to go to the table with the analysis of the nonfatal cases per type of health insurance coverage

Source: ImpactAr tool.

Graphs with detailed analysis of the epidemiological results

Interface of the Epidemiological Stage Spreadsheet: Second Part of the Detailed Epidemiological Results Section—3_EPIDEMIOLOGICAL_STAGE

ANALYSIS OF TOTAL WORK DAYS LOST DUE TO HOSPITALIZATIONS

BUS FLEET

	Pollutant	Period (years)	Cardiovascular disease	Respiratory disease	Total
WORK ABSENCES IN TERMS OF HOSPITALIZATIONS (in days)					
MORBIDITY	PM$_{2.5}$	1	-352	-474	-826
		30	-13,307	-16,076	-29,383
	PM$_{10}$	1	-228	-174	-402
		30	-8,214	-6,794	-15,008

Table with analysis of total workdays lost due to hospitalizations

ANALYSIS OF TOTAL WORK DAYS LOST DUE TO HOSPITALIZATIONS PER AGE RANGE

BUS FLEET

	Pollutant	Age range	Period (years)	Cardiovascular disease	Respiratory disease	Total
WORK ABSENCES IN TERMS OF HOSPITALIZATIONS (in days)						
MORBIDITY	PM$_{2.5}$	Elderly	1	-352	-195	-547
			30	-13,307	-8,530	-21,837
		Children	1	N/A*	-279	-279
			30	N/A*	-7,547	-7,547
	PM$_{10}$	Elderly	1	-228	-130	-358
			30	-8,214	-5,672	-13,886
		Children	1	N/A*	-45	-45
			30	N/A*	-1,121	-1,121

Table with analysis of total workdays lost due to hospitalizations per age range

* The average stay of public and private hospitalizations were assumed to be the same.

Source: ImpactAr tool.

Interface of the Epidemiological Stage Spreadsheet: Third Part of the Detailed Epidemiological Results Section—3_EPIDEMIOLOGICAL_STAGE

ANALYSIS OF NONFATAL CASES PER AGE RANGE

BUS FLEET

	Pollutant	Age range	Period (years)	Cardiovascular disease	Respiratory disease	Total
VARIATION OF NONFATAL CASES – PER AGE RANGE						
MORBIDITY	PM$_{2.5}$	Elderly	1	-44	-21	-65
			30	-1,684	-898	-2,582
		Children	1	N/A*	-57	-57
			30	N/A*	-1,540	-1,540
	PM$_{10}$	Elderly	1	-30	-14	-43
			30	-1,067	-597	-1,664
		Children	1	N/A*	-8	-8
			30	N/A*	-212	-212

Table with the analysis of nonfatal cases per age range

*No studies that measure the incidence of pollutants on cardiovascular diseases in children have been found

ANALYSIS OF NONFATAL CASES PER TYPE OF COVERAGE

BUS FLEET

	Pollutant	Period (years)	Coverage	Cardiovascular disease	Respiratory disease	Total
VARIATION OF NONFATAL CASES – PER TYPE OF HEALTH COVERAGE*						
MORBIDITY	PM$_{2.5}$	1	Public	-19	-39	-58
		30		-702	-1,187	-1,889
		1	Private	-26	-38	-64
		30		-982	-1,251	-2,233
	PM$_{10}$	1	Public	-12	-9	-21
		30		-445	-313	-758
		1	Private	-17	-13	-30
		30		-622	-496	-1,118

Table with the analysis of nonfatal cases per type of health coverage

*There is no data for the separation of public and private fatal cases avoided

Source: ImpactAr tool.

Analysis of the financial and economic results spreadsheet (4_FINANCE AND ECONOMIC_STAGE). In the first part of this section, the user can analyze the main financial and economic results according to the cases of mortality and morbidity linked to variations in $PM_{2.5}$ and PM_{10} concentration levels. These results are separated by fatal and nonfatal cases of respiratory and cardiovascular diseases, and by 1-year and 30-year analyses. This data is presented in two tables and four graphs that can be filtered. The spreadsheet also provides a second part with the detailed results of morbidity-related costs. These costs are separated into the total cost of morbidity, the direct cost of morbidity (cost of hospitalization), and the indirect cost of morbidity (cost of income loss due to absences at work caused by hospitalization). The analyses are made by age group and by type of financial coverage of the cases (public or private). This part provides six tables and 24 graphs that can

be filtered. We have not provided the analysis of the mortality costs by age group because one of the C-Rs for mortality does not offer this differentiation. Furthermore, we also have not included the analysis of the financial coverage of the mortality cases because the methodology used to measure the mortality costs (VSL) does not allow such classification (for further information, please see Section 2.1, Key Concepts).

In order to present the interface of the Financial and Economic Stage, we have broken the spreadsheet into Figure A10, which presents the main financial and economic results; Figure A11, which shows the first part of the detailed financial and economic results sections; Figure A12, which presents the second part of the detailed financial and economic results section; Figure A13, which presents the third part of the detailed financial and economic results section; and A14, which presents the fourth and final part of the detailed financial and economic results section.

