UNIVERSIDADE DE SÃO PAULO

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ANNE DOROTHÉE SLOVIC

Air pollution policies from an urban-oriented perspective: comparing implemented strategies to control vehicular emissions and mobility in São Paulo, New York City and Paris

Tese apresentada ao Programa de Pós-Graduação em Saúde Pública da Faculdade de Saúde Pública da Universidade de São Paulo para obtenção do título de DOUTOR em Saúde Pública.

Área de concentração: Saúde Ambiental

Orientadora: Profa. Titular Helena Ribeiro

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Banca Examinadora

Prof. Dr. ______________________________ Instituição: ________________________

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DEDICATION

Para minha mãe, que me ensinou que determinação e dedicação eram essências para a realização de qualquer sonho

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Quatro anos depois, eu só tenho a agradecer pelas pessoas extraordinárias que me apoiaram durante o doutorado. Este trabalho é dedicado especialmente a todos vocês. Pesquisar três países, três cidades e várias décadas de retrospectiva de políticas de qualidade do ar me fizeram optar por escrever minha tese em inglês, mas tendo sempre em mente uma gratidão e orgulho enormes por ter tido a chance de pesquisar no Brasil, na Faculdade de Saúde Pública da Universidade de São Paulo.

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The future of our urban world has yet to be realized, but brings both a price and a promise. To what extent we will pay the price, as opposed to fulfilling the promise, is in our hands.

WHO/ UN HABITAT – Hidden Cities, 2010

RESUMO

SLOVIC, A.D. **Poluição do ar sob a perspectiva urbana: comparando estratégias implementadas de controle de emissão veicular e mobilidade em São Paulo, Nova Iorque e Paris**. 2016. 156 f. Tese (Doutorado) – Faculdade de Saúde Pública, Universidade de São Paulo, São Paulo, 2016.

Objetivo: Este estudo teve por objetivo descrever e analisar as políticas e estratégias de controle da poluição do ar no meio urbano, com vistas a melhorar a qualidade do ar e apto a servir como referência para outras cidades em face de problemas críticos de poluição do ar. Usando os casos de Nova Iorque, São Paulo e Paris, este estudo destaca as diferentes políticas e tendências de gestão previstas nas três cidades, fornecendo uma caracterização destes três centros, descrevendo o período global e legal de desenvolvimento das principais políticas e destacando as principais estratégias implementadas ao longo dos últimos vinte anos. **Metodologia**: Tendo como abordagem um estudo múltiplo de caso, um primeiro componente fundamental da pesquisa consistiu na caracterização das três cidades, fornecendo dados sobre tendências das médias anuais da poluição do ar no que se refere a níveis de NO_2, PM_{10}, $PM_{2.5}$, Ozônio e SO_2 ao longo dos últimos quinze anos, apresentando uma visão geral dos meios de transporte e das frotas de veículos, e descrevendo as principais políticas desenvolvidas nas três cidades. Em seguida, a pesquisa propõe uma categorização das principais estratégias aplicadas, usando as abordagens de gestão da poluição do ar (regulatório, incentivos econômicos e outros) da OECD (Organização para a Cooperação e Desenvolvimento Econômico) para visualizar as escolhas estratégicas empregadas. Então, os resultados são condensados na matriz de análise SWOT e complementada a análise com sugestões de uma abordagem da qualidade do ar com maior inclinação para os direitos humanos. **Resultado**: Se prazos e contexto local variaram de uma cidade para outra, as três cidades têm um percurso histórico geral semelhante no desenvolvimento de certas políticas em oposição a outras. Níveis totais de poluição atmosférica têm diminuído ao longo dos últimos quinze anos, mas os níveis de poluição do ar continuam acima do que é recomendado nas diretrizes da OMS (Organização Mundial da Saúde). As cidades diferem no desenvolvimento de estratégias. De acordo com os critérios da OECD, se as abordagens reguladoras são uma tendência comum às cidades na redução dos níveis de poluição do ar, elas diferem na forma e até na extensão de seu investimento em mobilidade e transportes públicos e na matriz energética escolhida. Outra descoberta incluiu o desenvolvimento de incentivos econômicos, dados disponíveis e inclusão da indústria automobilística em questões ambientais. Elas têm em comum a capacidade tecnológica para desenvolver combustíveis de energia mais limpa e fomentar meios de transporte não-motorizados. No entanto, as disparidades em opções de transporte, infraestrutura e na distância entre trabalho e residência pareceu ter impacto sobre o uso de veículos privados, em parte devido à dificuldade de acesso da residência a transportes públicos disponíveis, além de opções políticas dos governos locais. Isto é particularmente verdadeiro no que tange a população de renda média, que constitui a grande parcela que faz uso de automóveis próprios, e população de baixa renda. **Conclusão**: abordagens regulatórias são estratégias historicamente preferidas no controle da poluição do ar, especificamente no caso de episódios de poluição do ar a níveis críticos, mesmo quando a cidade já fomenta sua rede de transporte público. Há melhorias a serem feitas em prol da qualidade dos índices relativos à poluição do ar em cada cidade e também pela melhor compreensão da contribuição e dos impactos das emissões veiculares na qualidade do ar. O foco na tecnologia veicular é uma escolha que só pode ser complementada se mais estratégias de transporte limpo atingirem um número maior de habitantes. Além disso, se é importante o compartilhamento de tecnologia e know-how entre as cidades, isso só pode ser feito se estudos prévios forem realizados localmente e se os moradores estiverem envolvidos no processo de tomada de decisão. Caso contrário, conforme as políticas de poluição do ar forem sendo desenvolvidas, elas correm o risco de fracassar. Para este fim, a abordagem da poluição do ar baseada nos direitos humanos poderia ser uma opção para o progresso das estratégias mais inclusivas no tratamento da qualidade do ar e de seu compartilhamento.

Palavras-chave: 1.poluição do ar, 2.política pública, 3.urbano, 4.estratégia, 5.Paris, 6.Nova Iorque, 7.São Paulo

ABSTRACT

SLOVIC, A.D. **Air pollution policies from an urban-oriented perspective: comparing implemented strategies to control vehicular emissions and mobility in São Paulo, New York City and Paris**. 2016. 156 f. Thesis (Doctorate) – School of Public Health, University of São Paulo, São Paulo, 2016.

Objective: The objective of this study was to describe and analyze urban air pollution control policies and strategies, with the goal of improving air quality and serving as a reference for other cities facing critical air pollution issues. Using the cases of New York City, São Paulo and Paris, this study highlights the different policies and management tendencies practiced in the three cities, by providing a characterization of the three centers, describing the global and legal timeframe of the development of main policies and highlighting major strategies implemented over the last twenty years. **Methodology**: Using a multi-case study approach, the first component of the research consisted of characterizing the three cities, providing data on air pollution yearly average level trends of NO_2, PM_{10}, $PM_{2.5}$, Ozone and SO_2 over the last fifteen years, giving an overview of modes of travel and the local vehicle fleet, and describing the main policies undertaken in the three cities. Then, the study proposed a categorization of the main strategies applied using OECD air pollution management approaches (regulatory, economic incentives and others) to foresee strategic choices employed. Finally, the results were synthesized with a SWOT analysis matrix and complemented with suggestions based on a human-rights approach to air quality. **Results**: While the timeframe and local context differed from one city to another, in general the three cities followed a similar historical pathway to developing certain policies as opposed to others. Overall levels of atmospheric pollution have decreased over the last fifteen years but air pollution levels continue above WHO recommended guidelines. The cities differ in the development of strategies used. According to OECD criteria, if regulatory approaches to air pollution are commonly used to lower air pollution levels, cities differ in the way and extent to which they have invested in mobility and public transportation and the chosen energy matrix. Another finding included the development of economic incentives, available data and inclusion of the automobile industry into environmental issues. While the three cities do have technological capacity to develop cleaner energy fuels and foster non-motorized modes of transports in common, disparities in transportation options, infrastructure and distance to and from work appeared to have an impact on the use of privately owned vehicles. This is partly due to the lack of available public transportation in residential neighborhoods and local government's political choices. In particular, this impacted low- and middle-income populations the most as they constitute the majority of car owners. **Conclusion**: Regulatory approaches have historically been the primary tool used to control air pollution. This is especially true when pollution has reached critical levels even when there is widely-used, reliable public transportation. There are some improvements to be made to advance the quality of the data related to air pollution in each city and to better comprehend the effects and long-lasting impacts of vehicular emissions on air quality. Focusing on vehicle technology is a choice that can only be complemented if more integrated clean transportation strategies reach a greater number of city inhabitants. Furthermore, technology and know-how are important factors which must be transferred from one city to another and must take into account past local studies as well as input from local communities. If not, as air pollution policies are being developed, they run the risk of failing. To this end, human-rights based approach to air pollution must be an option to progress towards more inclusive strategies and their replication.

Keywords: 1.air pollution, 2.public policy, 3.urban, 4.strategies. 5. Paris, 6.New York City, 7.São Paulo

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LIST OF ABBREVIATIONS

ADEME	*Agence de l´environnement et de la maîtrise de l´énergie* (Environmental French Agency)
CETESB	*Secretaria Estadual do Meio Ambiente* (São Paulo State Environmental Agency)
CO	Carbon monoxide
CPTM	*Companhia Paulista de Trens Metropolitanos* (São Paulo Metropolitan Train Company)
CVD	Cardiovascular Disease
DALY	Disability-Adjusted Life Years
DENATRAN	*Departamento Nacional de Transito* (Brazilian Federal Traffic Department)
DEVE	*Direction Voiries et Environnement* (Paris Department of Roads and Environment)
DRIEE	*Direction Régionale et Interdepartementale de l'Environnement et de l'Energie (*Regional and interdepartment environmental agency)
EC	European Commission
EPA	U.S. Environmental Protection Agency
HCs	Hydrocarbons
HDI	Human Development Index
HRBA	Human Rights Based Approach
I/M	Inspection and Maintenance Program
IACHR	Inter-American Court of Human Rights
IAG	*Instituto de Astronomia, Geofísica e Ciências Atmosféricas* (Institute of Astronomy, Geophysics and Atmospheric Sciences)
IBGE	*Instituto Brasileiro de Geografia e Estatística* (Brazilian Institute of Geography and Statistics)
INSEE	*Institut National de la Statistique et des Etudes Economiques (*French National Institute of Statistics and Economic Studies)
INSERM	*Institut National de la Recherche et de la Santé* (French National Institute of Research and Health)
INVS	*Institut National de Veille Sanitaire* (French National Sanitary Institute)
IPCC	Intergorvernmental Panel on Climate Change
KM	Kilometers
LAURE	French Federal Law on rational use of air and energy
LRTAP	Long Range Transboundary Air Pollution
MDIC	Brazilian Ministry of Development, Industry and International Trade
MMA	Brazilian Ministry of Environment
NAAQS	National Ambient Air Quality Standards
NO2	Nitrous Oxide
NOAA	National Oceanic and Atmospheric Administration
NOx	Nitrogen oxides
NYC	New York City
NYC DOT	New York City Department of Transportation
NYMTC	New York Metropolitan Transportation Council
NYS	New York State
NYS DEC	New York State Department of Environmental Conservation
O3	Ozone

OECD	Organization for Economic Co-Operation and Development rganização
PM	Particulate matter
PROMOT	Program for Air Pollution Control for motorcycles and similar vehicles
PRONAR	Programa Nacional de Controle de Qualidade do Ar
PRONCOVE	Program for the Control of Air Pollution from auto vehicles
RATP	*Régie Autonome des Transports Parisiens* (Parisian Autonomous Transport Agency)
SO2	Sulfur Dioxide
SOx	Sulfur Oxide
SP	São Paulo
SVMA	*Secretaria do Verde e do Meio Ambiente* (São Paulo Green and Environmental Department)
SPTRANS	São Paulo Transport
SWOT	Strengths, Weaknesses, Opportunities and Threats
UN	United Nations
UN HABITAT	United Nations Habitat
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environmental Program
USP	Universidade de São Paulo
VACS	Vehicle Automation and Communication Systems
VOC	Volatile Organic Compounds
WHO	World Health Organization
WHS	World Health Summit

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1 INTRODUCTION

Air pollution continues, today, to be one of the greatest challenges for the environment and global health. Indeed, in its most recent report on the effects of atmospheric pollution, the World Health Organization has published data showing how, in 2012, atmospheric pollution was responsible for the premature deaths of seven million people worldwide, among which 3.7 million were attributed to outdoor air pollution (WHO, 2014). In addition, in a recent study, the OECD has also reported that the health cost associated to air pollution amounts to 1.6 trillion dollars, out of which 50% are caused by road transports (OECD, 2014).

While there exists a broad range of severity of air pollution levels, sources and outcomes, urban centers have long been identified as one of the main air pollution hubs (MOLINA et al., 2004). Most notably, in urban centers, the link between air pollution and health has been clearly shown among ambient air pollutants such as particulate matter, nitrogen and ozone with diverse negative health outcomes (SCHWARTZ et al., 1992; DOCKERY et al., 1993; CLANCY et al., 2002; PETKOVA et al., 2014; POPE et al., 2009). Among such outcomes, exposure to these pollutants has been a causal factor in the development of respiratory diseases (BELL et al., 2007; DOMINICI, 2006; LAUMBACH et al., 2012; RESTREPO, 2012; VEGNI et al., 2005), cardiovascular diseases (DOMINICI, 2006; VAN DEN HOOVEN et al., 2011; VANOS et al., 2014), cancers (BOLLEN et al., 2009; LÓPEZ-APARICIO et al., 2013), pre-term birth and low birth weight (BACKES et al., 2013; MEDEIROS et al., 2005; RITZ et al., 2007; SHAH et al., 2011; ŠRÁM et al., 2005; STIEB et al., 2012; VAN DEN HOOVEN et al., 2011) and more recently diabetes (PARK et al., 2015).

Sources of air pollution vary, originating from natural settings such as volcanoes and forest fires to human-derived fixed and mobile sources such as industries and vehicles respectively. In the case of vehicles, these emissions are generated “when fuel is burned in an internal combustion engine and when air/fuel residuals are emitted through the vehicle tailpipe” (NYSDEC website). Major pollutants emitted from vehicles include nitrogen oxides (NO_x), particulate matter (PM_x), sulfur oxides (SO_x), hydrocarbons (HC_s) and carbon monoxide (CO) in addition to secondary pollutants such as ozone (O_3). Other pollutants more recently studied that have been associated with vehicular emissions and health damage because of their toxicity also include heavy metals, benzene, volatile organic compounds and formaldehyde.

In large metropoles, one of the primary sources of atmospheric pollution is that of vehicular emissions, creating the necessity for governments at all levels to implement public policies aimed to control their impacts. According to the United Nations, 55% of the world´s population lives in urban centers (UN, 2014), and cities ultimately have become a place of growing concern for the environment and health. Indeed, in 1990 the world included 10 cities greater than 10 million inhabitants, which represented 7% percent of the world's global population. In the last twenty-four years, the number of mega cities, cities with over 10 million inhabitants, has jumped to 28 (UN, 2014), and as cities concentrate the world's greatest share of exposed people, they face the challenge of coping with one of the major circumstances that aggravates the effects of air pollution: traffic density and people's exposure (PITT et al., 2006; PROGIOU et al., ZIOMAS, 2012). Indeed, the Institute for Health Metrics and Evaluation estimates that injuries and air pollution from road transport have caused 1.5 million deaths globally and are a greater source of death than HIV/AIDS, malaria and diabetes combined. In this same report, it was also possible to see trends in car ownership wherein it was identified that rapidly growing economies, with high levels of populations, also tend to have greater amounts of car ownership (GLOBAL ROAD SAFETY FACILITY & EVALUATION, 2014). In Nairobi, Kenya, Kinney et al. have found that, combined with commuting patterns, residents were "exposed on a regular basis to elevated concentrations of fine particle air pollution" due to traffic (KINNEY et al., 2012). In addition to the strong arguments for curbing air pollution to improve urban health, scientists also argue that addressing urban air pollution from vehicles will be key to mitigating the effects of climate change (JACOB et al., 2009; STREFLER et al., 2014; WALSH, 2008) as vehicle transport accounts for 14% of CO_2 emissions worldwide (WHS Yearbook, 2015)

Epidemiologic studies have increasingly established the link between traffic and health outcomes, in which the elderly, children and pregnant women are among the most affected populations. In children, for instance, studies have found that air pollution can trigger asthma prevalence in individuals that are exposed to nitrogen and traffic (FAVARATO et al., 2014). Other traffic-related outcomes such as allergic respiratory diseases, bronchiolitis and pneumonia are increasingly common and the subject of numerous studies (D'AMATO et al., 2008; D'AMATO et al., 2010; GEHRING et al., 2010; LAUMBACH et al., 2012). In New York City, Restrepo et al. have established an association between hospital admissions of children for asthma (ages 0-7 years) and exposure to NO_2, SO_2 and CO_2 with an even stronger association with particulate matter (PM) during the coldest months of the year (RESTREPO et al., 2012). The elderly (ages > 65 years) have also been found to experience higher rates of hospitalization for circulatory and respiratory diseases with an increase in mortality from air pollution exposure and extreme temperatures (RIBEIRO, 2012; TSANGARI et al., 2016; ZHOU et al., 2015). Furthermore, studies have identified that traffic noise is associated with increased risk of stroke in the elderly (HALONEN et al., 2015; SUNYER et al., 1996).

While the relationship between traffic and air pollution is well established, several groups including most notably Host et al. have pointed out that there is still a gap to better understand its health impacts. This gap is partly due to the fact that the characterization and measurement of population exposures are difficult to establish and that the broad range of epidemiologic study methodologies can be an aggravating factor. According to Host et al., closing this gap will enable a better comprehension for policymakers and health research (HOST et al., 2012). As air quality is seen as a global health challenge and an ally for coping with climate change mitigation (PARRISH et al., 2011), it raises the question of what kind of strategies and policies are being locally developed and implemented. Furthermore, as previously mentioned, mobile sources of air pollution such as vehicular emissions are one of the greatest challenges for policymakers in cities to preserve clean air and guarantee urban mobility. Moreover, if the link between urban air pollution and vehicular emissions has been a growing field of study, as for instance to better comprehend its health impacts, there is still a literature gap to envision and analyze in a qualitative way what local initiatives are being used.

Long-term and low levels of air pollution exposure continue to be associated with environmental health challenges, in particular when looking at early life exposure (CURRIE et al., 2014). In a recent United States cohort study, Thurston et al. have found that long-term exposure to $PM_{2.5}$, even at lower rates, was related to an increased risk of total and cardiovascular disease (CVD) mortality (THURSTON, 2015). Furthermore, in Ontario, Canada a cohort study had previously supported the hypothesis that long-term exposure to traffic-related air pollution increased the incidence and mortality of CVD (CHEN, 2011). Results of these works suggest the importance for a better understanding of how long-term exposure to low levels of air pollution impact health as well as of the establishment and global acceptance of air pollution levels that are considered safe for the environment. Thus, as previously mentioned, it also brings to attention the need to learn what kind of initiatives cities such as São Paulo, New York and Paris are developing to tackle high levels of exposure.