Figure A10 | Interface of the Financial and Economic Stage Spreadsheet: Main Financial and Economic Results–4_FINANCIAL AND ECONOMIC_STAGE
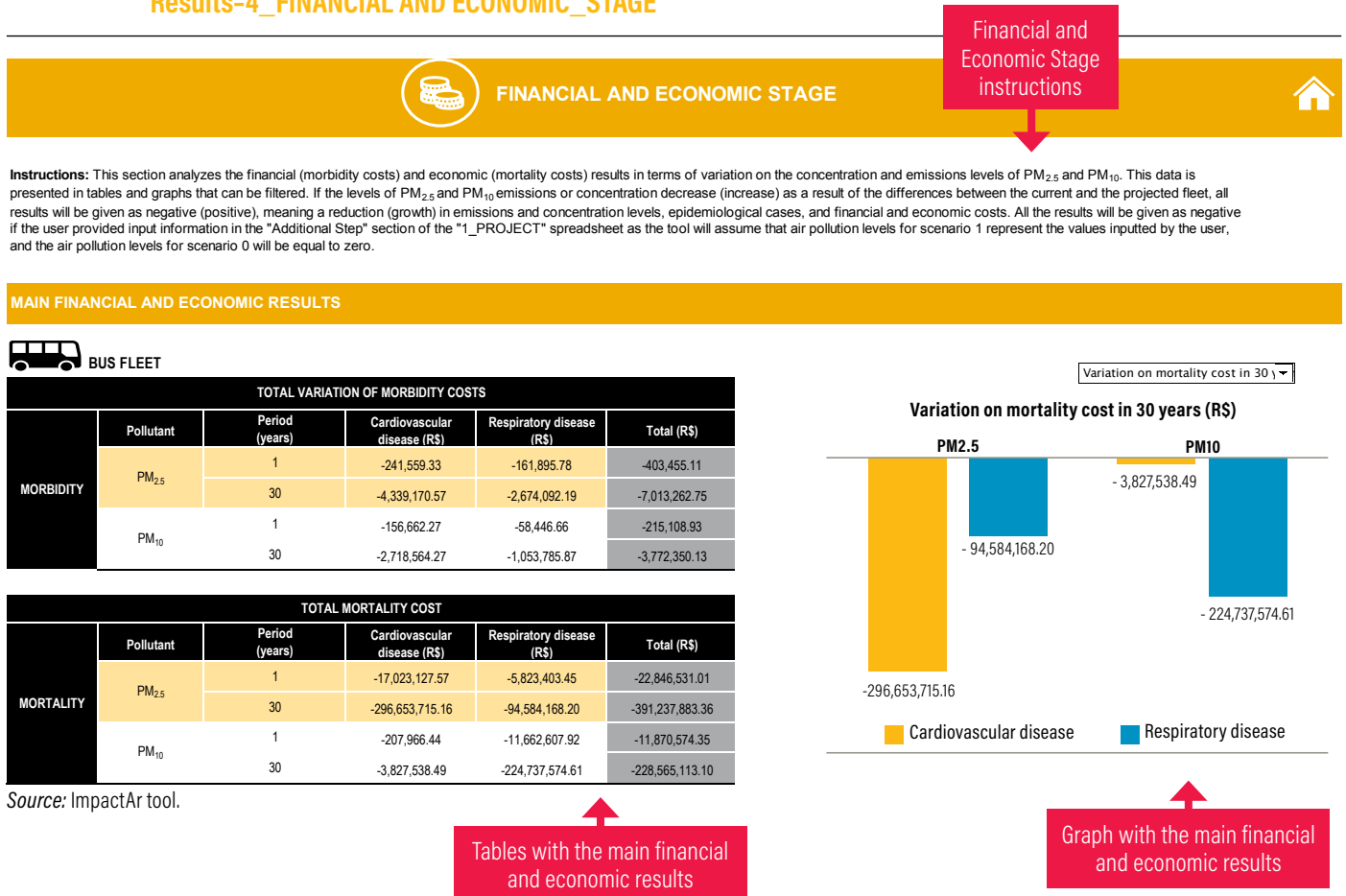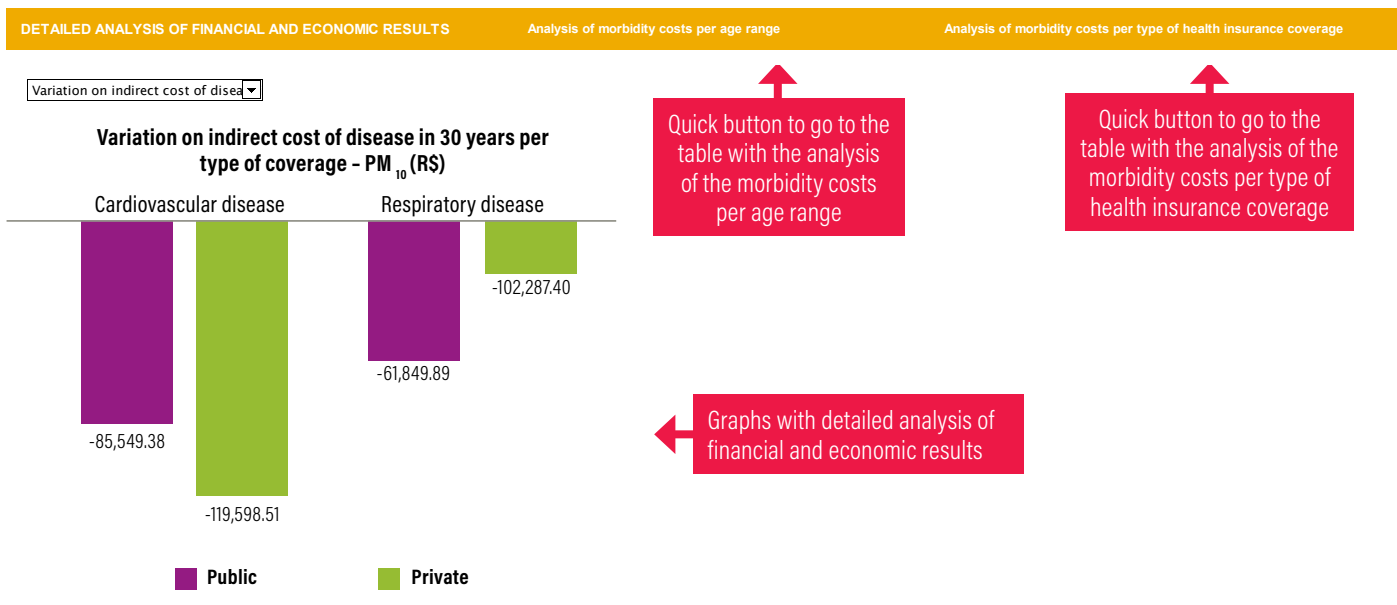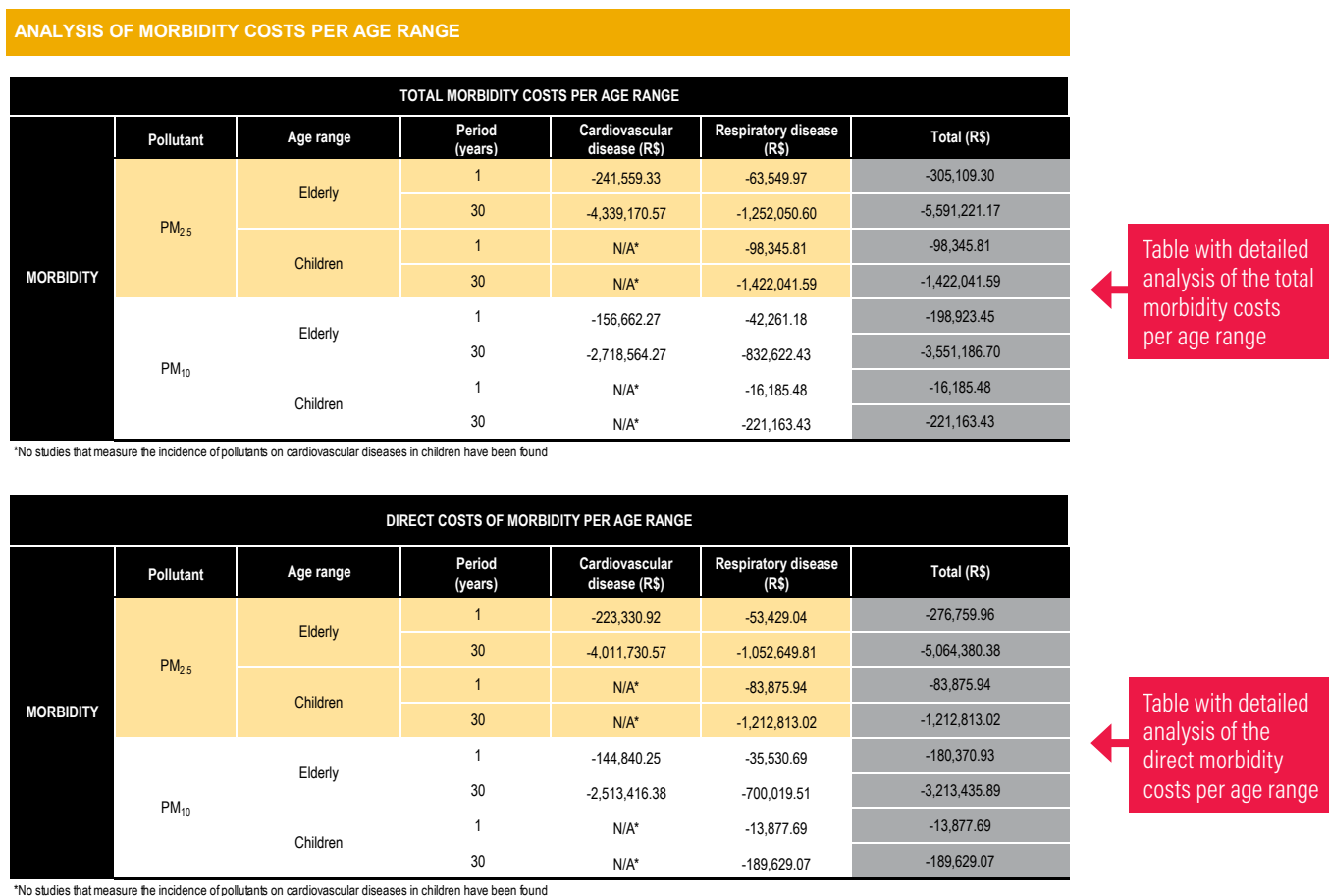

Source: ImpactAr tool.

Figure A11 | Interface of the Financial and Economic Stage Spreadsheet: Part 1, Detailed Financial and Economic Results Section—4_FINANCIAL AND ECONOMIC_STAGE

DETAILED ANALYSIS OF FINANCIAL AND ECONOMIC RESULTS	Analysis of morbidity costs per age range	Analysis of morbidity costs per type of health insurance coverage

Variation on indirect cost of disea ▼

Variation on indirect cost of disease in 30 years per type of coverage – PM$_{10}$ (R$)

Cardiovascular disease   Respiratory disease

-102,287.40

-61,849.89

-85,549.38

-119,598.51

■ **Public**   ■ **Private**

Quick button to go to the table with the analysis of the morbidity costs per age range

Quick button to go to the table with the analysis of the morbidity costs per type of health insurance coverage

Graphs with detailed analysis of financial and economic results

Source: ImpactAr tool.

Figure A12 | Interface of the Financial and Economic Stage Spreadsheet: Part 2, Detailed Financial and Economic Results Section, Tables with Total and Direct Costs of Morbidity per Age Range—4_FINANCIAL AND ECONOMIC_STAGE

ANALYSIS OF MORBIDITY COSTS PER AGE RANGE

		TOTAL MORBIDITY COSTS PER AGE RANGE				
	Pollutant	Age range	Period (years)	Cardiovascular disease (R$)	Respiratory disease (R$)	Total (R$)
MORBIDITY	PM$_{2.5}$	Elderly	1	-241,559.33	-63,549.97	-305,109.30
			30	-4,339,170.57	-1,252,050.60	-5,591,221.17
		Children	1	N/A*	-98,345.81	-98,345.81
			30	N/A*	-1,422,041.59	-1,422,041.59
	PM$_{10}$	Elderly	1	-156,662.27	-42,261.18	-198,923.45
			30	-2,718,564.27	-832,622.43	-3,551,186.70
		Children	1	N/A*	-16,185.48	-16,185.48
			30	N/A*	-221,163.43	-221,163.43

*No studies that measure the incidence of pollutants on cardiovascular diseases in children have been found

Table with detailed analysis of the total morbidity costs per age range

		DIRECT COSTS OF MORBIDITY PER AGE RANGE				
	Pollutant	Age range	Period (years)	Cardiovascular disease (R$)	Respiratory disease (R$)	Total (R$)
MORBIDITY	PM$_{2.5}$	Elderly	1	-223,330.92	-53,429.04	-276,759.96
			30	-4,011,730.57	-1,052,649.81	-5,064,380.38
		Children	1	N/A*	-83,875.94	-83,875.94
			30	N/A*	-1,212,813.02	-1,212,813.02
	PM$_{10}$	Elderly	1	-144,840.25	-35,530.69	-180,370.93
			30	-2,513,416.38	-700,019.51	-3,213,435.89
		Children	1	N/A*	-13,877.69	-13,877.69
			30	N/A*	-189,629.07	-189,629.07

*No studies that measure the incidence of pollutants on cardiovascular diseases in children have been found

Table with detailed analysis of the direct morbidity costs per age range

Source: ImpactAr tool.

Figure A13 | **Interface of the Financial and Economic Stage Spreadsheet: Part 3, Detailed Financial and Economic Results Section, Tables with Indirect Costs of Morbidity per Age Range and Total Costs of Morbidity per Type of Health Insurance Coverage—4_FINANCIAL AND ECONOMIC_STAGE**

					INDIRECT COSTS OF MORBIDITY PER AGE RANGE		
	Pollutant	Age range	Period (years)	Cardiovascular disease (R$)	Respiratory disease (R$)	Total (R$)
MORBIDITY	PM$_{2.5}$	Elderly	1	-18,228.41	-10,120.93	-28,349.34
			30	-327,440.00	-199,400.79	-526,840.79
		Children	1	N/A*	-14,469.87	-14,469.87
			30	N/A*	-209,228.56	-209,228.56
	PM$_{10}$	Elderly	1	-11,822.02	-6,730.49	-18,552.51
			30	-205,147.88	-132,602.93	-337,750.81
		Children	1	N/A*	-2,307.79	-2,307.79
			30	N/A*	-31,534.36	-31,534.36

*No studies that measure the incidence of pollutants on cardiovascular diseases in children have been found

ANALYSIS OF MORBIDITY COSTS PER TYPE OF HEALTH INSURANCE COVERAGE*   * The average stay of public and private hospitalizations were assumed to be the same. Therefore, the working day loss as well.

Table with detailed analysis of the indirect morbidity costs per age range

					TOTAL MORBIDITY COSTS PER TYPE OF COVERAGE		
	Pollutant	Period (years)	Coverage	Cardiovascular disease (R$)	Respiratory disease (R$)	Total (R$)
MORBIDITY	PM$_{2.5}$	1	Public	-50,599.22	-45,330.51	-95,929.73
		30	Public	-908,922.18	-716,445.85	-1,625,368.04
		1	Private	-190,960.11	-116,565.27	-307,525.38
		30	Private	-3,430,248.38	-1,957,646.34	-5,387,894.72
	PM$_{10}$	1	Public	-32,815.92	-12,279.86	-45,095.78
		30	Public	-569,455.49	-214,503.63	-783,959.12
		1	Private	-123,846.35	-46,166.79	-170,013.15
		30	Private	-2,149,108.78	-839,282.23	-2,988,391.01

Table with detailed analysis of the total morbidity costs per type of health insurance coverage

Source: ImpactAr tool.

Figure A14 | **Interface of the Financial and Economic Stage Spreadsheet: Part 4, Detailed Financial and Economic Results Section, Tables with Direct and Indirect Costs of Morbidity per Type of Health Insurance Coverage—4_FINANCIAL AND ECONOMIC_STAGE**

					DIRECT COSTS OF MORBIDITY PER TYPE OF COVERAGE		
	Pollutant	Period (years)	Coverage	Cardiovascular disease (R$)	Respiratory disease (R$)	Total (R$)
MORBIDITY	PM$_{2.5}$	1	Public	-42,997.73	-33,592.61	-76,590.33
		30	Public	-772,375.38	-528,202.63	-1,300,578.00
		1	Private	-180,333.19	-103,712.37	-284,045.56
		30	Private	-3,239,355.19	-1,737,260.20	-4,976,615.39
	PM$_{10}$	1	Public	-27,885.98	-8,791.42	-36,677.40
		30	Public	-483,906.11	-152,653.74	-636,559.85
		1	Private	-116,954.27	-40,616.96	-157,571.23
		30	Private	-2,029,510.28	-736,994.84	-2,766,505.11

Table with detailed analysis of the direct morbidity costs per type of health insurance coverage

					INDIRECT COSTS OF MORBIDITY PER TYPE OF COVERAGE		
	Pollutant	Period (years)	Coverage	Cardiovascular disease (R$)	Respiratory disease (R$)	Total (R$)
MORBIDITY	PM$_{2.5}$	1	Public	-7,601.49	-11,737.90	-19,339.39
		30	Public	-136,546.81	-188,243.22	-324,790.03
		1	Private	-10,626.92	-12,852.89	-23,479.82
		30	Private	-190,893.19	-220,386.13	-411,279.33
	PM$_{10}$	1	Public	-4,929.94	-3,488.45	-8,418.39
		30	Public	-85,549.38	-61,849.89	-147,399.27
		1	Private	-6,892.08	-5,549.83	-12,441.92
		30	Private	-119,598.51	-102,287.40	-221,885.90

Table with detailed analysis of the indirect morbidity costs per type of health insurance coverage

Source: ImpactAr tool.

Analysis of the main results spreadsheet (5_MAIN RESULTS).
In the first part of this section, a table is provided with the main environmental, epidemiological, financial, and economic results of the simulation for the 1-year and 30-year periods. After it, in the second part, the spreadsheet presents a table with a comparative analysis between the financial and economic results for the 1-year and 30-year periods and the municipal GDP, the 2018 annual municipal health expenditure, the 2018 annual municipal hospitalization expenditure, and the number

of medical appointments "saved" or "spent" as a function of the financial savings/losses caused by the bus fleet change or by the environmental input data.

In order to present the interface of the Main Results, we have broken the spreadsheet into Figure A15, which presents the first section of the spreadsheet, and Figure A16, which presents the second and final section of the spreadsheet.

Figure A15 | **Interface of the Main Results Spreadsheet: Sheet 5, Section 1**

Instructions for the Main Results section

MAIN RESULTS

Instructions: This section provides the main results – environmental, epidemiological, and economic-financial – that the changes in PM_{10} and $PM_{2.5}$ annual concentration levels originated by the fleet's renewal or by the direct air quality inputs of the user would produce. It also offers a comparative analysis between economic and financial results and economic indicators of the municipality, such as the municipal GDP, municipal annual health expenditure, and average cost of hospitalizations in the municipality. Values are provided for 1 year (short-run analysis) and 30 years (long-run analysis). If the levels of $PM_{2.5}$ and PM_{10} emissions or concentration decrease (increase) as a result of the differences between the current and the projected fleet, all results will be given as negative (positive), meaning a reduction (growth) in emission and concentration levels, epidemiological cases, and financial and economic costs. All the results will be given as negative if the user provided input information in the "Additional Step" section of the "1_PROJECT" spreadsheet as the tool will assume that air pollution levels for scenario 1 represent the values inputted by the user, and the air pollution levels for scenario 0 will be equal to zero.

MAIN SIMULATION'S RESULT

STAGE	SUBSTAGE	$PM_{2.5}$		PM_{10}	
		1 year	**30 years**	**1 year**	**30 years**
ENVIRONMENTAL	**Emissions** (tons/year)	-97.69		-139.55	
	Concentration (µg/m³)	-0.1397		-0.1996	
EPIDEMIOLOGICAL	**Morbidity cases** Number of disease cases	-122	-4,122	-52	-1,875
	Mortality cases Number of fatalities	-5	-184	-3	-115
	Workdays lost due to hospitalizations	-826	-29,383	-402	-15,008
FINANCIAL-ECONOMIC	**Morbidity costs** Cost of illness (R$)	-403,455.11	-7,013,262.75	-215,108.93	-3,772,350.13
	Mortality costs Value of statistical life (R$)	-22,846,531.01	-391,237,883.36	-11,870,574.35	-228,565,113.10

Source: ImpactAr tool.