Researchers have demonstrated that, in addition to time and exposure-associated health risks, not managing air pollution is in fact costly, particularly in urban centers where a higher number of individuals is exposed. Likewise, studies have shown that non-action in controlling air pollution via the "business as usual" scenario has a high health cost. By looking at the annual levels of ozone and particulate matter in Mexico City, São Paulo and Santiago between 2000 and 2020, Bell et al. have evaluated the health and concentration exposure response under two scenarios: "business as usual" and under air pollution control. They found that 156,000 deaths, 4 million asthma attacks, 300,000 children´s medical visits and 48,000 cases of chronic bronchitis could have been avoided in the three cities if the air pollution scenario were applied. They measured the economic value of avoided health impacts to $21-165 billion (BELL et al., 2006). Indeed, controlling air pollution has been the ultimate choice for cities and the most efficient tool to handle air quality and climate change (IPCC, 2013).

To this end, this research was designed through the creation of an in-depth multiple case study. The work was initiated with the premise that air pollution control policies have an important role in the improvement of air quality, and that comparative studies are key components to identifying strategies developed, providing insight where epidemiologic studies and policymakers could benefit. To do so, three of the world's most important cities – São Paulo, New York and Paris, for the years 2000 to 2014 – were chosen with the premise that:

- These cities share a common challenge, with vehicular emissions as one of their major sources of air pollution. Since 2000, these three cities have made great progress in decreasing overall concentrations of air pollutants, although they still possess levels above WHO air quality guidelines for selected pollutants, and they still struggle with vehicular emission growth and density (a global trend as per OECD, 2014).
- Each city has been innovative in the development of public policies, strategies and programs that make each of them unique cases of trends that could be replicated.

Moreover, three major events have motivated the choice of these three centers as important places for case studies:

- The launching of Plan NYC of 2007 by former New York City Mayor Bloomberg that established an action plan to tackle environmental local challenges such as air pollution and climate change. New York City has during Bloomberg's administration developed some innovative programs such as the closing of Times Square for vehicle circulation, and also the development of biking lanes over the entire city, an action that was one of the first of its kind in a metropolis.
- In Paris, another city administration, the one of Mayor Delanoe, brought attention to some of the unique actions that were taken, such as the closing of the left bank of the river Seine – former major axe of vehicle circulation. Paris was one of the first cities to launch a bicycle sharing program, among other actions. However, despite an extensive public transportation network, as presented in the characterization section, the city encountered extremely high levels of air pollution in March 2013 and 2014, when levels of particulate matter reached an average of 100 ug/m^3 for three days in a row. These episodes, despite having occurred after the beginning of this research, have emphasized the importance of comprehending the response at the policy level to address air pollution, in addition to having already implemented related strategies.
- In São Paulo and Brazil, the energy matrix choice with the introduction of the ethanol and flex vehicles makes it a unique case as well. Another important program that was launched as part of the PROCONVE government program, introduced in 1989 (explained in the results section) to address vehicular emission, was the Inspection and Maintenance program (I/M) that was only launched in the Municipality of São Paulo in 2009, and initiated a series of debates as to why such initiative was really effective to reduce vehicular emissions and improve air quality. The I/M program was finally suspended in 2013 with no prevision of return.

These points raise the question of what kind of policies could be duplicated and why looking at local initiatives could have a major impact for other cities.

The Nobel Prize winner in Economic Sciences Elinor Ostrom has developed an interesting perspective on the importance of local initiatives to the global environment. Her work brings into the air quality debate a perspective that highlights the importance of initiatives that develop strategies to manage public good, such as air, and common pool resources, such as energy, at the local level. For example, while addressing climate change and greenhouse gas emissions, Ostrom emphasized that “advanced forms of resource management often emerge in small-scale communities and that knowledge of this emergence should be used to develop larger scale governance systems” (HAARSTAD, 2014). For Ostrom, global policies are not enough to bring a quicker solution to climate change; instead, they generate a lack of trust that further prevents collective action. To this end, her polycentric approach to find climate change solutions can also be applied to air quality. The polycentric approach can be defined as “experimental efforts at multiple levels” (OSTROM, 2009) or one that fosters efforts to assess the efficiency of methods and strategies in a given place to address global common pool and public good issues, that in turn could have the greatest global impact. Ostrom’s vision encourages more cross-city studies that could benefit to a greater number of people and preserve common-pool resources, preventing the development of “inconsistent policies” (COLE, 2015). Indeed, as Ostrom has written about climate change:

> […] the advantage of a polycentric approach is that it encourages experimental efforts at multiple levels, as well as the development of methods for assessing the benefits and costs of particular strategies adopted in one type of ecosystem and comparing these with results obtained in other ecosystems (OSTROM, 2009, p.39).

Controlling air pollution, in particular from mobile sources, has become increasingly essential to managing urban air quality, and there is a need to better understand how large cities that have achieved air pollution reductions but still struggle with chronic exposure and health cost burdens are developing policies and programs that could serve as examples for other struggling cities.

2 OBJECTIVES

2.1 Main Objective

To identify and analyze air pollution management strategies implemented in São Paulo, New York City and Paris that are aimed to improve air quality and urban mobility and that can serve as a reference for other cities facing critical air pollution issues.

2.2 Specific objectives

1. To highlight the role of air pollution policies and programs in improving urban air quality within the global environmental context;
2. To characterize support information leading to air pollution control policy development in São Paulo, New York City and Paris;
3. To collect and describe policies, programs and initiatives in São Paulo, New York and Paris;
4. To systematize and analyze the main air pollution management strategies used in the studied cities;
5. To detect policy trends leading to recommendations.

3 METHODOLOGY

This section explains the different methodologies applied to enable this descriptive cross-study on air pollution policies, and the different approaches and steps taken.

They consisted of:

- Describing the bibliographic research;
- Explaining the case study methodology and its parameters;
- Giving a detailed account of every step of the methodology applied;
- Describing how the data were gathered and selected, including air pollution and meteorological data, legal framework, policies and programs, vehicle information (emissions, fleet age, number), academic evidence and government reports;
- Presenting how the field work and informational interviews were structured;
- Showing how the analysis of the different policies and programs were developed for the three cities;
- Explaining the different points that were chosen to guide the discussion section and the choice to only utilize secondary health data.

It is important to highlight that, as part of the thesis and methodology, two manuscripts have come out of this research:

- The first article, "How can urban policies improve air quality and help mitigate global climate change: a systematic mapping review" was published in December 2015 in the Journal of Urban Health. This article was primordial in the research process as it offered an overview of different policies and interventions applied in urban centers around the world. The text highlights the challenges and benefits from these different initiatives, applying OECD air pollution management strategies that were replicated to categorize the different policies used in São Paulo, New York City and Paris. Most prominently, it stresses the importance of controlling air pollution and seeing air quality improvements as an ally to mitigate climate change.

- The second manuscript has been added to the discussion section. Entitled "Clean air matters: an overview of traffic-related air pollution and pregnancy", the article stresses the importance of including clean air as an important right and health factor for pregnant women. This article presents how some concepts such as the exposome and epigenetics offer new research opportunities to the environmental and maternal health field. The manuscript has been approved for publication in the *Revista de Saúde Pública*.

A third manuscript of this research will be based on the results and discussion section of this dissertation.

During the doctorate program, a four-month internship (*bolsa sanduiche*) at the Center for Health and Well-Being at Princeton University, under the supervision of Dr. João Biehl, permitted the amplification of the bibliographic research and the interaction with scholars who are reference in the field. It also made feasible the insertion of the concept of the human rights-based approach to air pollution into this research.

3.1 Bibliographic research

The nature of this research has required an extensive bibliographic review and is organized around several themes:

- The relation between air pollution and vehicular emissions and climate change mitigation;
- The relation between urban air pollution and health;
- The role of public policy in urban air pollution control and quality;
- The review of existing literature on air pollution in São Paulo, Paris and New York City to understand what the challenges or improvements were;
- The assessment of existing theses and dissertations.

The bibliographic search was performed using several online databases such as: SIBiUSP, Google scholar, Scielo, PubMed, Proquest, Web of Science, Scopus and Lilacs. It was organized in the following manner around the redaction of the manuscripts and the four years of research.

For the first manuscript on air quality and urban policies (item 4.1 p. 51), the bibliographic research was done using PubMed, Proquest, Web of Science and Scopus databases. The methodology section of the manuscript provides a detailed description of keywords used for the search but to summarize it included:

- "air quality" OR "air pollution" OR "climate change" OR "atmospheric pollution"

AND

- "urban" OR mega* OR city OR cities

AND

- vehicle* OR car* OR traffic OR transport*

AND

- polic* OR intervention* OR control OR strategy* OR management

In addition to the keywords used in the first manuscript, the following keywords were used in the eight databases previously mentioned, with the insertion of keywords such as: air pollution, Paris, São Paulo, New York City, environmental justice, human rights and health.

For the second manuscript, the bibliographic research performed made feasible an overview of concepts related to air pollution and maternal health and keywords such as pregnancy, exposome and epigenetics and air pollution.

For the articles most related to the object of this study, a detailed reference check enabled the identification of academic field experts and further bibliography. Moreover, during the doctorate, several fieldwork trips (detailed in the data gathering section) were taken. Thanks to those trips, it was possible to search for existing dissertations and theses at Princeton University and Columbia University libraries. A documental search on several governmental institutions websites was done to gather information on the existing legislature, policies and programs. However, because this study was focused on the policy aspect of air pollution control, information on the health effects of air pollution was provided throughout a bibliographic search on Pubmed database, local government and institutions reports to give an overview of the current situation. This brief bibliographic research was focused on year 2008 onwards.

3.2 Case study

Case studies are a well-known tool to analyze situations, people, programs and places in a given period of time. Best defined by Yin, case studies are “studies that investigate a contemporary phenomenon in-depth in its real world context” (YIN, 2014). Case studies can have one single case or multiple cases. According to Yin, there are five necessary steps to elaborate and complete a case:

- Defining your case
- Designing it
- Collecting the data
- Analyzing the data
- Concluding

Case studies are extensively used as a tool to articulate and detect examples of current environmental health problems such as urban air quality and climate change. They can be single-case studies as mentioned earlier, focusing on one single place with a specific timeframe. Among the few examples of single-case studies on air pollution policy, Carvalho et al. have looked into the different trends of air quality in São Paulo as a result of emission control policies between 1996 and 2009 (CARVALHO et al., 2015). In the Flanders region, Belgian researchers have observed the impact of research and policy on particulate matter by applying the importance/performance feasibility developed by Martilla and James in 1977. This is a tool that works as a scoring methodology to air management in making decisions (MARTILLA et al. 1977), an analysis methodology over ten years of policy to understand what could have gone wrong in the policymaking process (BUEKERS et al., 2011). Multiple case studies can also be an important source to help environmental health policymakers design initiatives that will have a greater air quality impact. Bell et al. have looked at environmental health indicators in Latin American cities to help researchers and policymakers develop indicators that could contribute to reducing the impacts of environmental hazards (BELL et al., 2011). Other researches point out the contribution of heat and air pollution and their co-benefits to climate change (HARLAN et al., 2011; MOLINA et al., 2004; PARRISH et al., 2011). To this extent, this case study considered these three cities as good examples to identify a set of best practices proposed in the discussion and conclusion of the dissertation but did not aim to evaluate air pollution policies and initiative efficiency of the three cities.

The different steps described by Yin were used to plan and articulate this comparative study. Here, data collection of the three chosen cities was done simultaneously, as well as the identification of some trends in policy implementation. Case studies can be applied using either primary or secondary data. In this case, secondary data was used and interviews were only informational. The research took the form of a descriptive case study whose evidence is mostly based on documentation (e-mails to different air pollution monitoring agencies and governmental representatives, governmental documents, academic research, reports, evaluations, newspapers). It highlights the key air pollution strategies used in the cities of Paris, São Paulo and New York connecting them, when possible, to higher or lower levels of atmospheric pollution. The use of informational interviews was mostly done at the first stage of the research in order to better comprehend the scope of the study and identify where to find the data. Table 1 gives a list of the organizations where informal interviews were made.

Table 1 – List of organizations interviewed and information provided

Organization	City	Level	Information provided
AIRPARIF	Paris	Local	Air pollution data, air quality regulations, air quality reports
CETESB	São Paulo	Local	Air pollution data, air quality and emissions regulations, air quality reports
Cour des Comptes	Paris	Federal	Audit of government's programs spendings
Direction des Espaces Verts et Environnement - Agence Ecologie Urbaine (DEVE)	Paris	Local	Programs and reports
IAG - USP	São Paulo	Local	São Paulo meteorological data
INSERM	Paris	Federal	Health reports
INVS	Paris	Federal	Health reports and publications
Mailman School of Public Health, Columbia University	New York City	Local	Academic research data and NYC legislation sources
NYC DEC	New York City	Local	Policies, Programs and reports
NYC Department of Health and Mental Hygiene	New York City	Local	Policies, Programs and reports
Respire	Paris	Local	Air pollution information
Secretaria do Verde e do Meio Ambiente	São Paulo	Local	Policies, programs and reports

Elaborated by AD Slovic

Twelve organizations were approached in the three cities. NYC Department of Health and Mental Hygiene, INVS, Inserm and *Secretaria do Verde e do Meio Ambiente* were interviewed within the first year of the Ph.D. whereas others such as Columbia University scholars, CETESB, Airparif and NYC DEC were interviewed several times, providing insightful recommendations and access to data during the four years of research. The *Cour des Comptes*, *Respire* and DEVE were interviewed in 2014.

In order to accomplish some of these interviews and gather more data, two field trips were performed. As previously mentioned, a four-month stay at Princeton University, United States, also allowed developing this research using the Princeton University library database, besides going to New York City and connecting with NYC DEC and Professors at the Mailman School of Public Health, Columbia University. Two field trips to Paris were taken during years one and four of the doctorate program to collect the missing data. In São Paulo, several interviews were undertaken with the CETESB agency and the *Secretaria do Verde e do Meio Ambiente* during the four years of the doctorate program.

3.2.1 Scope of Study:

Following the steps recommended by Yin, this cross-study was achieved by:

1. Defining the case: because the goal was to determine which air pollution control policies and strategies were used in Paris, São Paulo and New York City and what kind of conclusions could be drawn from that, it was essential to explain what definition of "policy" was used. Indeed, "public policy" has different definitions that essentially focus on how a government decides to act or not to act on a given issue (SOUZA, 2006). To this extent, looking at air pollution control policies implied contextualizing the legal framework and gathering the different regulations developed to set government strategy: interventions, programs and plans.

   Policies follow a cycle that is illustrated in Figure 1 below. This research was focused on finding documents related to steps 4 and 5 of the implemented policy and its sets of actions and documents that offered evaluations or corrections to the policy or program.

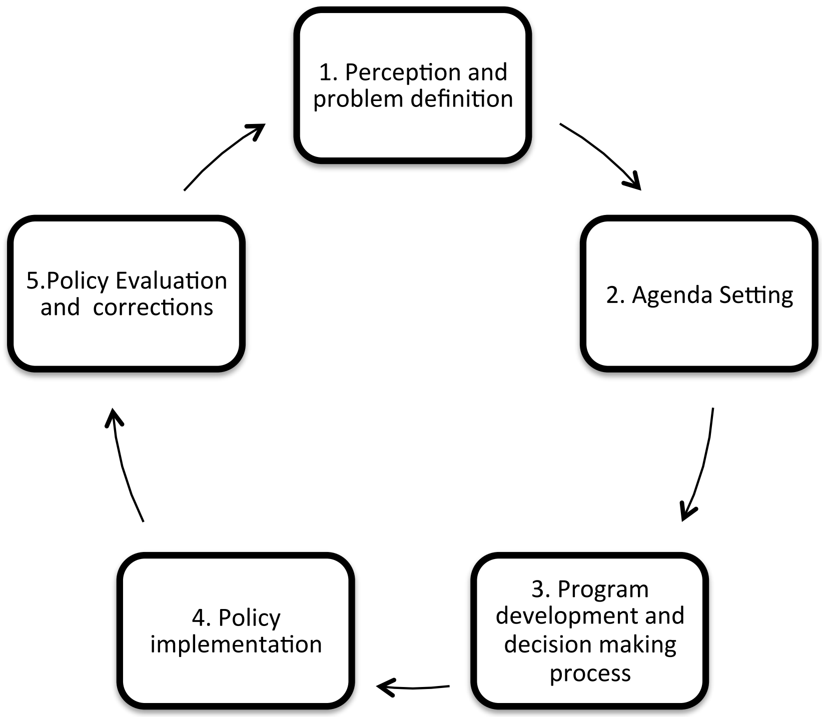


Figure 1 – Policy cycle according to Klaus Frey
Elaborated by AD Slovic, adapted from Frey (2000).

2. Designing the case: this consisted of defining the chronological timeframe, geospatial scope, type of information searched and methodology used to analyze the data. The overall timeframe used was 2000-2014, with the exception of the global and regional regulation and convention settings of air quality and some policies undertaken prior to 2000 and essential to this study, such as the Brazilian Federal Pro-Alcohol Program, which started in 1975. Further details are included in the bibliographic section. Population data were also provided for the three cities, being from 2000 to 2014 for New York City and the Municipality of São Paulo, and from 1999 to 2014 for Paris, given the available data (Federal French Census in 1999).

   A brief presentation of their global and regional context was added to envision what these cities represented within their local and global environment. The global data were obtained from the United Nations 2014 World Urbanization Prospects. The total population was then split by percentage to highlight the most vulnerable populations (children under five years of age and elderly over 65). The rest was divided between the young population (5-19 years old) and the workforce population (20-65 years old). The data was obtained from the Census Bureau for New York City, INSEE for Paris and IBGE, Tabnet/ *Prefeitura de São Paulo*, IMP, SEADE for the Municipality of São Paulo.

The geographical scope for São Paulo concerns the municipality of São Paulo (center city), for Paris, Paris *intra-muros* (Paris center city) and for New York, Bronx and Manhattan. The reason for this choice was that these regions are the ones that concentrate some of the largest numbers of jobs, residents and traffic density.

In addition to programs and plans for each city, it was important to look at the alternatives proposed to the use of private vehicles and the different restrictions imposed on vehicles and new technologies.

3. Collecting the data was done through web search and bibliographic review, all of which is explained in the data gathering section.

4. Analyzing the data: the Organization for Economic Development and Co-operation (OECD) air pollution strategy approach (detailed in Table 2) was used to categorize the different policies and identify trends. This methodology was first tested in the accepted manuscript: *"How can urban policies improve air quality and help mitigate global climate change: a systematic mapping review"* and replicated to look into the different strategies implemented in Paris, São Paulo and New York City, considering the same sub-classifications. In addition, the debate on air pollution policies that bring benefit for all started in the manuscript is continued in the discussion section, where there is a proposal to make the link between policies on air pollution levels.