Table with the main results of the simulation

Figure A16 | **Interface of the Main Results Spreadsheet: Sheet 5, Section 2**

COMPARATIVE ANALYSIS

| Period	Substage	Total Costs Variation (R$)		Total Costs Variation/GDPm (%)		Total Costs Variation/Annual Health Expenditure (%)		Total Costs Variation/Annual Hospital Expenditure (%)		Number of Hospitalizations due to Savings/Costs of the Fleet Changes (%)	
		$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
1 year	Morbidity	-403,455.11	-215,108.93	0.00031222	0.0001665	0.00408564	0.00217833	0.04827074	0.02573636	145	77
	Mortality	-22,846,531.01	-11,870,574.35	0.01768015	0.0091862	-*	-*	-*	-*	-*	-*
30 years	Morbidity	-7,013,262.75	-3,772,350.13	0.0054273	0.0029193	0.07102072	0.03820120	0.83909052	0.45133675	2526	1359
	Mortality	-391,237,883.36	-228,565,113.10	0.30276556	0.1768787	-*	-*	-*	-*	-*	-*

GDPm - municipal gross domestic product

*For the costs associated with mortality, the value of statistical life (VSL) methodology was used. VSL is an estimate of how much people are willing to pay to reduce the risk of death, taking into account issues such as suffering and discomfort. Therefore, this cost represents more than the financial impacts of mortality and cannot be compared with financial variables as health expenditures.

Source: ImpactAr tool.

Table with comparative analysis of the main financial and economic results and other macroeconomic variables

The long-term analysis spreadsheet (6_LONG-RUN ANALYSIS). In this spreadsheet, the user can filter eight types of graphs with information regarding the evolution of morbidity and mortality cases per year as well as the associated costs per year. Charts provide quantitative values every five years (Figure A17).

Figure A17 | **Interface of the Long-Run Analysis: Sheet 6**

Source: ImpactAr tool.
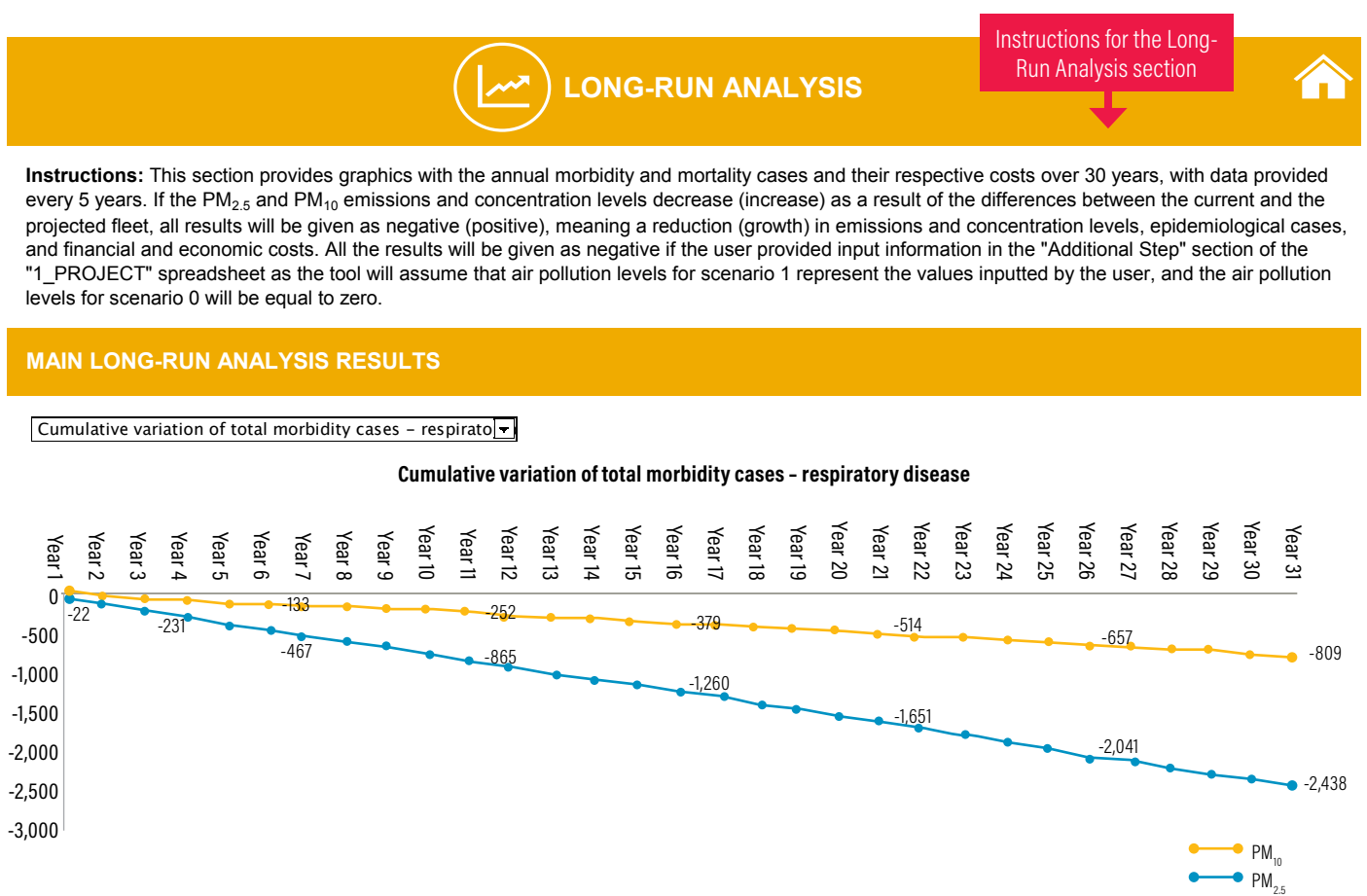
APPENDIX B. BRAZILIAN LITERATURE REVIEW ON HEALTH AND ECONOMIC IMPACTS OF AIR POLLUTION—METHODOLOGY DESCRIPTION, MAIN FINDINGS, AND CONTRIBUTIONS TO BUILD THE IMPACTAR TOOL

The methodology and data applied to build the ImpactAr tool was based on the most recent and well-grounded Brazilian empirical literature on the measurement of air pollution impacts on health and economy in the country. During the first stages of the ImpactAr tool project, WRI Brasil carried out a survey on the state-of-the-art studies that analyzed air pollution impacts in Brazilian cities to understand how the impacts linked to pollutants are manifested and measured in the Brazilian context. To that end, a literature review was conducted with the following research question: What are the economic and health impacts of urban air pollution in Brazil?

The review was stratified in a three-stage process (Table B1). In Stage 1, the WRI team carried out searches on the main academic search platforms with predefined keywords. Stage 2 consisted of researching publications from the key researchers and institutions identified in Stage 1. Finally, in Stage 3, the WRI team held a workshop with the key researchers and institutions for validation of the literature review. This process was carried out over a period of approximately six months and mapped 67 studies from which the main choices of health impacts and methodologies applied in the ImpactAr tool were retrieved.

Table B1 | **Description of the Literature Review Stages**

STAGE 1 | KEYWORDS ON ACADEMIC SEARCH PLATFORMS
Platforms: Scielo, Google Scholar, Capes, and Science Direct   **Keywords:** air quality, economic impacts, brazil, urban air pollution, impacts, valuation, urban, air pollution, urban, monuments, restoration, leisure   - Around 1.200 studies analyzed   **Number of studies retrieved:** 52
STAGE 2 | SEARCH OF KEY ACTOR PUBLICATIONS
- Names found on actors mapping (platform search)   **Number of studies retrieved:** 9
STAGE 3 | SPECIALIST SUGGESTIONS FROM WORKSHOP AND INSTITUTE PLATFORMS
- Workshop took place on June 22, 2018   - Platforms of institutes searched: Institute of Health and Sustainability (Instituto Saúde e Sustentabilidade, ISS); Institute for Energy and Environment (Instituto Energia e Meio Ambiente, IEMA)   **Number of studies retrieved:** 6

Source: WRI authors.