5. The Conclusion summarizes the findings and highlights some best practices and most utilized strategies.

Table 2 – Selected policy approaches for air pollution management according to the OECD

Regulatory (command and control) approaches	Economic instruments	Others
■ Ambient air quality standards. ■ Industrial emission standards, technology standards. ■ Reporting requirements for stationary sources (*e.g.* pollutant release and transfer registers). ■ Automobile emission standards (see Figure 6.7). ■ Fuel quality standards. ■ Vehicle inspection and maintenance programmes.	■ Tradable permits schemes for air emissions from stationary sources (*e.g.* SO_2 allowance trading system under the US Clean Air Act). ■ Fuel taxes (see Figure 6.9). ■ Congestion charges. ■ Taxes on emissions (see Figure 6.8). ■ Financial incentives for the development of alternative and renewable fuels and advanced transportation technologies (*e.g.* California's DRIVE programme).	■ Information collection: – emission and air quality monitoring; – cost-benefit analyses to support policy evaluation (with valuation of health impacts); – public education (*e.g.* Canada's Air Quality Health Index). ■ Voluntary car-scrapping schemes. ■ International conventions (*e.g.* The Convention on Long-range Transboundary Air Pollution). ■ Telework initiatives (*e.g.* the US Telework Enhancement Act of 2010).

Extracted from OECD Environmental Outlook to 2050: the consequences of inaction. (OECD, 2012)

3.3 Characterization of the studied cities

3.3.1 Overview of the studied cities

Studying air pollution policies and programs implemented in São Paulo, Paris and New York City required comprehending some characteristics such as population, size and climate in these three places. This said, the three cities all have in common to be the largest and most populated urban centers within their countries and concentrate the highest number of employment. The following brief sections will give a demographic description of each city and how their country is situated in terms of Human Development Index in addition to a meteorological background of average yearly temperatures and precipitations.

São Paulo, often called the municipality of São Paulo, is the capital of the State of São Paulo, Brazil, and divided into 31 "subprefeituras" or boroughs that are in turn divided into 96 districts with a density of 7,858 people/km^2. The municipality of São Paulo is the 11th most populated city in the world with 11.9 million inhabitants (IBGE) and sprawled over 1,521 km^2 (Annex 1). Its greater region, also called the Greater São Paulo, contains approximately 20 million people and is, according to the United Nations, ranked as the third largest metropolis after Mexico City and Mumbai.

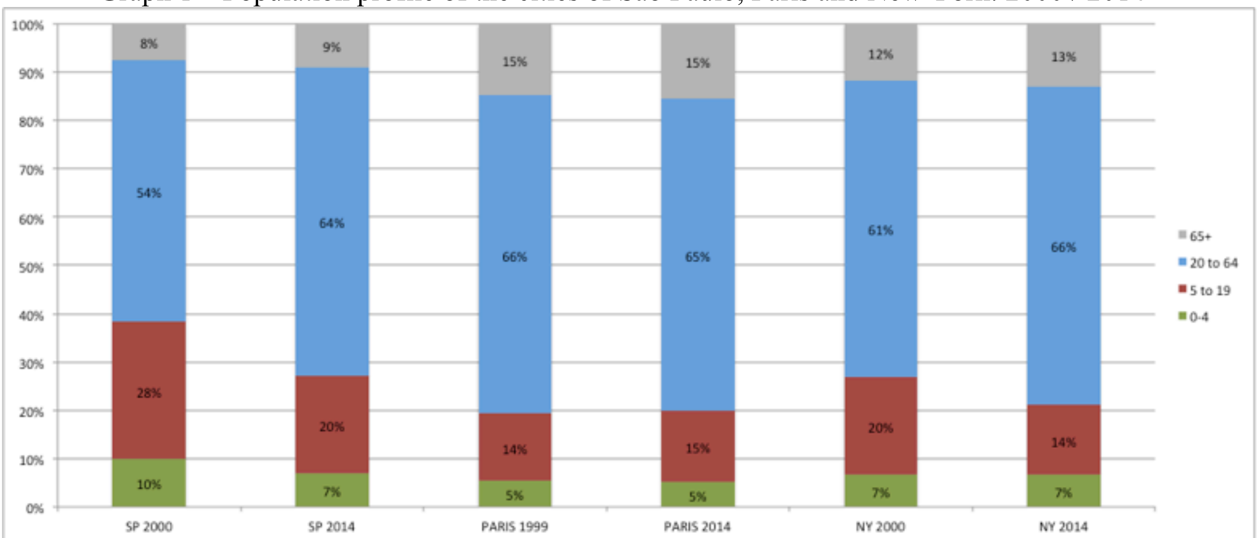
Looking at the overall population in the last fourteen years (Graph 1), São Paulo has seen a small variation in the percentage of its elderly (more than 65 years of age), which has increased 1% while a more significant change has occurred in the youngest population, in particular among those under five years of age, which represented 10% in 2000 and today account for 7% of the population. The most significant change has been seen for its population from 5 to 19 years old that has decreased 8%, and the group between 20 and 64 years of age, the working force, which has increased 10%. However, the reduction in its young population puts São Paulo into a similar demographic situation as Paris and New York City, and suggests a population that is starting to age (Graph 1).

Similar to São Paulo, New York City is the capital of its state and, combined with Newark, makes the world's ninth largest city (UN, 2014). Its five boroughs – Manhattan, Bronx, Queens, Brooklyn and Staten Island (Annex 1) – contain a total population of 8.5 million who live in a 789 km^2 area with a density of 10,800 people/km^2 (Manhattan and Bronx, the geographical zone of this study, have together a population of 3 million). NYC's five-borough population has seen a small increase over the last fourteen years, with a population less than five years old of 7%. NYC's 5- to 19-year-old population has experienced the greatest decline since 2000, when it represented 20% of the overall population and dropped to 14% in 2014. Its population of 19 to 64 years old has accounted for the largest increase since 2000, representing now 66% of the overall population. On the other hand, the group over 65 years of age has increased 1% since 2000.

Paris, the oldest of the three cities of study, is also the smallest one, with 105.4 km^2 and the highest density, 21,289 people/km^2 (Annex 1). Capital of France, Paris is located in the Île de France region and concentrates the highest number of jobs in France among its 12 million inhabitants. The center city of Paris, also called "Paris *intra-muros*" (intramural Paris), had a population of 2,3 million in 2014, a number similar to 1999 (French census) when the Parisian population totaled 2,1 million. Over the last fourteen years, the population's profile has remained almost the same, where the elderly account for 15% of the population and, among the youth, the ones less than five year-old embody 5% of the total population and the group with ages between 5 and 19 represents 15%. In contrast with São Paulo and New York City, Paris's population between 20 and 64-year-old has remained the same, 65%, over the years. Out of the three cities, Paris does have the largest share of population over 65 years of age.

Overall, although São Paulo was demographically different from New York City and Paris in 2000, fourteen years later it presents a demographic profile that is shared by the three cities.

Graph 1 – Population profile of the cities of São Paulo, Paris and New York: 2000 / 2014*



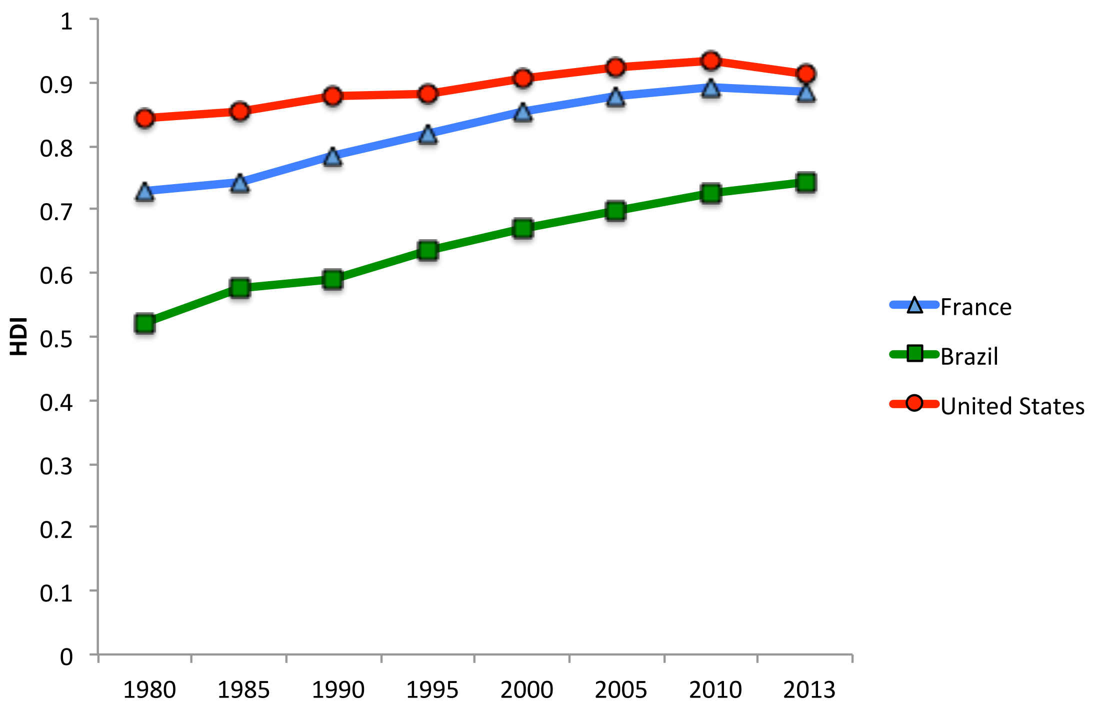
Elaborated by AD Slovic
Sources: INSEE (Paris), Census Track (NYC), IBGE and SEADE (São Paulo)
* 1999 was the year considered for Paris

The Human Development Index (HDI) is an international indicator adopted by the United Nations to capture non-economic factors and highlight equality in education, life expectancy and income per capita of given countries. The use of the HDI appeared to be of important use to help contextualize the three cities within their respective countries but also in the global context. In the case of Brazil, the country has seen a significant improvement since the eighties, when its index turned around 0.5 and increased to 0.744 in 2013 (Graph 2). It is imperative to emphasize that the city of São Paulo has an HDI of 0.80, one of the highest in the nation (IBGE, 2013). Greater São Paulo, in particular its municipality, holds the nation's greatest job center and economical hub. It is worth highlighting that the automobile industry in Brazil accounts for 65% of the GDP and is the eighth largest producer in the world (MDIC, [s.d.]).

On the other hand, the United States ranks as one of the highest in the world with 0.91, as represented in Graph 2, but has been slightly declining since 2010. According to the New York City Labor Statistics Bureau, although the food, education, professional and technical services employ the greatest number of people; it is actually the securities, commodities contracts and investment jobs that earn the greatest annual average rate ($ 405,000). (NYS DEPARTMENT OF LABOR, 2015).

France's HDI of 0.88 stands between the United States and Brazil, and has improved over the last thirty years. In 1980, France's HDI was of 0.74 but has been stable since 2010. In Paris, transports, services and commerce are source of 68% of jobs (INSEE, 2015).

Graph 2 – Human Development Index – Brazil, France and United States: 1980 / 2013



Elaborated by AD Slovic
Source: UNDP

3.3.2 Meteorological background of São Paulo, New York and Paris

Academic research has demonstrated the role that meteorological conditions have on air pollution and how it can contribute to show air pollution variations, particularly high levels. Although this is a very important aspect to explain certain air pollution levels, it is not the primary focus of this study. However, this section gives an overview of the average yearly temperatures and the yearly total value of the precipitation in the three studied cities as background information to better understand each city's context. To do so, data of temperatures and precipitations in the three centers were extracted for the years of 2000 to 2014. The annual average temperature and the total level of annual precipitations were calculated for each city. The different sources of data were:

- São Paulo: Instituto de Astronomia e Geofísica of the University of São Paulo (<http://www.estacao.iag.usp.br/boletim.php>)
- New York: National Oceanic and Atmospheric Administration website (<http://www.ncdc.noaa.gov/cdo-web/datatools/normals>)
- Paris: Météo France (<http://publitheque.meteo.fr/okapi/accueil/okapiWebPubli/index.jsp>)

In addition, the Köppen-Geige climate classification was used to identify the climate in the three cities. The Köppen-Geige climate classification is extensively used in geographical studies and climate change (KOTTEK et al., 2006), structured in letter groupings:

- The first letter indicates the vegetation group “between plants of the equatorial zone (A), the arid zone (B), the warm temperate zone (C), the snow zone (D) and the polar zone (E)” (KOTTEK et al., 2006);
- The second letter indicates the level of precipitation;
- The third one indicates the air temperature.

According to this classification, São Paulo is sub-tropical (Cfa), New York (Dfa) humid continental and Paris oceanic (Cfb) climate. São Paulo, with its sub-tropical climate, has warm summers, usually associated with the rainy season (December–March) and dry mild winters (June–August). New York is characterized by hot summers and cold winters while Paris has mild temperatures with more precipitations in the winter and the spring.

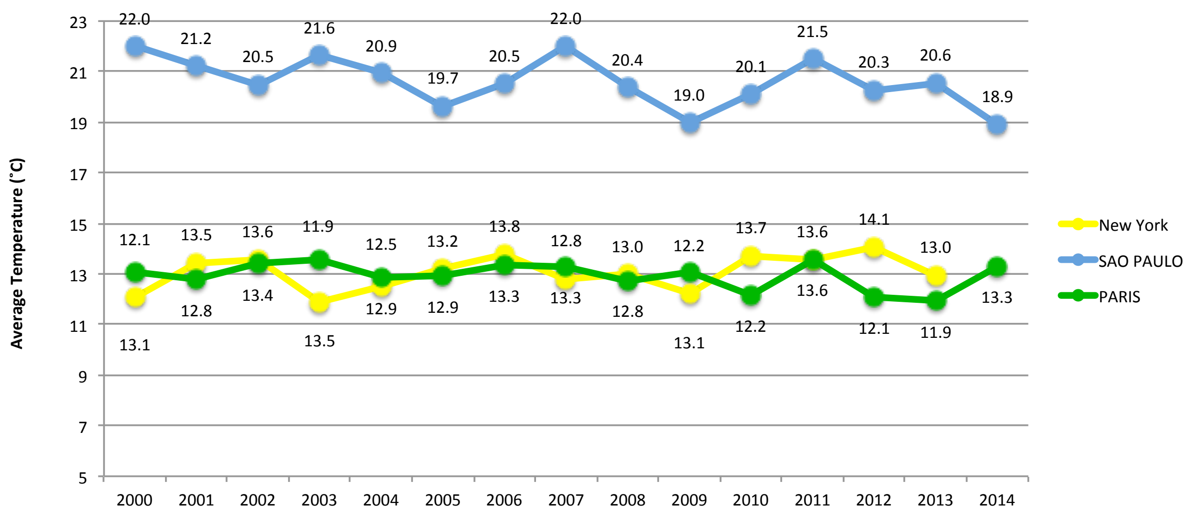
3.3.2.1 Temperature trends: São Paulo, New York and Paris

Out of the three cities, São Paulo is the one with the warmest temperatures, a characteristic of its sub-tropical climate, with temperatures that range from 22˚C to 18.9˚C as seen in Graph 3. Four years show an increase in temperature averages: 2000, 2003, 2007 and 2011, when averages varied between 22 and 21.5˚C. On the other hand, during the years of 2005, 2009 and 2014 lower average temperatures were observed. When looking at the overall average yearly temperature trends, New York and Paris varied between 14.1 and 11.9˚C. New York shows two years of lower temperatures, as seen in Graph 3: 2003, when the average yearly temperature was 11.9˚C and 2009, with 12.2˚C. The years 2006, 2010 and 2012 show an increase in temperatures with respectively 13.8, 13.7 and 14.1˚C.

For Paris, two years had higher temperatures: 2003, also known for its summer heat-wave that killed 3,000 people, with average temperatures of 13.4˚C, and 2011, with an average temperature of 13.6˚C. The years of 2010, 2012 and 2013 present lower temperatures between 12.2 and 11.9˚C. However, 2014 had a significant increase of temperature described by Airparif as the warmest year since 1900 (AIRPARIF, 2014).

Yearly average temperatures are an important tool to give an overview of the trends in these cities. However, they cannot capture any heat waves or extreme temperatures that might have occurred, such as the summer heat-wave of 2003 (7-14 of August 2013), when Paris experienced its highest summer temperatures since 1950 (INVS, 2003).

Graph 3 – Average yearly temperatures in São Paulo, Paris and New York City – 2000 / 2014



Elaborated by AD Slovic
Source: Méteo France (Paris), IAG - USP (São Paulo), NOAA (New York City)

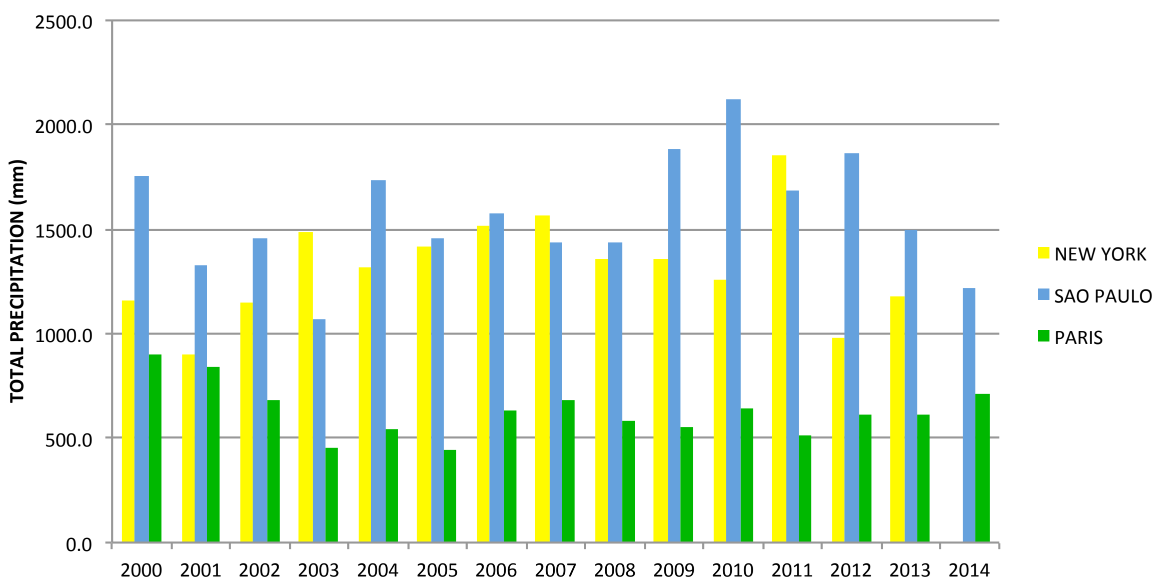
3.3.2.2 Precipitation outlook: São Paulo, New York City and Paris

Graph 4 shows the yearly values of precipitation in each city. As mentioned in the temperature section, São Paulo, with its sub-tropical climate, also faces the highest level of precipitation as compared to New York City and Paris. Some years merit special attention, like 2003 and 2014 which saw precipitation values drop lower than in other years. In 2003, the total value was of 1,100 mm, while it was of 1,250 mm in 2014. These two years are fairly low, as compared to 2009, 2010 and 2012, when some of the highest precipitation levels occurred (2010 as seen in Graph 4, the value was superior to 2,000 mm).

Being a sub-continental city, New York has experienced more precipitation than Paris over the last fourteen years. In general, New York City had an average of 1,250 mm of precipitation, with noted exception in 2011 and 2012, when it reached 1,800 and 1,000 mm respectively.

Paris, compared to the other cities, has the lowest precipitation values (never above 1,000 mm). These values show marked decrease from 2000 to 2005, reaching 400 mm from a high of 800 mm. From 2006 to 2014 the total precipitation values averaged between 600 and 700 mm.

Graph 4 – Yearly total value of precipitation – São Paulo, Paris and New York City: 2000 / 2014



Elaborated by AD Slovic
Source: Méteo France (Paris), IAG- USP (São Paulo), NOAA (New York City)

3.3.3 *Health effects of air pollution on the studied cities*

Researchers and local government agencies of these three cities indicate that urban air pollution, in some cases vehicle-related, continue linked to health damage and costs to individuals.

For instance, in 2009 the leading causes of death in New York City were heart disease (20,086) and cancer (13,180) (NYC DEPT. OF HEALTH AND MENTAL HYGIENE, 2009), among which one of the most aggravating environmental factors was air pollution from vehicle emissions and buildings burning high-sulfur heating oil, generating $PM_{2.5}$ and O_3. Back then, the NYC Health department estimated that air pollution from these sources was responsible for "3,000 deaths, 2,000 hospital admissions from heart and lung diseases and 6,000 emergency department visits for asthma in children and adults" (ibid.). The same report found that air pollution and attributable adult mortality deaths were unevenly distributed across New York City; for instance, the Bronx and Northern Manhattan were some of the districts most affected by $PM_{2.5}$ pollution. Furthermore, the same was discovered for respiratory and cardiovascular hospitalization rates and asthma emergency visits, particularly in the Bronx (MAANTAY, 2007). Ozone exposure in Staten Island had the highest mortality rates in NYC; however, asthma hospitalization and emergency department visit rates were concentrated in Northern Manhattan and Bronx. These results were emphasized by the outcome from the NYC Community Air Survey 2008-2009, which pointed out to higher $PM_{2.5}$ and NO concentrations in Manhattan and Bronx. However, in a recent air quality impact assessment, Kheiberk et al. have measured the morbidity and mortality due to $PM_{2.5}$ and ozone by looking at geographic location, season and health impacts. It was discovered that the geographic location was not the main factor of health incidences. Results differ by pollutant: for instance, $PM_{2.5}$ and asthma emergency visits were most affected by income while ozone attributable hospital visits for asthma was higher and more affected by seasons, particularly the summer (KHEIBERK et al., 2013).

Despite progress made over the last 15 years to control levels of air pollution, Paris has experienced levels of particulate matter that forced the authorities to activate emergency procedures over the last two years, as mentioned above, which led the government to take immediate initiatives to control and reduce concentrations of PM, such as vehicle circulation alternatives and free public transportation. France has been assigned in front of the European Court and has already been fined for the non-respect of the PM limitation values. In addition, Airparif's latest 2014 Air Quality Report states that although there was an improvement in the air pollution levels, they were not enough, in particular for NO_X and PMs near roads with intense traffic. It reports that 400,000 Greater Parisian inhabitants were exposed to daily levels above standards (ibid.).

In Paris, the Aphekom project, a European initiative to evaluate the health effects of air pollution in European cities had estimated that 5.8 months in the life of 30 year-old individuals could be gained if Paris applied the WHO standards for particulate matter (APHEKOM, 2011). The report concluded that 112 deaths and 476 hospital admissions could be avoided by lowering PM_{10} standards with a concomitant savings of 11 billion euros. The results were even more significant by reducing $PM_{2.5}$ standards where 1,423 deaths managed to be avoided and 4 billion euros saved (ibid.).

More recently, Deguen et al. found that exposure to NO_2 average concentrations for five years increased all cause mortalities in the lower income section of the city, particularly when exposure to NO_2 was above 55.8 ug/m^3 (DEGUEN et al., 2015). Bentayeb et al. looked at associations between long-term exposure to air pollution and mortality in individuals in a French cohort from 1989 to 2013. They found that long-term exposure to fine particles, nitrogen dioxide, sulfur dioxide and benzene was associated with an increased risk of non-accidental mortality in France and call for further investigation of the risk factors of air pollution in health (BENTAYEB et al., 2015).

In São Paulo, associated costs to air pollution were evaluated by Miraglia et al., as they looked at Disability-Adjusted Life Years to calculate the health impacts and costs. Results indicate that, in São Paulo, DALY added up to 28,212 years annually and cost 3.2 million dollars in the children and elderly population (MIRAGLIA, 2005). Particularly focused on traffic air pollution, Medeiros et al. found that it constituted an increasing risk for perinatal mortality in São Paulo (MEDEIROS et al., 2012). Da Silva et al. evaluated the variations of hospital admissions, temperature and intra-urban atmospheric pollution in the elderly population of São Paulo. Results from the study demonstrated an increase in hospital admissions for cardiovascular diseases and temperature decreases, and an increase in hospital admission for respiratory diseases due to high levels of atmospheric pollutants (DA SILVA et al., 2015). Vulnerable populations are not the only ones affected by air pollution in São Paulo: following a world trend, Habermann et al. found a correlation between traffic density, traffic volume and mortality from cardiovascular diseases (HABERMANN et al., 2012).

3.4 Data Gathering

In addition to the bibliographic research, documental research has been done to gather the different laws, policies and implemented programs that address air quality in São Paulo, Paris and New York. As explained earlier, the data was divided first to compile the major air pollution conventions and regulations. It was then assembled into a timeline that showed the global, regional (European Union legislation) and local legal framework. Programs, plans and initiatives were combined in an additional timeframe and were then analyzed using the OECD methodology. To establish a comparative framework, the search was structured by focusing on government reports, plans, programs and surveys referring to the period 2000 to 2014, but did consider previous ones in order to fully capture either a program continuation or the lack of new data. A different timeframe was used to look at the different global and nation-wide regulations as some conventions and regional regulations essential to control air quality had been established prior to 2000. It was then decided that the American Clean Air Act of 1963 (U.S. ENVIRONMENTAL PROTECTION AGENCY, 2015) and the Geneva United Nations Long Range Transboundary Convention of 1979 (UN ECONOMIC COMMISSION FOR EUROPE, 2015) would be the point of departure for the global and nation-wide setting.

The data gathering was performed following these steps:

- Research of previous and current global, federal and local regulations;
- Collection of each local agency's air pollution and health-related yearly reports, when available, and Implemented Programs;
- Compilation of air pollution data for PM_{10}, $PM_{2.5}$, NO_2 and O_3 (more detailed in the section on air pollution);
- Gathering population, vehicle fleet and transport network data;
- Assembly of average temperature and precipitation data (more detailed in the section on temperature and precipitation);
- Field trips and informational interviews with local governmental agencies.

Collection of Laws and Regulation data was done mostly through web search on the different local and international institutions that dealt with air pollution control and transports. Among the ones used as primary sources of data are WHO, EPA, United Nations (UNECE, UNEPE), OECD reports and European Union Commission.

For data on the different local air pollution control policies and programs, a web search was also undertaken of the different local governmental agencies and institutions specialized in air pollution, including legal, environmental, health and transportation-related. Information was obtained from:

- For New York: the NYC Mayor's office of sustainability website, NYS and NYC DEC, NYC Department of Health and Mental Hygiene, NYC Department of Urban Planning, Pratt Institute, NYMTC, EPA;
- For Paris: City of Paris: website of the *Mairie de Paris*. DRIEE (*Direction Régionale et Interdepartementale de l'Environnement et de l'Energie*), Ademe, Citepa, Airparif, Cour des Comptes, French Environmental Ministry;
- For São Paulo: the Municipality of São Paulo website, local environmental agencies such as *Secretaria do Verde e do Meio Ambiente*, CETESB, the Brazilian MMA (Ministry of Environment), SPtrans, Metrô, CPTM.

Part of the study also consisted of showing the alternative solutions developed by each city to cope with vehicular emissions and reduce the use of privately owned vehicles. To do so, a search was also done at the different entities responsible for public transportation and for the development of active transport programs such as bicycle sharing. A major source of data provided by local agencies was on reports from undertaken mobility surveys of the studied cities.

3.4.1 Air Pollution data

In order to further contextualize the three selected cities, their respective air pollution data were combined as background information to clarify trends over the last fourteen years. Each city's data were compared to the respective standards that applied to that region, including the WHO air pollution guidelines, European Commission on air quality standards and Environmental Protection Agency (EPA). This information is shown in Table 3, obtained from the following websites: WHO air quality guidelines, European Commission on air quality standards, EPA – National Ambient Air Quality Standards, Airparif and CETESB.

For each pollutant listed, a description of its health effects and characteristic was added to the air pollution results section. Air pollution graphs were made with data obtained from each city's local air quality monitoring agencies, as described in Table 3:

Table 3 – Data source of studied pollutants by city: PM_{10}, PM $_{2.5}$, NO_2, O_3, SO_2

POLLUTANT	YEARS	SÃO PAULO	NEW YORK	PARIS
PM_{10}	2000-2014*	CETESB/QUALAR	NYS DEC	AIRPARIF
$PM_{2.5}$	2000-2014*	CETESB/QUALAR	NYS DEC	AIRPARIF
NO_2	2000-2014	CETESB/QUALAR	NYS DEC	AIRPARIF
O_3	2006-2014	CETESB/QUALAR	EPA	AIRPARIF
SO_2	2000-2014	CETESB/QUALAR	NYS DEC	AIRPARIF

Elaborated by AD Slovic
* for $PM_{2.5}$ and SO_2 different starting years apply

For the three cities, the annual average was computed for PM_{10}, $PM_{2.5}$ and NO_2 and compared to the WHO guidelines. However, the data provided varied by city and by pollutant, and is explained in greater detail below.

For SO_2 the annual average was compared to the State of São Paulo's annual secondary mean of 40 ug/m^3 established by State Decree 59113 of 2013 and Brazilian federal ambient air quality standards of 1990 (CONAMA nr.3, 1990). The standard deviations were calculated from the annual mean of each station and plotted for PM_{10}, $PM_{2.5}$, NO_2 and SO_2.

For O_3, the 8-hour maximum average value was calculated for years 2012-2014 for the three cities, in order to show the number of days exceeding the WHO O_3 guidelines. The data for New York and Paris were obtained per hour and by station from the AirParif and EPA air database website respectively, meaning that there were 24 data points per day. From these 24 points, the rolling 8-hour average was calculated, for example the average from hour 1-8, 2-9, 3-10, until hour 24, producing 17 new averages. From these 17 new points, the maximum value for each day was separated, and finally the number of times that this maximum value was greater than 100 ug/m^3 was counted. For São Paulo, the value was obtained from Qualar, CETESB online air database. The information obtained from the website provided the exceeding time according to WHO guidelines. No further calculation was done for São Paulo. In Annex 3, graphs extracted from the city's report were added to show the evolution of O_3 in the three cities, yet considering that each city has different standards for O_3 as shown on Section 4 ahead.

In addition, Graph 9 (p.87) was plotted with the yearly averages for O_3, which were calculated based on the same data sources as the ones previously mentioned. In the case of Graph 9, hourly data for both Paris and New York was obtained and averaged together each year, to provide the yearly average. This data was plotted along with pre-calculated yearly averages for São Paulo retrieved from Qualar, CETESB.

Furthermore, after each pollutant graph, a table was added to show the number of monitoring stations used when calculating each pollutant's yearly mean. Stations with less than six months of data were not taken into consideration. With the exception of $PM_{2.5}$ for São Paulo; only automatic air monitoring stations were accounted.

Some key points should be highlighted:

<u>For São Paulo:</u>

- Data for PM_{10}, $PM_{2.5}$, NO_2, SO_2 and O_3 were obtained from CETESB's air pollutant online database: *Qualar,* where it was possible to access monthly and annual average data by station;
- $PM_{2.5}$: data compilation began in 2003, as there was no available information on São Paulo prior to this year. That said, it is important to note that manual air monitoring stations provided data from 2003 to 2010 for $PM_{2.5}$ in São Paulo, as presented in Graph 6 (p.86). These concentrations were obtained from CETESB annual reports and combined in one graph. For the years 2011-2014, the data for $PM_{2.5}$ in São Paulo originated automatic stations and were retrieved from Qualar. An additional graph (Graph 7, p.86) captures $PM_{2.5}$ trends for 2011-2014;
- Data for O_3 obtained from Qualar gave the number of days exceeding 100 ug/m^3 matching WHO guidelines. Following this, the number of days of each station was extracted and an

average of exceeding days was calculated. The annual mean of each station was used from Qualar to get the total annual mean.

For Paris:

- Ambient air concentrations for PM_{10}, $PM_{2.5}$, NO_2 and SO_2 were gathered from Airparif annual reports and requested online database. Online databases provided information by hour and by station, different from annual reports that only provided annual averages by station. Both were used, the online database to compute the data and the reports to verify the stations and the results of the annual mean. In these cases, yearly averages were calculated for each station, and the standard deviations of these annual values were computed. The online database was exclusively used for O_3 and for SO_2. Only the stations located in Paris *intra-muros* (center city) were taken into consideration.

For New York City:

- Only data for New York County and Bronx were considered
- Ambient annual mean concentrations for PM_{10}, $PM_{2.5}$, SO_2 and NO_2 were extracted from the NYS DEC online reports while O_3 data were provided by the EPA online database. The EPA database for O_3 had data by hour and was used to calculate the annual mean and number of days exceeding WHO O_3 guidelines. There was no data for New York County for the year of 2006.
- Available data for $PM_{2.5}$ started in 2001
- NYC stopped compiling PM_{10} data after 2012, so the data calculated for the three cities included the years prior to 2012, namely 2000-2012

3.4.2 Urban Mobility characterization:

3.4.2.1 Vehicle fleet information

In addition to policy data, it was essential to capture data on the local vehicle fleets, standards and emissions in addition to the modes of travels of each city. Information on the vehicle fleet differed tremendously from one city to another. For instance, finding the number of private vehicle owners in New York and Paris was very challenging. On the other hand, Paris and São Paulo had more available information on transportation modes for the last ten years and on the contribution of the circulating fleet emissions on air pollution. In New York, this data was scarce but two major studies helped to provide information the Peripheral Travel Study of 2010 and the Regional Household Survey (that included New York City, Northern New Jersey and Connecticut). Emission inventories have been compiled in São Paulo for many years but the most recent reports are available online starting 2010. Emission inventories were extracted from the most recent available report for each city.

Major sources of data were:

São Paulo	**New York City**	**Paris**
- CETESB emission inventory reports - Denatran for additional information on vehicle fleet - Observatório das Metrópoles	- NYC DEC for raw data on vehicular emissions - NYC Department of Motor Vehicle - NYC Department of City Planning - NY Metropolitan Travel Council - U.S. Census Bureau	- Airparif reports: studies that provided information on vehicular emissions - Enquête Global de Transport report - City of Paris website

3.4.2.2 Mode of transport trends

Highlighting vehicular air pollution policies also implied looking at what was available and being done to increase and improve public transportation in urban centers. This involved examining the public transport network in the three cities, understanding how people commute and what the active means of transportation fostered in those centers are. To structure this information, data was extracted on public transport network and mobility.

Public Transport data was obtained via the website of the following agencies:

For São Paulo:

- SPTrans for bus and subway information
- CPTM: light train rails
- Metro: mobility surveys

For Paris:

- *Mairie de Paris, Direction de la Voirie et des Déplacements Agence de la Mobilité*: Mobility Surveys and Global Transport Survey (2010)
- RATP: bus and subway information
- Airparif emission reports

For New York City:

- MTA
- Rockefeller Foundation and Pratt Institute
- NYC Mayor's office of sustainability
- US Census Bureau
- NY Metropolitan Transportation Council

To assess the information on modal types of transport, data was extracted from government's reports such as clean fuel programs, transport plans and urban mobility programs. Mobility studies were then consulted for Paris (*Bilan des déplacements* report from 2012 to 2014), for São Paulo (*Pesquisa Origem Destino,* Origin–Destination survey reports from 1997, 2007 and the Mobility Report of 2012) and for New York (Pratt Institute Report 2012, One New York Report 2015, the Peripheral Travel Study 2010, 2014 American Community Survey 1-Year Estimates from the US Census Bureau and the 2010/2011 Regional Household Survey).

3.4.3 Air pollution policy data

As previously seen, overall policies were obtained from the different local government websites as well as air quality and inventory reports for each city. For Paris, additional research was done on the European Commission website. For New York, statewide policies were extracted from the NYC DEC website. For New York, another source of information, provided by scholars at Columbia University, was the New York City Council Legislative Research Center: although this site offered insightful information on every piece of legislation developed and amended in the city, it fell out the scope of this study, in the sense that it did not capture the different initiatives and programs developed by the city, such as PlanNYC (2007). For São Paulo, academic publications and government's website provided the necessary information on policies implemented over the years.

3.5 Data analysis

This cross-city study had an important description component of the different policies of the three cities, that was included as part of the Result section. Furthermore, it used a similar methodology as the one applied in the first published manuscript, adopting the OECD air pollution management strategies categorization for São Paulo, New York City and Paris, which helped identify the different trends in each city.

In the discussion section, a more in-depth analysis has been provided through the compilation of air pollution strategies with the resource of a SWOT analysis that permitted to sum up findings looking at their strengths, weaknesses, opportunities and threats. This section also brings in the human-rights based approach of air pollution as a more inclusive one to address air quality for all. To this end, the second manuscript "Clean air matters: an overview of traffic-related air pollution and pregnancy", has been added, aiming to conceive insights on future-related field research.

4 RESULTS

This section presents a contextualization of the framework surrounding air pollution control policies and the strategy trends around the world and in the three studied cities. It brings a published manuscript on the subject. Besides, it portrays relevant background and support policy information settings such as the legal global and local frameworks, a timeline of the main policies implemented for the years of 2000-2014 of São Paulo, Paris and New York City, air pollution levels background and the available mode of transports and mode of transport use. It also offers a description of the main policies that have guided the development and implementation of programs that tackled air quality and mobility, and proposes the use of OECD air pollution management strategies categorization as a mean to compare the implemented program and the trends that can be foreseen.

4.1 Air pollution policies and air quality: an overview of urban initiatives around the world

The following section presents a published manuscript. In it, a systematic review was done of the different urban initiatives developed around the world to address air quality as an ally to cope with climate change mitigation. This article led to the classification of these various urban initiatives through the OECD air pollution management strategies, used also to look at the programs developed in Paris, New York and São Paulo.