Among the main features within these 67 studies, we were able to identify that the most commonly researched pollutant was PM_{10}, followed by ozone (O_3), but $PM_{2.5}$ was studied less frequently. Furthermore, we learned that, besides the fact that PM is strongly linked to bus emissions and is also considered the most harmful pollutant (WHO 2018), PM_{10} and $PM_{2.5}$ present different emissions sources from road transport activities (Hooftman et al. 2016) and different health impact incidence (Abe and Miraglia 2016; Silva et al. 2017). In this sense, although it is not possible to sum the total impacts of PM_{10} and $PM_{2.5}$, as PM_{10} particles circumscribe $PM_{2.5}$ particles, the WRI team has opted to include both pollutants in the scope of the ImpactAr tool.

In relation to the analysis of the studied health endpoints in the publications, a significant predominance of fatal respiratory (41.8 percent), fatal cardiovascular (28.3 percent), nonfatal respiratory (50.7 percent), and nonfatal cardiovascular (32.8 percent) diseases was verified. Therefore, the WRI team included these health impacts in the ImpactAr tool analysis and retrieved the C-Rs used to measure the epidemiological impacts from seven articles among the 67 publications.

Finally, regarding the financial and economic aspects addressed in the publications, a minor share of the studies, 22 out 67 (33 percent), monetized the health impacts of air pollution. Amid the main methodologies, we can list the COI to measure financial impacts of hospitalizations, which was added to this tool. In relation to the monetization of deaths, the WRI team opted to use the VSL method, which was presented in some publications. The literature did not present recent primary data on the VSL, nor did it provide a standard value for Brazil. Therefore, to obtain the VSL, we have transferred the reference value provided by the 2012 OECD study with adjustment to income and inflation (Roy and Braathen 2017).

ABBREVIATIONS

ANS Agência Nacional de Saúde Suplementar (National Agency for Supplementary Health)

BRAMS Brazilian Developments on the Regional Atmospheric Modeling System

BRIICS Brazil, Russia, Indonesia, India, China and South Africa

CCATT Coupled Chemistry Aerosol-Tracer Transport

CIFF Children's Investment Fund Foundation

COI cost of illness

CO$_2$ carbon dioxide

CPTEC Centro de Previsão do Tempo e Estudos Climáticos (Center for Weather Forecast and Climatic Studies)

C-R concentration-response coefficient

DALY disability-adjusted life years

DATASUS Departamento de Informática do Sistema Único de Saúde (Brazilian Health Informatics Department)

EPA U.S. Environmental Protection Agency

ExternE external costs of energy

FCM fixed conversion measure

GDP gross domestic product

GDPm municipal gross domestic product

GHG greenhouse gas

IBGE Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics)

ICD-10 10th revision of the International Statistical Classification of Diseases and Related Health Problems

IEMA Instituto Energia e Meio Ambiente (Institute for Energy and Environment)

ImpactAR Valuation tool for air quality health impacts of urban bus fleet changes in Brazil

INPE Instituto Nacional de Pesquisas Espaciais (National Institute for Space Research)

IPA impact pathway approach

IPCA Índice Nacional de Preços ao Consumidor Amplo (Broad National Consumer Price Index)

IPCC Intergovernmental Panel on Climate Change

ISS Instituto Saúde e Sustentabilidade (Institute of Health and Sustainability)

NOx nitrogen oxides

OECD Organisation for Economic Co-operation and Development

O$_3$ ozone

PM particulate matter

RCP Representative Concentration Pathway

SIDRA Sistema IBGE de Recuperação Automática (IBGE Automatic Recovery System)

SLCF short-lived climate forcer

VSL value of statistical life

WRI World Resources Institute

WTP willingness to pay

ENDNOTES

1. Anthropogenic sources are caused by human activities.
2. In terms of PM share of transport emissions from exhaust and wear/combustion, buses account for 17 percent and 14 percent, and trucks account for 75 percent and 64 percent, respectively (MMA 2014).
3. Information retrieved from literature review of the state-of-the-art Brazilian empirical studies on the issue of health and economic impacts of air pollution. For further information, please see Appendix B.
4. It is important to note that the ImpactAr tool does not aim to provide users with a benefit-cost analysis of projects to renew a bus fleet but rather to point to the existence and magnitude of the implicit costs of air pollution embedded in such plans.
5. To see the list of all data and variables used in the model, please see Section 4, Data Sources.
6. The BRAMS 5.2 modeling system is an online model with an Eulerian approach and basically solves the mass conservation equation for any tracer. It has an extensive network of collaborators in the world and has been developed and adjusted to the South American continent, which makes it an integrated environmental model tuned for tropical and extratropical areas. BRAMS also includes a surface scheme to simulate the energy, water, carbon, and other biogeochemical cycles (Moreira et al. 2013) and soil moisture initialization using real-time cycling estimation from an offline hydrological model (Gevaerd and Freitas 2006). In Brazil, BRAMS has been applied for numerical studies in several universities and research centers addressing local storms, urban heat islands, urban and remote air pollution, aerosol-cloud-radiation interactions, and so forth.
7. *ExternE* is the abbreviation for "external costs of energy." Between the 1990s and 2005, the European Union initiated a series of ExternE projects. The "ExternE Methodology" is an approach of calculating environmental external costs developed during the ExternE Project series called the IPA (ExternE n.d.).
8. For further information, please see Appendix B.
9. Whereas PM$_{2.5}$ emissions are linked to exhaust sources, such as fuel combustion, PM$_{10}$ emissions are linked to both exhaust and nonexhaust sources such as fuel combustion, brakes, tires, and road surface wear (Hooftman et al. 2016, 7).
10. Although both types of pollutants are linked to respiratory and cardiovascular diseases, PM$_{2.5}$ emissions present a greater risk for the development of cardiovascular diseases, and PM$_{10}$ emissions are more strongly linked to respiratory diseases.
11. See the National Traffic Department (Departamento Nacional de Trânsito), https://www.denatran.gov.br/component/content/article/115-portal-denatran/8558-frota-de-veiculos-2018.html.
12. Technology categories contemplated in the tool are Technology 1—Euro V, Technology 2—Euro III, Technology 3—Electric, Technology 4—Hybrid, Technology 5—Trolleybus, Technology 6—Biodiesel B20, and Technology 7—Euro VI.

13. Emissions factors (g PM/L diesel) and fuel consumption (L or kWh/100 km) by default per technology are Euro V, 0.07 and 59.3; Euro III, 0.30 and 57; electric, 0 and 1.3; hybrid, 0.04 and 41.5; trolleybus, 0 and 2.29; biodiesel B20, 0.06 and 57; and Euro VI, 0.03 and 59.3. For further information on emissions factors and average fuel consumptions by default, please see Table 4, Data Sources Specifications.

14. The Handbook Emission Factors for Road Transport, version 3.3, is published as an online software program by the German Environment Agency (Berlin); the Federal Office for the Environment (Bern, Switzerland); the Environment Agency Austria (Vienna); the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (Vienna); and the Austrian Ministry of Transport, Innovation and Technology (Vienna); the Swedish Transport Administration (Borlänge); the French Environment & Energy Management Agency (Angers); the Joint Research Centre of the European Commission (Ispra, Italy); and INFRAS (Bern, Switzerland). For more information, see https://www.hbefa.net.

15. For further information, please see linking function 2, from annual variations on emissions levels to annual variations on concentration levels, in this technical note.

16. The coefficient of determination obtained by the applied dispersion/chemical transport models was about one for all four Brazilian cities. Even though this relation does not seem common for these metropolises, the model uses an Eulerian approach, solving the mass conservation equation for any tracer. The main aspect is the homogeneity of meteorological initial and boundary conditions for all scenarios and the existence of only emissions associated with the public transport in the chosen cities, with other emissions information not being used in the simulations. In addition, only primary PM dispersion was studied (transport, sedimentation, wet and dry deposition), without chemical transformations.

17. As we are unable to obtain the specific age of deaths and diseases (due to the predefined age ranges provided by the Department of Information Technology of the National Public Health System (Departamento de Informática do Sistema Único de Saúde, DATASUS), we preferred not to use the disability-adjusted life years (DALY) methodology.

18. For this tool, nonfatal and fatal diseases cover respiratory and cardiovascular events (Chapters I and J of the ICD-10, respectively) because these are the most studied impacts when it comes to air pollution among Brazilian empirical literature.

19. For further information on the total annual number of fatal and nonfatal diseases for each city's population, covered by the public health system and private health system, please see Box 1.