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How Can Urban Policies Improve Air Quality and Help Mitigate Global Climate Change: a Systematic Mapping Review

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João Biehl, and Helena Ribeiro

ABSTRACT *Tackling climate change at the global level is central to a growing field of scientific research on topics such as environmental health, disease burden, and its resulting economic impacts. At the local level, cities constitute an important hub of atmospheric pollution due to the large amount of pollutants that they emit. As the world population shifts to urban centers, cities will increasingly concentrate more exposed populations. Yet, there is still significant progress to be made in understanding the contribution of urban pollutants other than* CO_2*, such as vehicle emissions, to global climate change. It is therefore particularly important to study how local governments are managing urban air pollution. This paper presents an overview of local air pollution control policies and programs that aim to reduce air pollution levels in megacities. It also presents evidence measuring their efficacy. The paper argues that local air pollution policies are not only beneficial for cities but are also important for mitigating and adapting to global climate change. The results systematize several policy approaches used around the world and suggest the need for more in-depth cross-city studies with the potential to highlight best practices both locally and globally. Finally, it calls for the inclusion of a more human rights-based approach as a mean of guaranteeing of clean air for all and reducing factors that exacerbate climate change.*

KEYWORDS *Megacities, Climate change, Urban health, Air pollution, Public policy, Vehicle emissions, Air quality control*

INTRODUCTION

The Link between Air Pollution, Cities and Climate Change

The debate on anthropogenic atmospheric pollution and climate change has focused largely on its general effects and the sources of certain pollutants but has also begun to address its geographical dimensions. Generally speaking, greenhouse gases (GHGs) are composed of gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases such as ozone (O_3) and chlorofluorocarbons (CFCs) (EPA), while on a local scale, major sources of pollutants include sulfur dioxide (SO_2), nitrogen oxide (NO_x), particulate matter (PM), ozone, and

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lead. These pollutants all damage air quality, but the specific links between their effects on the atmosphere and air quality are a growing field of research. Thus, an increasing number of recent studies have demonstrated the importance of tackling local air pollution as an ally in the effort to cope with and mitigate global climate change.[1–3] This phenomenon is particularly important in megacities, defined by the United Nations as cities with more than ten million people[4], where high levels of both pollutants and people are concentrated. Furthermore, according to the Stern Review, urban centers account for 75 % of the global emissions of GHGs,[5] making cities important hubs of anthropogenic atmospheric pollution and contributors to climate change. Megacities concentrate high levels of fossil fuel emissions from mobile and fixed sources of pollution that contribute to the formation of urban heat island effects[3,6] and to global warming. Thus, looking at megacities as experimental hubs[7] to mitigate climate change offers an important opportunity to decrease the effects of global warming and improve air quality.[2]

The relationship between air pollution and health has long been studied by scholars, establishing the association between high levels of air pollution and outcomes such as allergies, respiratory disease, and cardiovascular disease.[8–12] This health burden is particularly concentrated in urban centers, where it has led to an increase in mortality rates[13] and reduction of life expectancy[14] and has also been associated with economic costs for cities and health systems.[15] Moreover, the impacts of climate change on health are known and have been an important site of research, particularly of how people will adapt and how to mitigate negative effects.[16,17] While Molina et al. have previously addressed atmospheric pollution in megacities,[18] it is only in the last decade that urban air pollution and climate change mitigation have been investigated. This raises questions about controlling air quality and understanding its sources.

Air pollution policies have been focused on controlling emissions, improving air quality, and avoiding negative health outcomes.[19] Given the growing need to decelerate the effects of global climate change, urban policy makers have the responsibility to "think global and act local" and to develop interventions that will influence local air quality while also mitigating climate change and adverse health outcomes. Fang et al. have found that "the change in global premature mortality and years of life lost (YLL) associated with changes in surface O-3 and PM2.5"[20] was significant and concluded that stronger emission controls is needed to maintain air quality and reduce the negative effects of climate change on health.

In urban centers, vehicles are one of the primary sources of mobile pollution.[21] Transport vehicles also account for 14 % of global greenhouse emissions and represent an important problem in developing countries.[22,23] Privately owned cars also constitute a significant source of emissions in cities that must now prioritize strategies and cope with their negative environmental health outcomes.[24] Vehicle emissions are sources of pollutants such as particulate matter, nitrogen, and ozone that can contribute to global warming.[20] However, there are very few initiatives to manage the effects of air quality on climate change mitigation.[25] As cities become an important site for climate response,[7] mitigation policies for global climate change must focus on the control of air pollutants as a strategy, with particular emphasis on those coming from vehicular emissions.

While the majority of climate-related policies at the national level have focused on GHG emissions, there remains a significant gap regarding policies that address the contribution of vehicular emissions other than CO_2 in cities and how they contribute to global climate change. Existing work has demonstrated the need for integrating both strategies at the local policymaking level. Walsh, for example, has used the example of how diesel control could improve urban air pollution and also help reduce CO_2.[21] Other studies have attempted to underline the importance of air pollution intervention and its impacts on health and equity,[26] analyzing the impact of heat, air pollution, and co-benefits on mitigation and adaptation.[6] Some papers prioritize air pollution policies or climate change mitigation,[2,27] but there are no existing reviews of global urban initiatives taking into consideration both contexts, supporting our hypothesis that air pollution in large urban centers can have a global impact.

OBJECTIVE

In this paper, we present a *systematic mapping review* of studies that have investigated policies in urban centers aimed at addressing vehicular emissions, supporting the argument that these policies have a significant impact on climate change mitigation as well as on the reduction of local air pollution.

METHOD

The primary goal of this review is to identify and discuss articles addressing policies to control air pollution in urban milieus, targeting the impacts of vehicle emissions on climate change and local air quality. To this end, we searched for articles that addressed the role of policies focused on reducing mobile sources of air pollution and their effects on climate change mitigation. Selected studies focused on strategies deployed at the local level, which were proven either efficient or non-efficient in reducing air pollution levels and the resulting impacts on climate change, while also identifying policy trends. The methodology used to organize and interpret the data was that of a "systematic mapping review." Mapping reviews offer the possibility to detect gaps and opportunities within a particular field of research that can assist policy makers in identifying the efficacy of an urban intervention.[28]

A systematized search of studies undertaken between the years 2000 and 2015 was performed using the Web of Science (WOS), ProQuest, PubMed, and Scopus databases in three levels, as demonstrated in Fig. 1. The keywords used for this search were: ("air pollution" OR "atmospheric pollution") OR "air quality" AND "climate change") AND (mega* OR city or cities OR urban AND vehicle* OR car* OR traffic OR transport) AND (polic* OR intervention* OR control OR management OR strateg*). The search for each database was adapted as follows: for WOS, the "topic" search field was used; for PubMed, all fields; and for SCOPUS, "titles," "abstracts," and "keywords." Only scholarly articles were considered, and no restrictions on geographic location were applied. In order to avoid duplicates from the four databases, the data were combined at the end of stage one, and all duplicates were eliminated.

Selection Process

The process for selecting articles was performed in three stages and can be visualized in Fig. 2. In the first stage, only titles were looked at, excluding conference abstracts and articles that researched indoor and non-anthropogenic air pollution. Papers whose titles did not apply to the local level were also disregarded. The local level was defined as the "city" or "urban" or "mega city."

In the second stage, both titles and abstracts were examined. Here, articles that dealt exclusively with "climate change" and showed no link to vehicle emissions were excluded. In addition, regional studies that looked at urban centers smaller

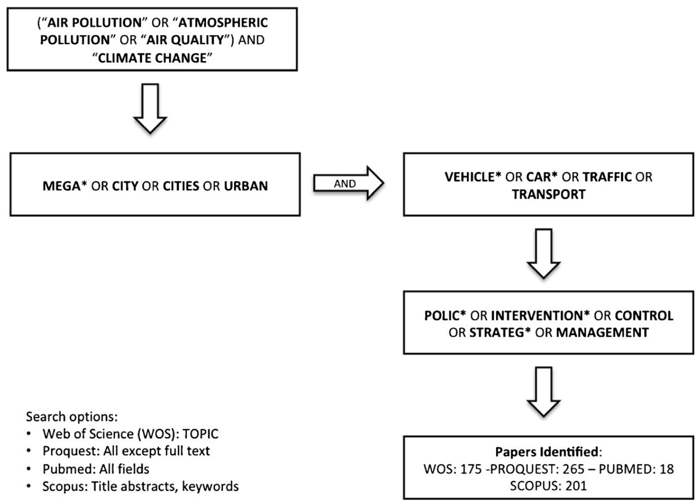

FIG. 1 Overview of the search process.

than two million inhabitants were also excluded. The rationale behind this cutoff was that the urban centers studied had to contribute significant emissions in order to have an impact on global climate change, consistent with the hypothesis that air pollution in large urban centers can have a global impact.

In the third and final stage, a full reading of articles and a final selection was conducted. The information from the articles was organized and divided into two tables: (1) articles that provided policy development support, including their

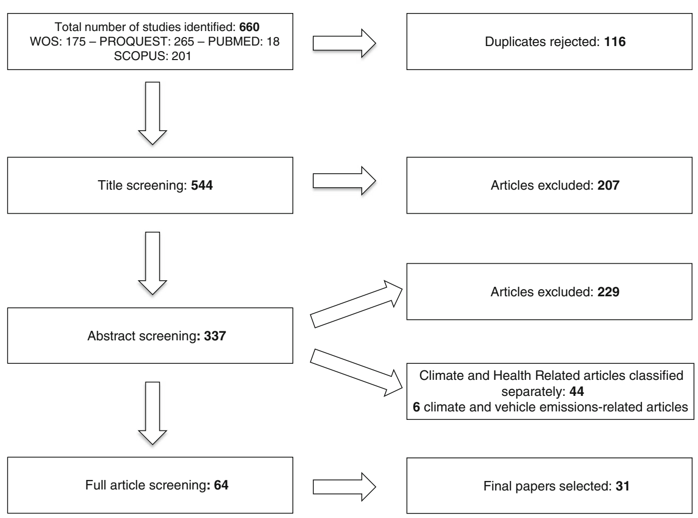

FIG. 2 Selection process overview.

expected results, and (2) articles that described post-policy implementation and included an evaluation of accomplished results. Within these two categories, data were organized by source (authors and year of publication), geographic location, type of pollutant, type of policy and recommendations for policy development, and primary findings post-policy. Finally, articles that presented an additional perspective by bringing in a socially inclusive dimension such as “equity” or the “right to clean air” were highlighted.

In terms of the research databases employed, PubMed returned the smallest number of articles (18). Considering the interdisciplinary nature of this research, a potential gap between articles in the fields of environment and health was identified, revealing the need for a stronger interaction between these fields. A potential explanation for this gap is that measuring the effects of mobile sources of air pollution on health requires access and technological “know-how” in order to produce high-quality data on vehicle emissions and levels of air pollutants. This is supported by Fajersztajn et al. who, after a study of air monitoring stations around the world, concluded that information on air pollution monitoring in low-income countries constitutes a major gap and called for a stronger focus on improving data collection as a first step to help reduce its detrimental effects on health.[29]

Data were analyzed by year of publication, country, pollutant, and type of policy, following the air pollution management approaches stipulated by the Organization for Economic Co-operation and Development (OECD) classification.[30] In its 2050 Economic Outlook, the OECD classified air policy approaches in three categories: regulatory or command and control (REG), economic instruments (ECO), and others (OTH). REG approaches established rules and standards that aim to reduce air pollution (EPA website). Where this approach takes the form of mandated rules, the second, ECO, is a financially based approach which works via taxes, charges, and financial incentives. The third strategy, OTH, combines initiatives that focus on policy support, such as educational tools, conventions, or other innovative solutions that do not imply any restrictions or financial inputs.

The OECD’s criteria for air pollution management strategies[30] were used to examine the methodologies, recommendations, and primary findings from the selected articles. To each of the three OECD air pollution policy approaches, three sub-classifications were added: (a) *circulation-restriction initiatives*, (b) *alternative initiatives*, and (c) *technology/fuels approaches*. *Circulation-restriction initiatives* were defined as policies that aim to control vehicle mobility within urban centers. For example, the alternate traffic circulation policy can be considered a *restriction initiative*. *Alternative initiatives* are policies that offer alternative forms of mobility in urban centers, such as public transportation, and also include fostering active transportation such as walking or biking. The third sub-classification, *technology/fuels initiatives*, is aimed at directly improving emissions via technology or the use of alternative fuels. Examples include the use of bioethanol as a fuel or any technological improvement that succeeds in reducing air pollution.

RESULTS

A total 660 articles were obtained from the four different databases under the keyword search criteria; 116 articles were duplicates and 207 articles were excluded after a title screening. After reviewing the abstracts, 108 articles were selected based on criteria for inclusion. Out of these 108 articles, 44 articles dealing with climate factors, health effects, and air pollution were discarded. From these 44, only six articles[31–36] established a direct link between vehicular emissions and air pollution, demonstrating the impact of traffic on emission levels. Although not considered here, it is important to highlight that these climate-related articles constitute an opportunity for further research. They offered valuable information on air pollution and its correlation with climate variation (wind, humidity, seasonal trends, urban heat island, heat waves, and global warming), as well as associations between mortality, morbidity, hospital admissions, and the most vulnerable populations. Yet, because they did not explicitly address specific reduction or remediation policies, they were not included in this review.

Thirty-one articles were finally selected for data interpretation. Two texts that analyzed cities smaller than two million inhabitants were included, as one reported on an important pilot project in its country and the other was based in the most important city within the region. One evaluated the efficiency of eco-driving training in Calgary, Canada,[37] while the other measured the co-benefits of the urban public bus system in the city of Yogyakarta, Indonesia,[38] exemplifying a specific initiative that helped improve the transportation system.

The selected articles are categorized in Table 1, grouping studies that served as policy support instruments. Table 2 combines those that served as evaluation tools for the efficiency of an implemented policy. Fourteen studies fell into the first category and 17 into the second.

Drawn from the 31 articles in Tables 1 and 2, major trends have been identified, as illustrated in Fig. 3. First, the number of publications is greater in the years 2011 and 2013 (seven for each), and the cities with the highest number of studies are in India (ten), China (seven), and the UK (four). Most case studies located in India are focused in Delhi, which includes New Delhi,[39–44] while in China, they are set in Beijing,[3,45–48] Shenyang,[49] and Chongqing.[47] Of the four articles based in the UK, all of them are situated in London.[43,50–52] The high number of studies for Delhi and Beijing reflects the severity of the air pollution situation, as they are two of the world's most polluted cities. On the other hand, London is considered a pioneer in the implementation of control policies for reducing vehicular urban air pollution. The rest of the articles are unevenly distributed around the world, with only three studies in Africa (one in Nigeria and two in South Africa) and few studies in developed countries other than the UK.

The pollutants most frequently assessed were CO_2 (24 articles), CH_4 (14), N_2O (13), and PM_{10} (13), while the least frequently assessed were $PM_{2.5}$ (6), SO_2 (5), NO_2 (4), BC (2), SO_x (2), TPS (1), and O_3 (1), suggesting that the metering of vehicular control measure efficiency prioritizes reductions of major climate change contributors and not necessarily local pollutants (with the exception of PM_{10}). A more detailed look at the years of publication of these articles shows that an increasing number of studies of carbon-containing pollutants have been performed since 2011. This suggests that there is a growing preoccupation on the part of local policy makers with lowering transport and vehicular emissions, while acknowledging that their policies can contribute to climate change mitigation in addition to local air pollution mitigation.

When the policies were categorized under the OECD classification schema, the policies addressed were evenly distributed between the categories "regulatory" and "others," which each accounted for 42 %. "Economic instrument" approaches were the least common, comprising only 16 % of policies. These results indicate that regulatory policies are still the most frequently used strategy to control air quality,

TABLE 1 Policy development support—expected results

Source	Geographic location	Pollutant					Policy			Primary findings
		C	N	S	PM	O3	REG	ECO	OTH	
Komolafe et al.[53]	Lagos, Nigeria	✓	✓						A, B ,C	Intervention of all stakeholders in mitigation and adaptation measures are essential in fostering educational programs and to bring awareness about environmental risks and carbon footprint.
Macmillan et al.[54]	Auckland, New Zealand	✓		✓			B			Transformation of urban roads over the next 40 years such as physical separation on main roads and bicycle-friendly speed reduction on local streets would yield benefits 10–25 times greater than cost.
Beccera et al.[76]	Bogotá, Colombia, Brazil; Santiago, Chile								B	Bus rapid transit, bike paths/lanes, and car use restriction contribute to promote active transportation. More studies should study the relationship between transport and physical activity while car ownership increases. The public health sector needs a stronger activism in the transport policy decision-making to incorporate health issues into the related agenda in Latin America.
Doll and Balaban[39]	Delhi, India	✓	✓	✓					B, C	An efficient transport policy should consider CDM and integrated policies to maximize co-benefits. The study highlights great challenges of data gathering.
Shrestha et al.[58]	Kathmandu Valley, Nepal	✓	✓	✓			C			Vehicle emissions in Kathmandu are higher than in other developing cities, mostly for PM and NO_x from bus fleet. If the whole Kathmandu Valley fleet complied with Euro III, emission would decrease by 44 %

TABLE 1 ***(continued)***

Source	Geographic location	Pollutant: C	N	S	PM	O3	Policy: REG	ECO	OTH	Primary findings
										for toxic air pollutants and 31 % for climate forces in a 20-year horizon CO_2 equivalent.
Thambiran and Diab[27,56]	Durban, South Africa	✓	✓		✓				A	Two most important interventions identified were the ones reducing distance travelled by private vehicle and improving efficiency of road freight transport.
Moodley et al.[57]	Durban, South Africa		✓							Passive samplers are an economical and reliable collector for NO_2 under several climatic conditions. This cost should be well within the budgets of most municipalities, thus motivating them to develop policies to alleviate traffic congestion.
Garg[40]	New Delhi, India	✓		✓				B		Improving air quality would bring more health benefits for the poor. The study found that most measures that reduce PM_{10} pollutants also reduce CO_2 emissions while simultaneously imposing more costs on the better-off.
Brady and O'Mahony[60]	Dublin, Ireland	✓	✓	✓					C	Electric vehicles offer potential for reductions in all road traffic-related emissions. However, the time required for electric vehicles to take a portion of the fleet suggests their limited impact on climate change and urban air quality for at least the next decade.
Kanto et al.[59]	Toronto, Canada	✓	✓	✓	✓				C	FCPHEVs may achieve almost twice this reduction. All vehicles exhibit similar impacts on the precursors for photochemical smog although the province-wide effects differ significantly.
Woodcock et al.[43]	London, UK; New Delhi,	✓							B, C	The combination of the active travel and lower-

TABLE 1 ***(continued)***

Source	Geographic location	Pollutant C	N	S	PM	O3	Policy REG	ECO	OTH	Primary findings
	India									emission motor vehicles would grant more environment health benefits. Policies to increase the acceptability, appeal, and safety of active urban travel, and discourage private motor vehicles would provide larger health benefits than policies focused on lower-emission vehicles.
Wright and Fulton[22]	Bogotá, Colombia	✓	✓				A, B			Various measures with an emphasis on mode shifting are likely to be the most cost-effective means to GHG emission reductions
Iglesias et al.[52]	London, UK	✓	✓	✓					C	More stringent emission standards would decrease emissions of NO_x, PM_{10}, and HC from a conventional vehicle fleet by 2020.
Yedla et al.[44]	Delhi, India; Mumbai, India	✓		✓	✓				C	There was a considerable influence of CO_2 mitigation on the dynamics of local pollutants in both cities. However, the percentage reduction in local pollution was higher than target CO_2 cutback. Local pollutants other than TSP and SO_x tend against CO_2 mitigation strategies in Delhi.

C CO_2, CO, CH_4, and HC; *N* NO_2, N_2O, and NO_x; *S* SO_x; *PM* $PM_{2.5}$, PM_{10}, black carbon, total particulates; *REG* regulatory approach; *ECO* economic incentives; *OTH* other; *A* circulation-restriction initiatives; *B* alternative initiatives; *C* technology/fuels

while "economic instrument" and "other" approaches have the potential to bring innovative solutions to urban air pollution.

The results combined articles that used either *qualitative*, *quantitative*, *or both methodologies*. *Qualitative methodologies* were considered in articles that used one or more of the following tools: interviews, surveys, case studies, literature review, inventories, or descriptive studies of environmental degradation. *Quantitative studies* were defined as articles that develop scenario constructions to measure the current or projected impacts of the policies studied. In this latter case, pollutant levels and emission estimates were measured to determine their respective health effects. Quantitative studies largely required the use of modeling and statistical analysis, co-benefit analysis, life cycle assessment, and risk assessment. Quantitative

TABLE 2 Post policy—accomplished results

Source	Geographic location	Pollutant					Policy			Primary findings
		C	N	S	PM	O3	REG	ECO	OTH	
Chong et al.[51]	Greater London, UK	✓	✓	✓	✓				C	Of the five technologies tested, the one with the greatest impact on reducing population exposure (about 83 %) to particular matter ($PM_{2.5}$) occurred with LB-CNG buses.
Vedrenne et al.[61]	Madrid, Spain	✓		✓		✓	B		C	Shifting from traditional diesel vehicles to ecological alternatives (CNG, LPG, and hybrid) have reduced impact associated with the vehicle use-phase, fuel refining, and fuel transportation, while it increases the share of the vehicle manufacturing stage.
Wadud and Khan[63]	Dhaka, Bangladesh	✓	✓						C	NG use for vehicle helps reduce air pollution but not the impacts of climate change mitigation.
Geng et al.[49]	Shenyang, China	✓	✓	✓	✓			B, C		CNG bus has the best overall economic and environmental performances, while diesel car is a choice for taxi. For more co-benefits in public transportation, an integrated effort is needed, including gradual phase-out of inefficient vehicles, green vehicle purchase, infrastructure improvement, and capacity-building.
Dirgahayani[38]	Yogyarta, Indonesia	✓	✓	✓	✓				C	•Intended benefit could solve local problem, whereas GHG emission reduction was perceived as co-benefit •Provides insights regarding obstacles and opportunities to advance environmental co-benefits.
Wang et al.[47]	Beijing and Chongqing, China	✓	✓				A, C			Current emissions standard in Beijing and nationwide may have limited impact on NO_x reduction, once they are ineffective on control technologies and lack compliance programs. It calls for a better fuel quality and a multi-pollutant control strategy.

TABLE 2 ***(continued)***

Source	Geographic location	Pollutant					Policy			Primary findings
		C	N	S	PM	O3	REG	ECO	OTH	
Worden et al.[3]	Beijing, China	✓					A			As compared to emission scenarios being considered for the Intergovernmental Panel on Climate Change, 5th Assessment Report (IPCC AR5), this result suggests that urban traffic controls on the Beijing Olympics scale could play a significant role in meeting target reductions for global CO_2 emissions.
Li and Crawford-Brown[66]	Bangkok Metropolitan Area, Thailand			✓			A			Inspection maintenance programs produce health benefits whose economic impacts considerably outweigh the expenditures on policy implementation.
Wang et al.[48]	Beijing, China	✓		✓			A, C			Emission control programs should include identification and removal of heavy emitters or improve their emissions. •BC and $PM_{2.5}$ emission factors of trucks registered in regions outside Beijing outnumber those of that capital, improving engine, and fuel standards alone is not sufficient to reduce traffic-related air pollution. •Lower emissions from Euro IV and CNG buses are effective in reducing overall vehicle emissions for pollutants studied. •Refined chasing method demonstrates a cost-effective approach to characterize the emissions from many on-road diesel vehicles.
Rayle et al.[77]	Mumbai, India Ahmedabad, India Surat, India	✓						A		Overall emissions increased under all circumstances. It was found that land use strategies to maintain high density, limit sprawl, and promote local destinations could moderate growth in travel distances.
Li[4]	Indian cities							B, C		Urban governance should account public transport

TABLE 2 ***(continued)***

Source	Geographic location	Pollutant C	N	S	PM	O3	Policy REG	ECO	OTH	Primary findings
										infrastructure quality and efficiency coupled with integrated land use/ transport planning as well as economic instruments to reconcile imperatives of economic and urban growth aspire to higher life quality, improvement in social welfare.
Labriet et al.[65]	Mexico City, Mexico Khon Khaen, Thailand Beijing, China; Bogota, Colombia	✓	✓		✓				C	Clean development mechanisms help reduce GHG and air pollution and measure accountability and all sustainable aspects.
Creutzig et al.[46]	Beijing, China	✓		✓				B		Road charge addresses congestion and has environmental benefits. Demand elasticity demonstrates synergies provided by joint demand and supply-side policies.
Reynolds et al.[48]	New Delhi, India	✓	✓	✓					C	The switch to CNG fueling in 2002 caused significant increase in CO_2 and CH_4 emissions and reduction in BC emissions for buses. BC reductions should be considered when addressing GHG reduction
Mazzi et al.[64]	UK cities	✓					C			It is suspected that CO_2 policies have contributed substantially to diesel growth, but impact has yet to be quantified, more stringent CO_2 emission standards would save lives.
Beevers et al.[67]	London, UK	✓	✓	✓				A, B		The expected increase in emissions from buses was offset by the introduction of particle traps to new/exiting bus fleet as well as of newer engines: •Reduction in CO_2 emissions (−19.5 %) apparently with little additional benefit from new vehicle technology •Evidence that the congestion charging schemes could assist in both UK government's air pollution target and those relating and

TABLE 2 ***(continued)***

Source	Geographic location	Pollutant					Policy			Primary findings
		C	N	S	PM	O3	REG	ECO	OTH	
										other international obligations.

C CO_2, CO, CH_4, and HC; *N* NO_2, N_2O, and NO_x; *S* SO_x; *PM* $PM_{2.5}$, PM_{10}, black carbon, total particulates; *REG* regulatory approach; *ECO* economic incentives; *OTH* other; *A* circulation-restriction initiatives; *B* alternative initiatives; *C* technology/fuels

and qualitative methodologies both use case studies but differ in their outcomes. A tendency from the selected articles was that qualitative studies tend to be used for policy support as opposed to quantitative studies that are more utilized to evaluate an existing policy.

What policy approaches are more associated with qualitative or quantitative methodologies? As shown in Fig. 4, the largest number of articles (nine) used quantitative methods and addressed a regulatory policy that primarily included technology, fuels, and circulation-restriction initiatives. Approaches combining qualitative and quantitative methods represented the second highest number of articles (six). In this case, alternative approaches to mitigating air pollution were studied, although the focus remained but on technology and fuels. In this category, alternative initiatives represented an important component of the research. This is evident in the number of articles evaluating alternative initiatives that used exclusively qualitative methodology and looked at other air management policy types. Few studies (two) used qualitative methodology to look at regulatory and economic initiatives, and both looked at policies that had a circulation-restriction motivation.

Data Interpretation

In terms of outcomes, articles that provided support to policy development usually delivered expected results and recommendations, as described in Table 1. In the case of Lagos, Nigeria, for example, the study offers an overview of the environmental degradation taking place and prioritizes local needs, while calling for measures to increase awareness and urging for policy intervention.[53] This article points out the risks of air pollution due to vehicular emission, waste burning, and industries, emphasizing the need for mitigation and adaptation measures. Importantly, this article brings in a social dimension as an essential and complementary tool for a successful policy via educational programs. Such social dimensions are also seen in a study in New Delhi, India, where improvements to air quality are linked not only to PM_{10} reductions—also found to reduce CO_2—but to greater health benefits for the poor.[40] Garg goes one step further, suggesting that since poor people are the first victims of air pollution, higher-income populations should take on the burden of the cost associated with air pollution as a way to promote health equity. Questions of responsibility are also emphasized in the cities of Bogotá, Colombia, Curitiba, Brazil, and Santiago, Chile, where transport can exacerbate inequalities. Indeed, a suggested way to cope with it would be for policy makers to incorporate health aspects into their agenda, particularly when addressing public transportation interventions.[45]

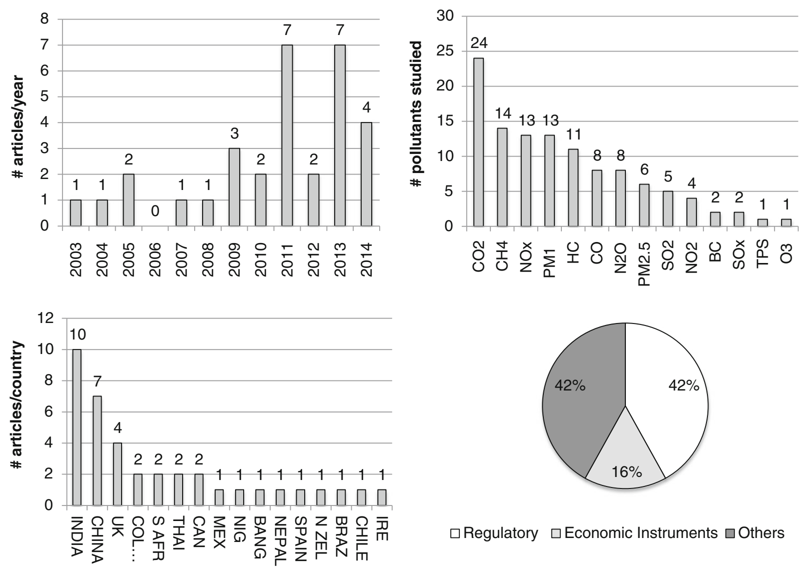

FIG. 3 Overall trends.

Garg, Becerra et al., and Wright and Fulton also highlight more efficient policies using an exploratory description of different challenges and initiatives based on a cross-study of cities, recommending the most beneficial measures. They identify mode shifting (referring here as the change in the type of way people use to get around) as the most cost-effective means of reducing GHG emissions.[22] Furthermore, restrictions on cars, integrated public transportation, rapid transit, and bike lanes appear to be efficient ways to promote and encourage active transportation. Active transportation and multi-modal modes of transport are mentioned in several studies as the best way to lower vehicle emissions, while also increasing physical activity and improving health,[43,45,54] by encouraging walking or the use of bicycles, as suggested in studies based in Auckland, New Zealand, London, UK, and New Delhi, India.

Another recurrent recommendation is to improve road conditions. In Auckland, New Zealand, the improvement of road conditions showed positive results in lowering emissions and encouraging more active transportation mobility, as measured by estimates in the reduction of travel time. The authors calculated what the effects on health would be if short car trips were substituted by cycling (about 5 % of trips) and found that such a change could reduce the number of injuries due to traffic accidents and lower the effects of vehicular emissions.[55] In Durban, South Africa, in addition to technology, road improvement interventions appeared to reduce time of travel and the efficiency of road freight transport by lowering GHG emissions.[56] Moreover, in Latin American cities, Becerra et al. urge for a greater inclusion of health considerations in transport policy design and point out that the number of cars is still increasing in the cities studied.

Articles that provide policy support and development tend to focus on identifying how to improve public transport networks in the city, prioritize its use by locals, and

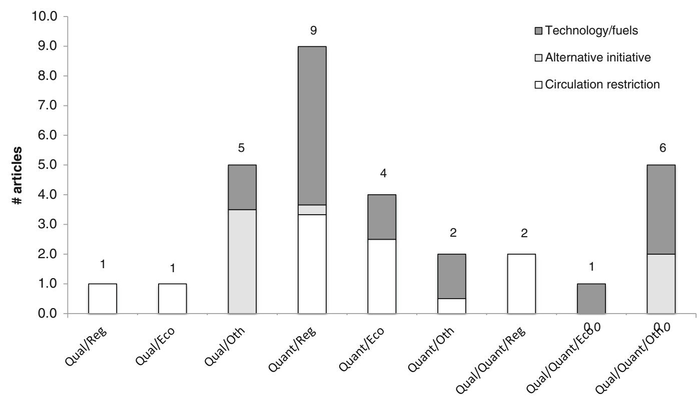

FIG. 4 Air pollution policy management. *QUAL* qualitative, *QUANT* quantitative, *REG* regulatory approach, *ECO* economic incentives, *OTH* other.

discourage the use of privately owned vehicles. The bus transit system in Bogotá, Colombia is cited twice as an example of an efficiently integrated system[23,45] that encourages use and significantly reduces CO_2 emissions. The idea of promoting transport policies is raised for New Delhi, where clean development mechanisms (CDM) and integrated policies are seen as having the greatest co-benefits.[39] However, data collection in Delhi is seen as a challenge for improving public transportation. In Durban, the lack of data is cited as a challenge to policy development. Aiming to overcome this challenge, tests were conducted using passive samplers, which were proven to be effective and affordable for pollution monitoring in most surrounding municipalities,[57] offering a low-cost potential solution for bridging the data gap and improving technology.

Lowering emissions is one of the major means of improving local air quality, in addition to being the most frequent approach to coping with vehicular pollution. This is being done in three main ways: technology and fuel improvement (electric vehicles, biofuels, and natural gas); restriction policies such as emission standards, mandatory vehicle inspections, and improvement of road conditions; and limitations on allowable travel distances, as in Durban and Auckland. Emission inventories seemed to be a departure point, as in Kathmandu, Nepal, where it was possible to construct different scenarios applying EURO emission standards.[58] The results were rather promising and supported the thesis that prioritizing vehicular policies could have an impact on both local air pollution and climate change. Indeed, if Kathmandu were to apply EURO III standards, in 20 years, toxic air pollutants would decrease by 44 % and climate-forcers by 31 %.[58] In London, a 2004 study also recognized the importance of strict emission standards and vehicle technology improvements, prior to t he implementation of vehicle congestion charge. The authors found that although emission standards were an important tool for reducing emissions, technology, in particular those that foster alternative fuels, was most successful at improving local air quality and reducing climate change by 2020.[52] In Delhi and Mumbai, India, energy efficiency was tested on vehicles using natural gas technology (compressed natural gas (CNG)), four-stroke wheelers, and battery-operated vehicles (BOV) for GHG and local air pollutant mitigation strategies.[44] Results demonstrated an important contribution to CO_2 mitigation among local air pollutants but noted challenges associated with the use of natural gas as a fuel, demonstrating the difficulties in finding the optimal vehicle mix to improve air quality and mitigate climate change.

Indeed, as seen in the Indian cities studied, lowering emissions in the policy development stage requires looking for and testing for the most efficient technologies for vehicles. In Toronto, Canada, fuel cell/plug-in hybrid electric vehicles (FCPHEVs) were found to achieve greater outcomes to pollutant reductions.[59] However, all of the tested alternative vehicle technologies, including hybrid electric vehicles (PHEVs), fuel cell vehicles (FCVs), and fuel cell/plug-in hybrid electric vehicles, had in common to be impact precursors of photochemical smog.[59] Interestingly, a study on the potential of electric vehicles in Dublin, Ireland showed that such technologies are beneficial for reducing traffic-related pollutants, but that the time required to change part of the taxi fleet could offset these benefits for climate change and air quality.[60] In London, five technologies were tested for their impact on $PM_{2.5}$ levels and percentage of population exposed, the most efficient being LB-CNG buses.

The choice of fuels is indeed an important tool for policy makers at the local level but also has been considered for contributing to global CO_2 target reductions. On the other hand, the London example showed that emission standards are essential for coping with local air pollution, but their health benefits can be reduced if they are not combined with vehicle technology improvements and alternative means of transportation.[43,52]

On a different level, post-policy studies offered the opportunity to emphasize beneficial and non-beneficial interventions by measuring their results and highlighting primary findings. As expected, a common concern in lowering emissions is the choice of fuels and technology. Out of 15 articles, five evaluated the use of CNG for vehicles to calculate their environmental impact and determine the best available "ecological alternatives," e.g., CNG, liquefied petroleum gas (LPG), or a hybrid.[61] For instance, in Madrid, Spain, a life cycle analysis of the introduction of "ecological alternative fuels" on a diesel taxi fleet concluded that this choice of fuels had a positive environmental impact overall but not at the manufacturing stage. Indeed, another major contributor to the effects of fuels was related to vehicle speed rather than choice of fuel.[61] In Chinese cities, CNG was found to be a better option for buses, while diesel was better for taxis.[47,62] A study carried out in New Delhi correlated the 2002 switch to CNG fueling with an increase in CO_2 and CH_4,[42] but also with a reduction in black carbon (BC), an important pollutant for GHG reduction. A similar result was found in Dhaka, Bangladesh, where CNG helped reduce local air pollution but had little effect towards climate change mitigation.[63] In UK cities, a study found that CO_2 policies led to diesel growth and higher emissions of particulate matter but cautioned that there was a need for further research to understand such impacts.[64] In addition, post-policy articles combined studies that were mostly located in Asia, with the exception of two European, London and Madrid, and two Latin American cities, Bogotá and Mexico.

Moreover, with regard to the transport sector, the most efficient policies were those that had developed and integrated into their strategy approaches that considered CDM to target emission reductions. There is an emphasis on encouraging more co-benefit analysis as a way to improve transport policy overall,[38,41,49,65] including land use and transport planning. In Shenyang, China, results showed the necessity to include bus fleet renovation in transport policies, green vehicle purchase, and improved infrastructure to maximize benefits. In a cross-city study, Labriet concluded that CDM was not only beneficial to GHG and air pollution mitigation but went one step further by identifying it as a tool to measure accountability and policy sustainability.[65]

Other articles evaluated restriction policies, particularly in measuring the impacts of current emission standards. In Beijing, studies found that current emission standards had little effect on reducing NO_x, demonstrating the lack of efficient control technologies and compliance to programs as a limitation to the success of these standards,[47] and calling for better-quality fuels and multi-pollutant reduction strategy. According to Wang, the benefits of emission standards were also offset by the number of trucks circulating around Beijing[48] that constituted a high source of BC and $PM_{2.5}$, suggesting that measures that focus only on standards and improving engines are not sufficient. However, in Bangkok, Thailand, the Inspection Maintenance Program for vehicles was a successful restriction policy,[66] where health benefits were greater than the costs of implementation. Another measure with positive effects was road charges, which lowered congestion. In London, the anti-congestion charging scheme was an important tool to lower NO_x and PM_{10} and enabled the government to reach its pollution reduction and climate change targets.[67] Creutzig also found benefits from road charges imposed in Beijing and highlighted the importance of developing policies that look at the supply and demand aspects of these initiatives.[46] Traffic control in Beijing was essential during the Olympics in helping the city meet its global target of CO_2 emission reduction[3] and also encouraged the use of satellite-based technology for collecting data. During the Olympics, satellites were very helpful in identifying reductions and increases in pollutant levels.