20. It is important to note that morbidity costs can also be measured in terms of welfare losses, such as pain and suffering. We opted to use a financial measure, however, as we intended to compare such costs with the municipal health expenditure. For further discussion on the economic costs of air pollution morbidity impacts in Brazil, please see Ortiz et al. (2011).

21. For further discussion on national contingent valuation to assess the economic costs of air pollution mortality, please see Ortiz, Markandya, and Hunt (2009).

22. Revealed preference methods consist of the analysis of individual preferences based on the observation of individual behaviors in the market. In turn, stated preference methods consist of the analysis of individual preferences through interviews and questionnaires.

23. The Intergovernmental Panel on Climate Change (IPCC) projections for greenhouse gas (GHG) concentrations commonly used in regional climate models for impact projection.

24. For further discussion of the factors affecting the VSL, please see Alberini et al. (2016), OECD (2012), and Urvashi and Sall (2016).

25. The only epidemiological parameter obtained outside of the Brazilian context was retrieved from Fajersztajn et al. (2017).

26. Population data consist of an estimate of 2018 values and GDP data consist of an estimate of 2016 values (2018 prices), according to the IBGE.

27. For more information, see the National Traffic Department (Departamento Nacional de Trânsito), https://www.denatran.gov.br/component/content/article/115-portal-denatran/8558-frota-de-veiculos-2018.html.

28. According to municipal law 16.802/2018, article 50, "From the date of publication of this Law, the operators of collective transportation services by bus, members of the Urban Passenger Transportation System of the Municipality of São Paulo, as well as the companies that render services for the collection of Urban and Hospital Solid Waste in the Municipality of São Paulo should promote the progressive reduction of emissions of carbon dioxide (CO_2) of fossil origin and of toxic pollutants emitted in the operation of their respective fleets through the gradual use of cleaner and more sustainable fuels and technologies" (Prefeitura do Município de São Paulo 2018b, article 50).

29. After meeting with the city representative of the transit department, SPTrans, we learned that the city intended to increase the trolleybus fleet by 49 buses.

30. We note once more that $PM_{2.5}$ and PM_{10} emissions and concentration variations and impacts cannot be summed because $PM_{2.5}$ is contained in PM_{10}.

31. According to the 2011 United Nations Environment Programme report, "Short-lived climate forcers (SLCFs): substances such as methane, black carbon, tropospheric ozone and many hydrofluorocarbons (HFCs) which have a significant impact on near-term climate change and a relatively short lifespan in the atmosphere compared to carbon dioxide and other longer-lived gases" (UNEP 2011, 7).

32. Please note that the size of the figures varied greatly in comparison with the actual size of the Excel sheet in order to make the information legible. Furthermore, the arrows in the figure are not in the tool and were added in the technical note to improve the understanding of the user.

REFERENCES

Abe, K., and S. Miraglia. 2016. "Health Impact Assessment of Air Pollution in São Paulo, Brazil." *International Journal of Environmental Research and Public Health* 13 (7): 694. https://doi.org/10.3390/ijerph13070694.

Alberini, A., A. Bigano, J. Post, and E. Lanzi. 2016. "Approaches and Issues in Valuing the Costs of Inaction of Air Pollution on Human Health." OECD Environment Working Paper 108, OECD, Paris. https://doi.org/10.1787/5jlww02k83r0-en.

Alonso, M.F., K.M. Longo, S.R. Freitas, R.M. da Fonseca, V. Marécal, M. Pirre, and L.G. Klenner. 2010. "An Urban Emissions Inventory for South America and Its Application in Numerical Modeling of Atmospheric Chemical Composition at Local and Regional Scales." *Atmospheric Environment* 44 (39): 5072–83. https://doi.org/10.1016/j.atmosenv.2010.09.013.

Amato-Lourenço, L.F., T.C.L. Moreira, V.C. de Oliveira Souza, F. Barbosa Jr., M. Saiki, P.H.N. Saldiva, and T. Mauad. 2016. "The Influence of Atmospheric Particles on the Elemental Content of Vegetables in Urban Gardens of São Paulo, Brazil." *Environmental Pollution* 216 (September): 125–34. https://doi.org/10.1016/j.envpol.2016.05.036.

André, P.A. de, M.M. Veras, S.G.E.K. Miraglia, and P.H.N. Saldiva. 2012. "Lean Diesel Technology and Human Health: A Case Study in Six Brazilian Metropolitan Regions." *Clinics* 67 (6): 639–46. https://doi.org/10.6061/clinics/2012(06)15.

André, P.A. de, E. Vormittag, and P.H.N. Saldiva. 2017. *Avaliação e valoração dos impactos da poluição do ar na saúde da população decorrente da substituição da matriz energética do transporte público na cidade de São Paulo.* São Paulo: Instituto Saúde e Sustentabilidade. https://www.saudeesustentabilidade.org.br/wp-content/uploads/2017/05/GP_ISS_Relatorio_ImpactosOnibusSP-1.pdf.

BCB (Banco Central do Brasil). 2018. "Taxas de juros." https://www.bcb.gov.br/estatisticas/txjuros.

Beelen, R., O. Raaschou-Nielsen, M. Stafoggia, Z.J. Andersen, G. Weinmayr, B. Hoffmann, K. Wolf, et al. 2014. "Effects of Long-Term Exposure to Air Pollution on Natural-Cause Mortality: An Analysis of 22 European Cohorts within the Multicentre ESCAPE Project." *Lancet* 383 (9919): 785–95. https://doi.org/10.1016/S0140-6736.

Booth, H., and L. Tickle. 2008. "Mortality Modelling and Forecasting: A Review of Methods." *Annals of Actuarial Sciences* 3 (1–2): 3–43. https://doi.org/10.1017/S1748499500000440.

Carriazo Osorio, F. 2001. "Impacts of Air Pollution on Property Values: An Economic Valuation for Bogotá, Colombia." Paper presented at the second workshop on Population, Economy and the Environment: Modeling and Simulating Their Complex Interaction, Max Plant Institute for Demographic Research, Rostock, Germany, May 18–19. https://www.researchgate.net/publication/255659723_Impacts_of_Air_Pollution_on_Property_Values_an_Economic_Valuation_for_Bogota_Colombia.

Cohen, A., M. Brauer, R. Burnett, R. Anderson, J. Frostad, K. Estep, K. Balakrishnan, et al. 2017. "Estimates and 25-Year Trends of the Global Burden of Disease Attributable to Ambient Air Pollution: An Analysis of Data from the Global Burden of Diseases Study 2015." *Lancet* 389 (10082): 1907–18. https://doi.org/10.1016/S0140-6736(17)30505-6.

Conceição, G.M. de Souza, P.H.N. Saldiva, and J. da Motta Singer. 2001. "Modelos MLG e MAG para análise da associação entre poluição atmosférica e marcadores de morbi-mortalidade: Uma introdução baseada em dados da cidade de São Paulo." *Revista Brasileira de Epidemiologia* 4 (3): 206–19. http://dx.doi.org/10.1590/S1415-790X2001000300007.

Costa, A.F., G. Hoek, B. Brunekreef, and A.C.M. Ponce de Leon. 2017. "Air Pollution and Deaths among Elderly Residents of São Paulo, Brazil: An Analysis of Mortality Displacement." *Environmental Health Perspectives* 125 (3): 349–54. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5332200/.

Detran SP (Departamento Estadual de Trânsito de São Paulo). 2019. "Frota de veículos em SP—por tipo de veículo." https://www.detran.sp.gov.br/wps/wcm/connect/portaldetran/detran/detran/EstatisticasTransito/sa-frotaVeiculos/d28760f7-8f21-429f-b039-0547c8c46ed1?presentationtemplate=portaldetran%2FAT-detranPaginaODetranImpressao.

EPA (U.S. Environmental Protection Agency). n.d. "Basic Information of Air Emissions Factors and Quantification." https://www.epa.gov/air-emissions-factors-and-quantification/basic-information-air-emissions-factors-and-quantification. Accessed May 2020.

ExternE (External Costs of Energy). n.d. "The Impact Pathway Approach." http://www.externe.info/externe_d7/?q=node/46. Accessed December 2018.

Fairburn, J., S.A. Schüle, S. Dreger, L.K. Hilz, and G. Bolte. 2019. "Social Inequalities in Exposure to Ambient Air Pollution: A Systematic Review in the WHO European Region." *International Journal of Environmental Research and Public Health* 16 (17): E3127. https://doi.org/10.3390/ijerph16173127.

Fajersztajn, L., P. Saldiva, L.A.A. Pereira, V.F. Leite, and A.M. Buehler. 2017. "Short-Term Effects of Fine Particulate Matter Pollution on Daily Health Events in Latin America: A Systematic Review and Metaanalysis." *International Journal of Public Health* 62 (7): 729–38. https://doi.org/10.1007/s00038-017-0960-y.

Freitas, S.R., K.M. Longo, M.F. Alonso, M. Pirre, V. Marecal, G. Grell, R. Stockler, R.F. Mello, and M. Sánchez Gácita. 2011. "PREP-CHEM-SRC—1.0: A Preprocessor of Trace Gas and Aerosol Emission Fields for Regional and Global Atmospheric Chemistry Models." *Geoscientific Model Development* 4 (2): 419–33. https://doi.org/10.5194/gmd-4-419-2011.

Fundação SEADE (Sistema Estadual de Análise de Dados Estatísticos). 2017. "Projeções demográficas 2050." June 26. http://visualizesp.seade.gov.br/tag/projecao-populacional/.

Gevaerd, R., and S.R. Freitas, 2006. "Estimativa operacional da umidade do solo para inicialização de modelos de previsão numérica da atmosfera. Parte I: Descrição da metodologia e validação." *Revista Brasileira de Meteorologia* 21 (3): 1–15.

Gouveia, N., F.P. Corrallo, A.C.P. de Leon, W. Junger, and C.U. de Freitas. 2017. "Air Pollution and Hospitalizations in the Largest Brazilian Metropolis." *Revista de Saúde Pública* 51 (December): 117. https://doi.org/10.11606/S1518-8787.2017051000223.

Hettfleisch, K., L. Bernardes, M. Carvalho, L. Pastro, S. Vieira, S. Saldiva, P. Saldiva, and R. Francisco. 2017. "Short-Term Exposure to Urban Air Pollution and Influences on Placental Vascularization Indexes." *Environmental Health Perspective* 125 (4): 753–59. https://doi.org/10.1289/EHP300.

Hooftman, N., L. Oliveira, M. Maarten, T. Coosemans, and J. Van Mierlo. 2016. "Environmental Analysis of Petrol, Diesel and Electric Passenger Cars in a Belgian Urban Setting." *Energies* 9 (2): 84. https://doi.org/10.3390/en9020084.

IBGE (Instituto Brasileiro de Geografia e Estatística). 2010. "População residente por situação de domicílio, 2010." https://www.ibge.gov.br/estatisticas/sociais/saude/9662-censo-demografico-2010.html?=&t=destaques.

IBGE. 2015. "Tabela 5795—Rendimento médio mensal nominal das pessoas de 15 anos ou mais de idade, com rendimento, por cor ou raça." Sistema IBGE de Recuperação Automática. https://sidra.ibge.gov.br/tabela/5795.

IBGE. 2017. "Produto interno bruto dos municípios." https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/9088-produto-interno-bruto-dos-municipios.html?=&t=resultados.

IBGE. n.d.a. "Estimativas da População." https://www.ibge.gov.br/estatisticas/sociais/populacao/9103-estimativas-de-populacao.html?=&t=o-que-e. Accessed May 2020.

IBGE. n.d.b. "Índice Nacional de Preços ao Consumidor Amplo—IPCA." https://www.ibge.gov.br/estatisticas/economicas/precos-e-custos/9256-indice-nacional-de-precos-ao-consumidor-amplo.html?=&t=o-que-e. Accessed May 2020.

Ignotti, E., S. de Souza Hacon, W.L. Junger, D. Mourão, K. Longo, S. Freitas, P. Artaxo, and A.C.M.P. de Leon. 2010. "Air Pollution and Hospital Admissions for Respiratory Diseases in the Subequatorial Amazon: A Time Series Approach." *Cadernos de Saúde Pública* 26 (4): 747–61. http://dx.doi.org/10.1590/S0102-311X2010000400017.

Karagulian, F., C. Belis, C. Dora, A. Prüss-Ustün, S. Bonjour, H. Adair-Rohani, and M. Amann. 2015. "Contributions to Cities' Ambient Particulate Matter (PM): A Systematic Review of Local Source Contributions at Global Level." *Atmospheric Environment* 120 (November): 475–83. https://doi.org/10.1016/j.atmosenv.2015.08.087.

Lichtenfels, A.J., J.B. Gomes, P.C. Pieri, S.G.E.K. Miraglia, J. Hallak, and P.H. Saldiva. 2007. "Increased levels of Air Pollution and a Decrease in the Human and Mouse Male-to-Female Ratio in São Paulo, Brazil." *Fertility and Sterility* 87: 230–40. https://doi.org/10.1016/j.fertnstert.2006.06.023.

Marcilio, I., and N. Gouveia. 2007. "Quantifying the Impact of Air Pollution on the Urban Population of Brazil." *Cadernos de Saúde Pública* 23 (4): S529–36. http://dx.doi.org/10.1590/S0102-311X2007001600013.

Martins, M.C.H., F.L. Fatigati, T.C. Véspoli, L.C. Martins, L.A.A. Pereira, M.A. Martins, P.H.N. Saldiva, and A.L.F. Braga. 2004. "Influence of Socioeconomic Conditions on Air Pollution Adverse Health Effects in Elderly People: An Analysis of Six Regions in São Paulo, Brazil." *Journal of Epidemiology & Community Health* 58 (1): 41–6. https://doi.org/10.1136/jech.58.1.41.

Miraglia, S., N. Gouveia. 2014. "Costs of Air Pollution in Brazilian Metropolitan Regions." *Ciência e saúde coletiva*, 19 (10): 4141-41-47.

Miraglia, S.G.E.K., M.M. Veras, L.F. Amato-Lourenço, F. Rodrigues-Silva, and P.H.N. Saldiva. 2013. "Follow-Up of the Air Pollution and the Human Male-to-Female Ratio Analysis in São Paulo, Brazil: A Times Series Study." *British Medical Journal Open* 3 (7): e002552. https://doi.org/10.1136/bmjopen-2013-002552.

Miranda, R.M. de, M. de Fatima Andrade, A. Fornaro, R. Astolfo, P.A. de Andre, and P. Saldiva. 2012. "Urban Air Pollution: A Representative Survey of $PM_{2.5}$ Mass Concentrations in Six Brazilian Cities." *Air Quality, Atmosphere & Health* 5 (1): 63–77. https://doi.org/10.1007/s11869-010-0124-1.

MMA (Ministério do Meio Ambiente). 2011. *Inventário nacional de emissões atmosféricas por veículos automotores rodoviários.* Brasília: MMA. https://www.mma.gov.br/estruturas/163/_publicacao/163_publicacao27072011055200.pdf.

MMA. 2014. *Inventário nacional de emissões atmosféricas por veículos automotores rodoviários.* Brasília: MMA. http://www.mma.gov.br/images/arquivo/80060/Inventario_de_Emissoes_por_Veiculos_Rodoviarios_2013.pdf.

Moreira, D.S., S.R. Freitas, J.P. Bonatti, L.M. Mercado, N.M.É. Rosário, K.M. Longo, J.B. Miller, M. Gloor, and L.V. Gatti. 2013. "Coupling between the JULES Land-Surface Scheme and the CCATT-BRAMS Atmospheric Chemistry Model (JULES-CCATT-BRAMS1.0): Applications to Numerical Weather Forecasting and the CO_2 Budget in South America." *Geoscientific Model Development* 6 (4): 1243–59. https://doi.org/10.5194/gmd-6-1243-2013.

Nascimento, A.P., J.M. Santos, J.G. Mill, J.B. de Souza, N.C. Reis Júnior, and V.A. Reisen. 2016. "Association between the Concentration of Fine Particles in the Atmosphere and Acute Respiratory Diseases in Children." *Revista de Saúde Pública* 51:3. http://dx.doi.org/10.1590/s1518-8787.2017051006523.

National Research Council. 1988. *Air Pollution, the Automobile, and Public Health*. Washington, DC: National Academies Press. https://doi.org/10.17226/1033.

NTU (Associação Nacional das Empresas de Transportes Urbanos). 2020. "O transporte público por ônibus em números: Cenário nacional." http://www.ntu.org.br/novo/AreasInternas.aspx?idArea=7&idSegundoNivel=107.

OECD (Organisation for Economic Co-operation and Development). 2012. *Mortality Risk Valuation in Environment, Health and Transport Policies.* Paris: OECD. http://dx.doi.org/10.1787/9789264130807-en.

OECD. 2014. *The Cost of Air Pollution: Health Impacts of Road Transport.* Paris: OECD.