DISCUSSION

The contribution of vehicles to air quality and climate change mitigation has been demonstrated by academic studies, in particular in the transport sector. However, there is potential for further research, in particular to identify the most beneficial policies that point to the right fuel and right technology for lowering emissions. In addition, few articles address the issue of privately owned vehicles, but those that do implicitly note that implemented polices are offset by the growing number of privately owned vehicles. Furthermore, replacement of the old vehicle fleet constitutes another important element to be incorporated into policymaking, most notably in cities of the developed world. Interestingly, urban policies tend to incorporate outcomes not only for air quality but also for climate change mitigation. The reviewed articles reflect the many challenges to developing and implementing policies that with a positive impact on both air quality and climate change mitigation. However, in the pre-policy table, efforts seem to be concentrated on offering other approaches while focusing on fuels and technology (C). Indeed, in the pre-policy stage, few articles support the circulation-restriction initiatives (A) while acknowledging that the speed of vehicles is one of the main components in reducing emissions.

In the post-policy section, policy approaches are evenly distributed between restriction of circulation initiatives and fuels and technology. Future studies should be encouraged to evaluate the benefits of alternative initiatives in urban centers as opposed to focusing on emissions. Studies have demonstrated that multi-modal modes of transportation have the greatest benefit, as does the integration of clean development mechanisms. As seen in Madrid, Spain, it is essential to look at the effects of a policy from its early stages to evaluate its full impact. CNG as a fuel, for example, showed mixed results as an offsetting of climate change mitigation strategies but, combined with the implementation of "ecological fuels," was shown to be an important way to reduce emissions. Initiatives such as the maintenance program in Bangkok, Thailand or the congestion charge program in London have had overall positive impacts, in particular in terms of health. Reduced vehicle emissions can also be an ally to climate change mitigation: the study on the effects of the restricted circulation of vehicles during the Beijing Olympic games proved how the absence of vehicles managed to lower CO_2 emissions.

In Tables 1 and 2 (pre- and post-policies), only three articles addressed equity and the basis of the right to clean air. As the issue of "clean air for all as a human right" gains traction,[40,68–70] it will be crucial to integrate a social dimension to local air quality and climate change mitigation policies. In Indian cities, Li and Garg call for the importance of strong policy instruments that include concepts of social welfare, quality of life, and equity.[40,41] O'Neill et al. have stressed the importance of applying the social determinants of health to measure and reduce health disparities,[71,72] strengthening Becerra's suggestion to expand the inclusion of health into the transport policy agenda. This issue raises the question of scale, a limitation found in this study. Indeed, the chosen focus on the level of the city might have resulted in missing potentially important nationwide policies with an impact on air quality and on climate change.

Urban planning and governance are also important factors in developing successful policies. For instance, urban planning has been discussed as a crucial issue and an important potential solution for improving transport infrastructure. Urban governance was also reported as a challenge for efficient policymaking in Indian and Chinese cities. As urban environmental problems are increasingly linked at the global level, challenges concerning governance reinforce the problem of responsibility[73]: who will bear the burden of reinforcing and monitoring these policies? Although beyond the scope of the present study, the purpose of such issues is fundamental to the well functioning of air policies. As cities become experimental hubs of climate change initiatives,[7] challenges also arise as to how this knowledge will be disseminated and how to improve data access. In this sense, academics have an important role to play.

CONCLUSION

This study has addressed the importance of incorporating air pollution measurement while developing climate change control experiments in cities. It highlighted what kinds of policies are being developed around the world and what kinds of primary outcomes have been documented. While each city must be understood in its particular social and economic timeframe, and we recognize that certain policies implemented in one place might not be the most suitable elsewhere, understanding which energy choices have been made for mobile sources of air pollution in certain cities can be critical in showing that addressing air pollution is an ally of climate change mitigation, reducing local air pollution does not harm climate change mitigation, and ignoring climate change mitigation pollutants can harm local air quality.[2,20,40]

Local air pollution and global climate change policies should work together to maximize the benefits of lowering pollution levels and mitigating climate change.

Cross-city studies are fundamental, and there is a gap in scholarship studying southern-hemisphere cities.[74] Given the lack of available data in certain parts of the world, studying the efficacy of successful air pollution policies implemented elsewhere should be seen as an important tool for better comprehending successful initiatives and their benefits. Ostrom believed that local initiatives are indeed the ones that have a greater global impact.[75] In this study, the local examples highlighted show a growing concern of cities to fight air pollution and tackle climate change at the local level.

This review demonstrates that local air pollution policies are not only beneficial to cities but also important for mitigating and adapting to global climate change. In addition, we see a need to further study policies that address private vehicle emissions and the correlation between traffic patterns and air pollution. This study suggests that more in-depth cross-city studies have the potential to highlight best practices, in both local and global terms. Finally, this research calls for the inclusion of a more human rights-based approach, which aims to insure the right to "clean air for all people" and to reduce factors that exacerbate climate change.

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4.2 Controlling Air Pollution in São Paulo, New York City and Paris: a background

4.2.1 Historical background of the legal framework surrounding air quality and air pollution control policies

Improving air quality has been a long-time concern for both cities and the international community. One of the first and most important actions to regulate air quality was initiated in the United States, with the adoption of the Clean Air Act in 1963, soon followed by Europe which, in 1970 established its first standards for vehicles' exhaust emissions. With better evidence that air pollution travels, the international community created one of the most important agreements: the Convention on Long-Range Transboundary Air Pollution (LRTAP), which was hosted by the United Nations Economic Commission for Europe (UNECE) and adopted in 1979. The LRTAP is of tremendous significance for understanding the legal air quality framework, as it formalized the fact that the sources of air pollution might be very distant from where the pollution itself ends up, and that it may even cross national boundaries. This fact implies the need for both the global and local communities to address the issue. The Convention was signed by 51 member countries and became the genesis of the main protocols that guide many local regulations and policies.

The 1980's and 1990's witnessed a series of UN Protocols that helped set the global awareness to reduce emissions of pollutants, seen in important policies such as the 1985 Helsinki Protocol on the reduction of sulfur and VOCs; the 1987 Montreal Protocol on substances that depleted the ozone layer; the 1988 Sofia Protocol on the control of emissions of nitrogen oxides or their transboundary fluxes; the 1991 Geneva Protocol on the control of emissions of volatile organic compounds or their transboundary fluxes; the 1998 Aarhus Protocol on persistent organic pollutants; and the Gothenburg Protocol in 1998 to abate acidification, eutrophication and ground-level ozone. It is only in 1997 that the Kyoto Protocol established the UN framework convention on climate change currently being outdated by Climate accords in Paris to regulate greenhouse gases.

In Europe, the revision and development of emission standards came in the early 1990's, implementing different standards for heavy and light duty vehicles, as seen in Figure 2. However, it is only in 1996 that the European Commission adopted the 96/62/EC directive on ambient air quality that was followed by what is most commonly known as the "four daughters directive" (legislation European commission) and sets the following limits and values:

- First daughter: council directive 99/30/EC limiting values for sulfur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air
- Second daughter: directive 2000/69/EC limiting values for benzene and carbon monoxide
- Third daughter: directive 2002/3/ EC related to ambient air ozone
- Fourth daughter: directive 2004/107/EC about arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air.

These directives, in turn, have guided French regulations and led to the 1996 Federal Law on rational use of air and energy (LAURE), followed by the 1998 Federal Law on conditions for air pollution alert procedure. The LAURE law also established the conditions of air quality surveillance and information that gave rise to the creation of local air quality monitoring agencies, such as Airparif for the Île de France region and Paris. Furthermore, it is the LAURE law that has fostered several French plans on air quality and mobility, as described in the program section of this study (AIRPARIF, 2015).

Another major European directive related to air quality is the EU Directive of 2001 on national emissions ceilings, and the EU Directive on ambient air quality standards, that generated the Clean Air for Europe Program in 2010. The 2008 directive was done after the WHO air quality guideline reviews of 2005. Moreover, two major United Nations global goals are worth citing in this context: the UN Millennium Development Goals and the recent UN Sustainable Development Goals, as they bring to countries' agenda the need to address poverty and environmental quality, such as clean air, particularly in cities.

This said, the French regulations are bound to the European legislation. The different EURO standards applied to vehicle emissions from the 2004 and 2008 directives have a direct impact on the French regulations that are using the EURO VI standards since 2014. Other important French air-related laws are the Grenelle I and II on the federal environmental engagement of 2009 and 2010. The Grenelle laws are at the origin of several federal and regional plans on environmental health, climate and energy to also be addressed in more details in the program sections.

More recently, the alert and health info during air pollution episodes were reviewed and adopted in 2014, motivated by Paris' critical air pollution episodes of the previous two years. Furthermore, the Energy Transition Law of 2015 is enabling France to focus on cleaner sources of energy for vehicles and has generated several new programs such as circulation restriction of Heavy Duty Vehicles (2015), air quality certificate for vehicles (2015) and the revision of the Air Protection Plan – PPA (*Plan de Protection de l'Atmosphère*). France also, as compared to the United States and Brazil, started to work very early on transport laws such as the Domestic Transport Act of 1982, that legalized the right to low-cost public transport and encouraged local urban transport plans.

The United States, as previously mentioned, was the first country out of the three to regulate the air with the Clean Air Act in 1963 and set National Ambient Air Quality Standards in 1970. The 1977 and 1990 amendments of the Clean Air Act provided two important measures for air quality: the New Source Review, for industries, and the prohibition of using lead in gasoline for motor vehicles. The United States then concentrated its regulatory efforts on energy and emission improvements from vehicle exhausts via the Energy Policy Act for diesel emission reductions of 2005, the Energy Independence and Security Act and the Moving Ahead for Progress in the 21st Century Act. It was only in 1998 and then in 2005 that the Transportation Equity Act for the 21st Century addressed transport infrastructure as one of the tools for improving the environment and controlling air quality.

Brazil's overall legal settings follow the same international trends as France and the United States. The country established its federal law on control and prevention of environmental pollution in 1976, implemented in the state of São Paulo the same year under the Law 997 of May 31, that started with the industrial pollution control program. Ribeiro et al. describe the standards established according to the US Environmental Protection Agency (RIBEIRO et al., 2005). It is only in 1990 that the Brazilian Government implemented the PRONAR (Federal Air Quality Control Program) that established ambient pollution standards still currently applied (MMA). In the case of the State of São Paulo, in 2013, new standards were established by state decree 59113/2013 that set stages, with intermediary objectives and a final goal (to meet WHO air quality guidelines) to improve air quality (CETESB). These different objectives are introduced in three steps. Currently, São Paulo applies the MI1 standards (intermediary goal 1) with no information on when step two (MI2) will be introduced.

In 1986, Brazil started controlling mobile sources of air pollution. This regulation, also called PROCONVE *(Programa de Controle de Poluição do Ar por Veículos Automotores* or Program for the Control of Air Pollution from auto vehicles*)*, set emission standards for the Otto vehicles[1] and diesel vehicles[2]. The PROCONVE was implemented in several stages as mentioned in Figure 2 and played a major role in reducing vehicular emissions at the same time that it brought some major advancements in car technology to Brazil. For instance, the PROCONVE stimulated the introduction of the catalytic converter and electronic injection, which permitted the use of ethanol in Otto vehicles and the introduction of Flex cars. In its second stage it also introduced the control of vehicle noise while stages 4 and 5 focused on reducing HC and NO_x via technology improvement. Another important advancement in the control of vehicular emissions was the Federal Law 418 of 2009 that set the path for the elaboration of the PCPV (Plans of vehicular pollution control) and the development of local Inspection and Maintenance Programs, which, in the case of the Municipality of São Paulo, was suspended in 2013.

In 2002, the PROMOT (Program for Air Pollution Control for motorcycles and similar vehicles) was introduced following EURO vehicle standards. Similar to the PROCONVE, the PROMOT experienced several adjustments to its initial regulation, instigating revision of the emission standards as demonstrated in Figure 2. Currently, the PROMOT has established emission standards similar to the EURO 4.

Controlling vehicular emission in Brazil also implies understanding the importance of the energy matrix, as the introduction of the Pro-Alcohol Program in 1975 that came as a way to cope with the impacts of the world petroleum crisis. Sugar cane ethanol for Otto vehicles entered the fuel market and expanded over the years. In 2005, the law 11.097 officially introduced biodiesel in Brazil, followed by two major ANP (National Petroleum Agency) regulations that reduced the sulfur content of diesel in 2009 and 2013, to reach 50 ppm (see Annex 2 for an overview of the evolution of legislation on Sulfur content). At first, the 50 ppm sulfur content in diesel was restricted to the bus fleet but was progressively introduced into gas stations. In 2013 the content of sulfur for diesel 50 ppm stopped and was reduced to 10 ppm, a measure introduced in the most recent PRONCOVE stage. Since 2014, the sulfur content of gasoline vehicles has remained at 50 ppm.

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[1] Defined by CETESB as "internal combustion engine which employs the thermodynamic cycle of the Otto type. The main feature of this engine is the spark plug that causes combustion. It is typically used in automobiles, motorcycles and some commercial vehicles using gasoline C, hydrated ethanol or CNG as fuel. Also used in flex fuel vehicles". In *Relatório de emissões veiculares* (CETESB, 2014, p.25)

[2] "Internal combustion engine whose fuel burning occurs due to temperature rise caused by compression of the air. This engine uses diesel as fuel and has no spark plug. It is usually used in trucks, buses and partly from commercial vehicles". In *Relatório de emissões veiculares* (CETESB, 2014, p.25)

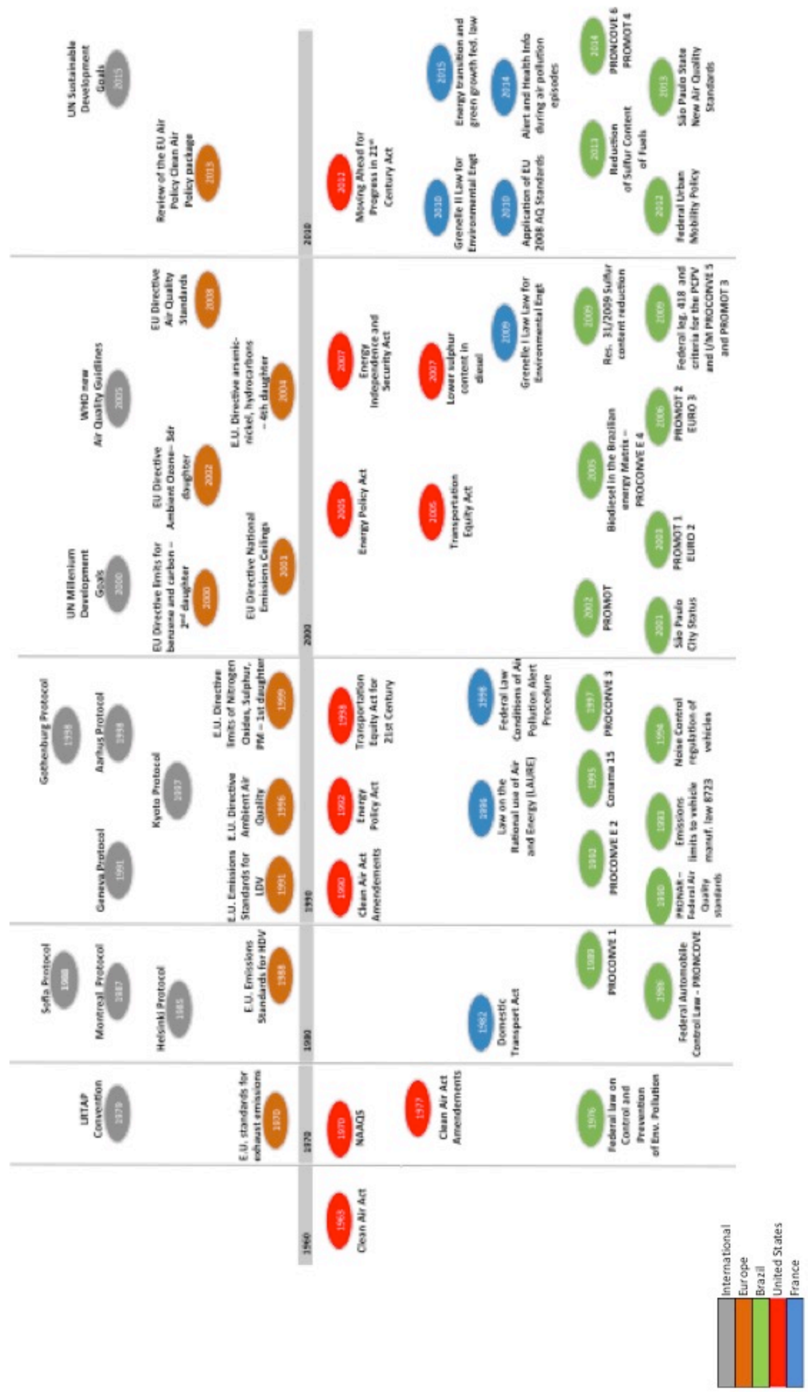


Figure 2 – Overview of the legal air quality framework: a global, regional and federal background of Brazil, United States and France – 1960 / 2015

Elaborated by the AD Slovic and SL Oliver

Sources: EU Commission, EPA, Brazilian MMA, WHO, UNECE, French Environmental Ministry, Legifrance.gouv

4.2.2 Current air quality parameters

This section proposes an overview of air quality limits and provides a historical background of regulations that have helped construct control parameters. In a second part, it delivers air pollution evolution over the years in the three cities.

An important component of air quality is the way it is regulated. At the global level, the World Health Organization sets the world guidelines, followed by regional and local level standards. In the case of the three studied cities, Table 5 relates the applied standards currently used for PM_{10}, $PM_{2.5}$, NO_2 and O_3. Some points can be underlined from this data:

- The WHO suggested guidelines are stricter than the ones adopted locally, with the exception of NO_2 that has similar restrictive values. Ozone, for the three cities, continues having levels above the 2005 WHO guidelines of 100 ug/m^3. New York has a more tolerant standard for O_3 than the other two cities;

- $PM_{2.5}$ is a real challenge for cities like Paris, because under the 2008 EU directive, the city must reach a reduction of this standard to 20 ug/m$_3$ per year by 2020 (EUROPEAN ENVIRONMENT COMMISSION, 2015). This said, São Paulo and New York have already adopted annual average standards stricter than the one currently applied in Paris; but the 24h average in São Paulo allows higher levels.

- São Paulo presents an interesting case because although it has revised its air quality standards as part of the 2013 São Paulo State new directive (CETESB, 2013), it continues having standards that are less strict than those for Paris and New York. This said, CETESB has developed short- and long-term air quality goals (with no clear prevision on dates). The State of São Paulo has developed four different metrics aiming to meet WHO guidelines in the long-term. The metrics currently used fall into category MI1 (CETESB), as reported in Table 5 below.