Ortiz, R., A. Markandya, and A. Hunt. 2009. "Willingness to Pay for Mortality Risk Reduction Associated with Air Pollution in São Paulo." *Revista Brasileira de Economia* 63 (1): 3–22. http://dx.doi.org/10.1590/S0034-71402009000100001.

Ortiz, R.A., A. Hunt, R. Seroa da Motta, and V. MacKnight. 2011. "Morbidity Costs Associated with Ambient Air Pollution Exposure in São Paulo, Brazil." *Atmospheric Pollution Research* 2 (4): 520–29. https://doi.org/10.5094/APR.2011.059.

Ortiz-Durán, E.Y., and N.Y. Rojas-Roa. 2013. "Estimación de los beneficios económicos en salud asociados a la reducción de PM_{10} en Bogotá." *Revista de Salud Pública* 15 (1): 90–102. https://revistas.unal.edu.co/index.php/revsaludpublica/article/view/38444/62074.

Pope, C., III. 2007. "Mortality Effects of Longer Term Exposures to Fine Particulate Air Pollution: Review of Recent Epidemiological Evidence." *Journal of Inhalation Toxicology* 19 (1): 133–38. https://doi.org/10.1080/08958370701492961.

Pope, C.A., III, and D. Dockery. 2006. "Health Effects of Fine Particulate Air Pollution: Lines That Connect." *Journal of the Air & Waste Management Association* 56 (6): 709–42. https://doi.org/10.1080/10473289.2006.10464485.

Prefeitura da Cidade do Rio de Janeiro. 2018. "Balanço orçamentário." http://www.rio.rj.gov.br/dlstatic/10112/9568115/4236451/BalancoOrcamentario.pdf.

Prefeitura do Município de São Paulo. 2018a. *Demonstrativos consolidados (comparativos) e notas explicativas.* São Paulo: Departamento de Contadoria, Prefeitura do Município de São Paulo. https://www.prefeitura.sp.gov.br/cidade/upload/02-demconsol-comparativos-notas_explicativas-balanco2018_1552077569.pdf.

Prefeitura do Município de São Paulo. 2018b. "Lei No. 16.802, de 17 de Janeiro de 2018." LeisMunicipais, January 19. https://leismunicipais.com.br/a/sp/s/sao-paulo/lei-ordinaria/2018/1680/16802/lei-ordinaria-n-16802-2018-da-nova-redacao-ao-art-50-da-lei-n-14933-2009-que-dispoe-sobre-o-uso-de-fontes-motrizes-de-energia-menos-poluentes-e-menos-geradoras-de-gases-do-efeito-estufa-na-frota-de-transporte-coletivo-urbano-do-municipio-de-sao-paulo-e-da-outras-providencias.

Prefeitura Municipal de Belo Horizonte. 2018. "Demonstrativo da aplicação de recursos em ações e serviços públicos de saúde." https://prefeitura.pbh.gov.br/sites/default/files/estrutura-de-governo/fazenda/Balan%C3%A7os/2018/12/20-%20Demonstrativo%20da%20Aplica%C3%A7%C3%A3o%20de%20Recursos%20em%20A%C3%A7%C3%B5es%20e%20Servi%C3%A7os%20de%20Sa%C3%BAde.pdf.

Rivas, I., P. Kumar, and A. Hagen-Zanker. 2017. "Exposure to Air Pollutants during Commuting in London: Are There Inequalities among Different Socio-Economic Groups?" *Environment International* 101 (April): 143–57. https://doi.org/10.1016/j.envint.2017.01.019.

Rodrigues, P.C.O., S.I. Pinheiro, W. Junger, E. Ignotti, and S.S. Hacon. 2017. "Climatic Variability and Morbidity and Mortality Associated with Particulate Matter." *Revista de Saúde Pública* 51: 91. https://doi.org/10.11606/S1518-8787.2017051006952.

Rodrigues-Silva, F., U. de Paula Santos, P.H.N. Saldiva, L.F. Amato-Lourenço, and S.G.E.K. Miraglia. 2012. "Health Risks and Economic Costs of Absenteeism Due to Air Pollution in São Paulo, Brazil." *Aerosol and Air Quality Research* 12: 826–33. https://doi.org/10.4209/aaqr.2011.12.0235.

Rosen, S., and T. Gayer. 2008. *Public Finance*. 8th ed. Boston: McGraw-Hill Irwin.

Roy, R. 2016. "The Cost of Air Pollution in Africa." OECD Development Centre Working Paper 333, OECD, Paris. http://dx.doi.org/10.1787/5jlqzq77x6f8-en.

Roy, R., and N. Braathen. 2017. "The Rising Cost of Ambient Air Pollution Thus Far in the 21st Century: Results from the BRIICS and the OECD Countries." OECD Environment Working Paper 124, OECD, Paris. https://doi.org/10.1787/d1b2b844-en.

Sclar, R., C. Gorguinpour, S. Castellanos, and X. Li. 2019. *Barriers to Adopting Electric Buses*. Washington, DC: World Resources Institute. https://www.wri.org/publication/barriers-adopting-electric-buses.

Silva, L.T. da, K.C. Abe, and S.G.E.K Miraglia. 2017. "Avaliação de impacto à saúde da poluição do ar no município de Diadema, Brasil." *Revista Brasileira de Ciências Ambientais* 46: 117–29. https://doi.org/10.5327/Z2176-947820170258.

SMU (Secretário Municipal de Urbanismo e Mobilidade). 2015. *Revisão do Plano Diretor de Niterói.* Niterói: Prefeiture Niterói Urbanismo e Mobilidade. http://urbanismo.niteroi.rj.gov.br/wp-content/uploads/2015/09/PDDU_CENARIOS_APRESENTACAO-AUDIENCIAS-PUBLICAS.pdf.

SPTrans (São Paulo Transporte). 2012. "Livo ecofrota." https://www.slideshare.net/trans_smt/livro-ecofrota?from_action=save.

Stoeldraijer, L., C. van Duin, L. van Wissen, and F. Janssen. 2013. "Impact of Different Mortality Forecasting Methods and Explicit Assumptions on Projected Future Life Expectancy: The Case of the Netherlands." *Demographic Research* 29 (13): 323–54. https://doi.org/10.4054/DemRes.2013.29.13.

UNEP (United Nations Environment Programme). 2011. *Near-Term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers: A UNEP Synthesis Report*. Nairobi: UNEP. http://hdl.handle.net/20.500.11822/8048.

Urvashi, N., and C. Sall. 2016. *Methodology for Valuing the Health Impacts of Air Pollution: Discussion of Challenges and Proposed Solutions.* Washington DC: World Bank Group. http://documents.worldbank.org/curated/en/832141466999681767/Methodology-for-valuing-the-health-impacts-of-air-pollution-discussion-of-challenges-and-proposed-solutions.

Watt, J., J. Tidblad, V. Kucera, and R. Hamilton. eds. 2009. *The Effects of Air Pollution on Cultural Heritage.* Boston: Springer.

WHO (World Health Organization). 2016. *Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease.* Geneva: WHO. https://apps.who.int/iris/handle/10665/250141.

WHO. 2018. "Ambient (Outdoor) Air Quality and Health." May 2. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health.

WHO/Europe (World Health Organization Regional Office for Europe) and OECD (Organisation for Economic Co-operation and Development). 2015. *Economic Cost of the Health Impact of Air Pollution in Europe: Clean Air, Health and Wealth.* Copenhagen: WHO/Europe.

World Bank and IHME (Institute for Health Metrics and Evaluation). 2016. *The Cost of Air Pollution: Strengthening the Economic Case for Action.* Washington, DC: World Bank. http://documents.worldbank.org/curated/en/781521473177013155/The-cost-of-air-pollution-strengthening-the-economic-case-for-action.

Yanagi, Y., J.V. Assunção, and L.V. Barrozo. 2012. "The Impact of Atmospheric Particulate Matter on Cancer Incidence and Mortality in the City of São Paulo, Brazil." *Cadernos de Saúde Pública* 28 (9): 1737–48. https://doi.org/10.1590/s0102-311x2012000900012.

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ABOUT WRI

The World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT
We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT
We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT
We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

CIFF **CHILDREN'S INVESTMENT FUND FOUNDATION**

About CIFF
The Children's Investment Fund Foundation (CIFF) is an independent philanthropic organization with offices in Addis Ababa, Beijing, London, Nairobi, and New Delhi. Established in 2003, CIFF works with a wide range of partners seeking to transform the lives of children and adolescents across the world. CIFF's areas of work include maternal and child health, adolescent sexual health, nutrition, education and income generation, child protection, and supporting smart ways to slow down and stop climate change.