- New York has stricter standards for NO_2.

Table 4 – Global air quality guidelines and local currently applied air quality standards of studies cities

POLLUTANT	Sample time (average)	WHO (ug/m3)	EPA (ug/m3)	E.U. (ug/m3)	Brazilian MMA* (ug/m3)	São Paulo (ug/m3)	New York City (ug/m3)	Paris (ug/m3)
PM10	24 h	50 - not to exceed more than 3 days/ year	150 - not to be exceeded more than once per year on average over 3 years	50 - not to exceed more than 35 days/ year	150 - not to exceed more than once/ year	120	150	50 - not to exceed more than 35 days/ year
	1 year	20 - not to exceed more than 3 days/ year		40	50	40		40
PM2.5	24 h	25	35 - 98th percentile, averaged over 3 years			60	35	n/a
	1 year	10	15 - annual mean, averaged over 3 years	25*		20	15	25
NO2	1 h	200	100 - 98th percentile of 1-hour daily maximum concentrations, averaged over 3 years	200 - not to exceed more than 18 hours/year	320	260	100	200 - not to exceed more than 18 hours/year
	1 year	40	53	40	100	60	53	40
O3	8 h	100	158	120 - not exceed more than 25 days average /year over 3 years	160 not to exceed more than once a year	140	158	120 - not exceed more than 25 days average /year over 3 years
SO2	min	500 - 10 min mean						
	1 hour		(Primary) 153 - 99th percentile of 1-hour daily maximum concentrations, averaged over 3 year - (Secondary) **3h** - 1.02 - not to be exceeded more than once per year	350 - not to exceed more than 24/ year			(Primary) 153 - 99th percentile of 1-hour daily maximum concentrations, averaged over 3 year - (Secondary) **3h** - 1.02 - not to be exceeded more than once per year	350 - not to exceed more than 24/ year
	1 day	20		125 not to exceed more than 3 days/ year	(Primary) 365 not to exceed more than once a year - (Secondary) 100 not to exceed more than once a year	60		125 not to exceed more than 3 days/ year
	1 year				(Primary) 80 - (Secondary) 40	40		

Elaborated by AD Slovic
Source: WHO, EPA (NAAQS), EU, Airparif, CETESB, MMA

* For $PM_{2.5}$ in Europe, phase 2 will mean that the annual mean will drop to 20 in 2020 –

4.3 Air Pollution trends over the last fourteen years in São Paulo, New York City and Paris

4.3.1 Major sources of air pollution in São Paulo, New York City and Paris

In São Paulo, according to CETESB, the major sources of air pollution in 2000 included vehicles, industries and waste burning. In 2014, industries and waste burning were no longer a major source of air pollution while vehicles continue being the main challenge. In New York City, according to the NYC DEC, fossil fuel burning from oil boilers (emitted from buildings), water boilers, industrial processes, building and construction were, in 2008, the main sources of air pollution. In 2012, NYS imposed a reduction of sulfur content in oil, which produced direct impact on reducing the contribution of boilers in air pollution (NYC DEC, 2014). In Paris, the sources are similar to the ones in New York City.

4.3.2 PM_{10} concentration levels in São Paulo, New York City and Paris: 2000/2014

Particulate matter (PM) consists of solid particles or liquid droplets that are either released directly from specific sources such as vehicle emissions or are formed in complex reactions in the atmosphere. These particles usually come in two size ranges: less than 2.5 um ($PM_{2.5}$) or from 2.5 to 10 um (PM_{10}). The former, $PM_{2.5}$, is generally produced in emissions from combustion engines, whereas PM_{10} is produced in mechanical processes such as construction and road-dust suspension from wind (AIRNOW, 2015). The major chemical components of PMs are sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water, and the particles that have the largest impact on health are those that measure ≤ 10 ug/m^3, since they can penetrate and lodge deep inside the lungs (WHO, 2005). Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases, as well as lung cancer (WHO, 2014). Typically, measurements are reported as the average concentration of particles per volume (m^3) of air, such as mean of ug/m^3.

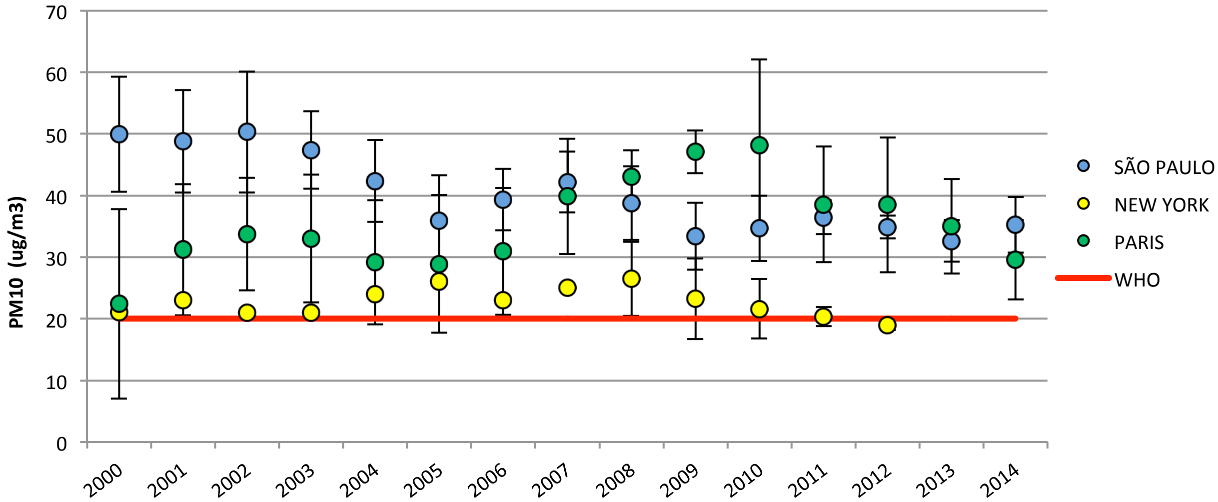
In an analysis of PM_{10} levels during the period 2000/2014, Graph 5 shows clearly that the three chosen cities struggle throughout the year to maintain their levels below the WHO recommended levels of 20ug/m^3. However, of the three cities, New York has maintained a consistent level of around 20 ug/m^3 with a significant decrease each year beginning in 2008. In the case of New York City, data was not available subsequent to 2012.

Paris and São Paulo present quite different trends, particularly between the years 2005 and 2011. In the case of São Paulo, the city's levels in 2000 were the highest as compared with New York and Paris, with an average of 50 ug/m^3 unchanged from 2000 to 2003. Following 2003 however, a steady decrease every year of roughly 10 ug/m^3/year is observed, having ended after two years, in 2005, when levels reached a minimum of roughly 35 ug/m^3.

In this same period, Paris appeared to show a steady increase in its levels of PM_{10}, beginning with 20 ug/m^3 in 2000 and raising sharply to 35 ug/m^3 in 2002 and 2003 to see a decrease between 2004 and 2006. During the years of 2006 to 2010, Paris presented a sharp increase in emissions again, but it is in 2009 that a tight dispersion of data suggests that levels of PM_{10} in Paris reached historically high levels. The year 2010 shows an opposite situation from 2009 levels, where despite another increase, the spread out of the data are the biggest out of all the years, suggesting a strong variation of the monthly values for that year. From 2010 on, emissions in Paris maintained a consistent decrease once again of roughly 5 ug/m^3/year, culminating in a return to 2001 levels of 30 ug/m^3. However, it is important to highlight that the standard deviation after 2010 continued being spread out, which suggests that the years after 2010 persisted in encountering a strong variation on the values of monthly emission levels.

São Paulo's trends seem to follow contrary to those of Paris between the years 2000 to 2005, when they begin at roughly 50 ug/m^3 with a significant spread of the monthly values and a steady decrease of 5 ug/m^3 from 2002 to 2005. Following 2005, a slight increase from 35 to 40 ug/m^3 is seen, with a subsequent decrease to 30 ug/m^3 again in 2009. Data from 2009 suggest essentially a stable level of just over 30 ug/m^3 until 2014. Overall it is clear that São Paulo and Paris faced the largest challenges maintaining their levels low, aiming to meet WHO air quality guidelines, whereas New York City kept levels close to WHO recommendations.

Graph 5 – PM_{10} yearly average concentrations – São Paulo, New York City and Paris: 2000 / 2014



n stations	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
SAO PAULO	14	10	10	13	11	11	9	11	12	12	10	9	10	13	12
NEW YORK	2	2	1	1	1	1	1	2	4	4	5	3	4	0	0
PARIS	5	5	5	5	5	5	4	4	2	2	4	5	8	7	7

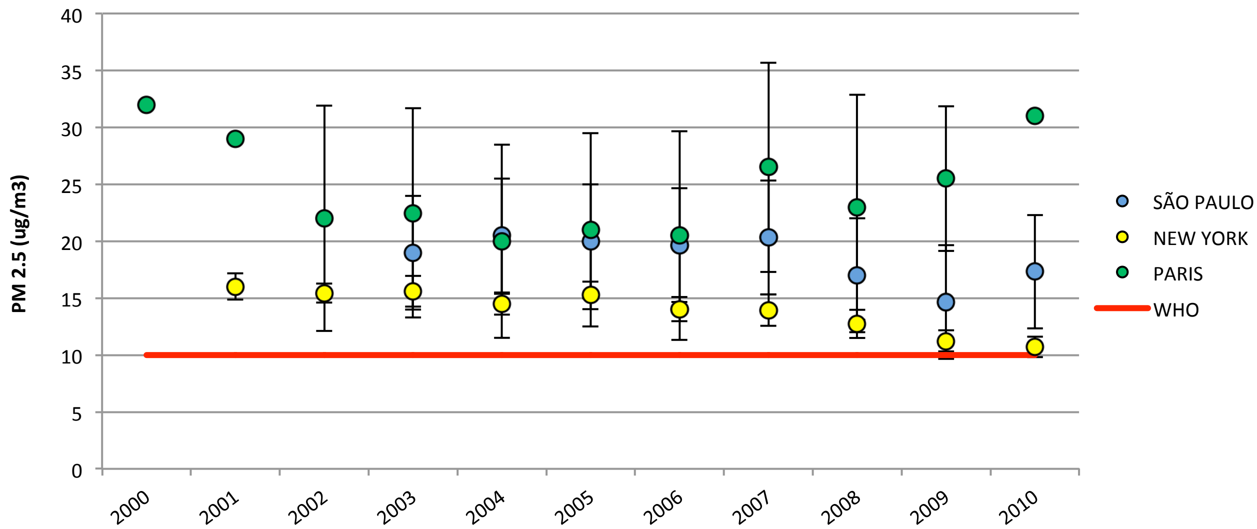
Elaborated by AD Slovic.
Source: CETESB, Airparif, NYSDEC Bureau of Air Quality and EPA

4.3.3 $PM_{2.5}$ concentration levels in São Paulo, New York City and Paris: 2003/2014

The data displayed for $PM_{2.5}$ are shown in two separate graphs: Graph 6 reflects data collected from manual stations for the city of São Paulo (2003-2010) and Graph 7 from automatic stations for the three cities (2011-2014). A similar trend is perceived with PM_{10}, where New York tends to have the lowest levels of pollution, closest to the WHO recommended levels of 15 ug/m^3. Again, Paris shows a rather stable level of roughly 20 ug/m^3 from year 2003 to 2008, but then there is a sharp increase in emissions up until 2011, when they peak at over 30 ug/m^3. This peak is simultaneous with the one seen for PM_{10} with a wide spread of the monthly average values for the years of 2007, 2008 and 2009. Again, subsequent to 2011 we observe a return to more historical levels of $PM_{2.5}$ until 2014, around 20 ug/m^3 but in which the amount of variation of the data are nonexistent.

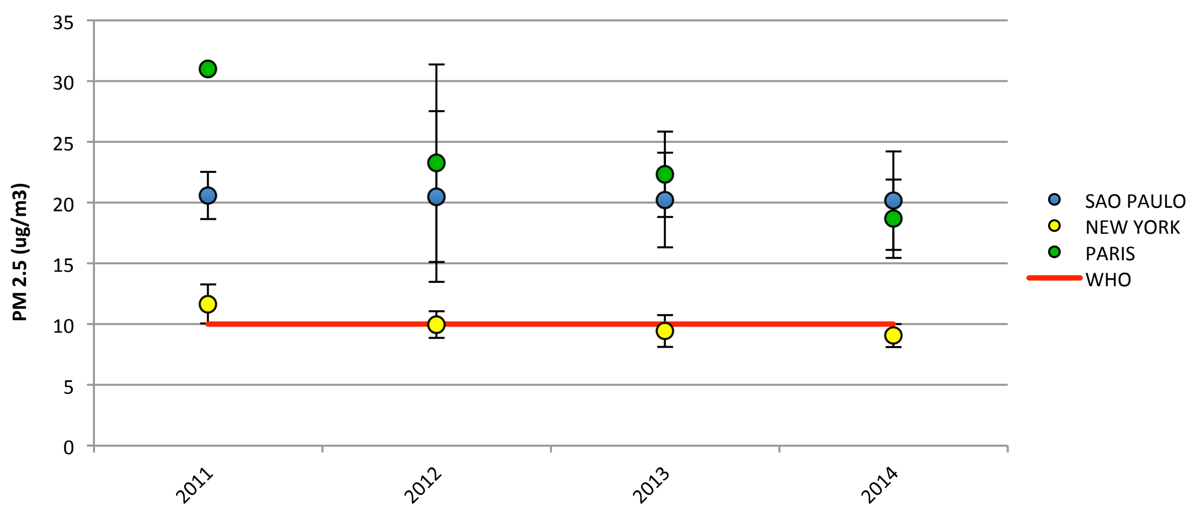
São Paulo follows a relatively stable trend of 20 ug/m^3 with slight improvement in 2008 and 2009, also seen in PM_{10}. However, after 2010 two trends can be seen, a slight increase in the concentration levels but also a stabilization of the annual mean.

Graph 6 – $PM_{2.5}$ yearly average concentration – São Paulo, New York City and Paris: 2003 / 2010



* The $PM_{2.5}$ information for Sao Paulo from 2003 to 2010 was manually collected data
Elaborated by AD Slovic.
Source: CETESB, AIRPARIF, NYSDEC Bureau of Air Quality and EPA

Graph 7 – $PM_{2.5}$ yearly average concentration – São Paulo, New York City and Paris: 2011 / 2014



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
# stations															
SAO PAULO	0	0	0	3	2	2	3	3	3	3	4	5	6	5	6
NEW YORK	0	12	13	12	12	11	12	13	10	9	11	9	7	9	9
PARIS	1	1	2	2	2	2	2	2	2	2	1	1	2	3	3

Elaborated by AD Slovic
Source: CETESB, AIRPARIF, NYSDEC Bureau of Air Quality

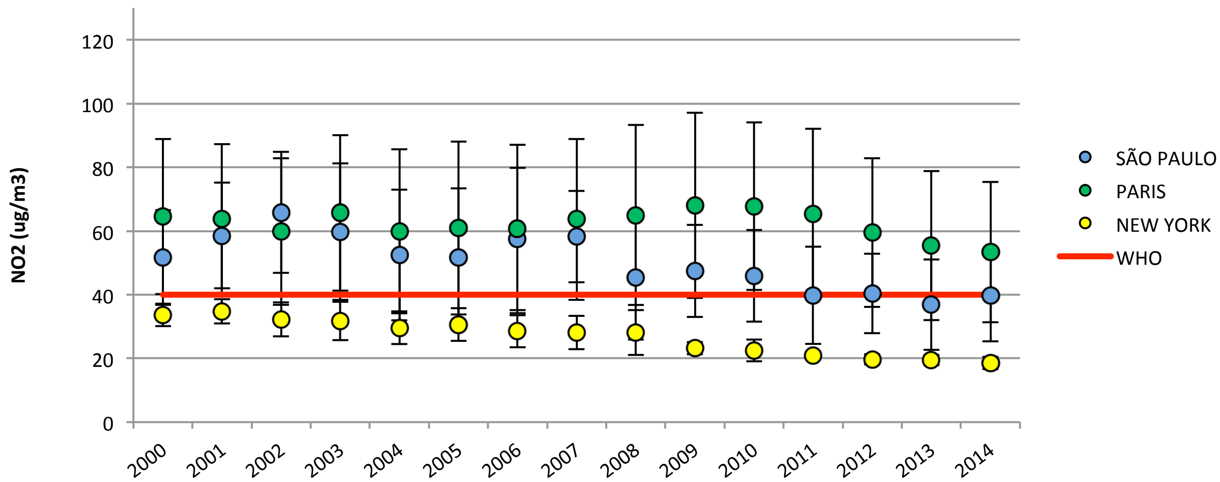
4.3.4 NO_2 concentration levels in São Paulo, New York City and Paris: 2000 / 2014

The nitrous oxides (NO_x) are a family of molecules formed between the inert atmospheric gas nitrogen (N_2) and oxygen (O_2) under high heat and pressure. This family consists of seven compounds that can be formed, with the main product being nitrous oxide (NO_2), of which over 50% is produced in typical combustion engines. NO_2 is expressive air pollution by itself, as well as in the context of the atmosphere, where it readily combines with water droplets to form acid rain in the form of nitric acid (HNO_3). Acid rain, for its part, can cause significant damage to lakes and rivers by both reducing their pH and adding inorganic nitrogen to the water, causing eutrophication. In addition, NO_2 may be produced from the reaction of NO with O_2, which may result in the production of ozone (O_3) in a photo-catalyzed reaction (U.S. ENVIRONMENTAL PROTECTION AGENCY, 1999). As a pollutant and health risk, NO_2 has been associated with consequential effects on respiratory capacity such as inflammation of the lungs and asthma, with particular impact on children and the elderly.

The trends observed in Graph 8 for NO_2 follow once again similar trend as in the two previous data sets, those of $PM_{2.5}$ and PM_{10}, wherein a peak of emissions for Paris in 2009 and 2010 is seen. In the case of New York, there appear to be two phases to the data, where the levels remain stable from 2000 to 2008 at 30 ug/m^3, this time below the WHO recommended maximum levels of 40 ug/m^3, and a subsequent phase of roughly 20 ug/m^3 from 2009 onwards. New York seems to have been able to significantly reduce its NO_2 emissions following 2008.

Regarding São Paulo and Paris, the two cities seem to follow a parallel trend of a general reduction of levels from 2000 to 2005, although the broad spread of the data do not allow for a statistically relevant difference between the two cities. After 2006, Paris seems to have followed a worsening trend until 2009 and then begun a steady reduction from a peak of 70 ug/m^3 to a low of 50 ug/m^3 in 2014. São Paulo also appears to show two trends, with levels close to 60 ug/m^3 until 2007, with a subsequent reduction in 2008 closer to 45 ug/m^3. Again, this trend is seen reflected in the previous graphs.

Graph 8 – NO_2 yearly average concentration – São Paulo, New York City and Paris: 2000 / 2014



n. stations	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
SAO PAULO	6	7	5	4	5	5	6	5	7	7	7	7	8	9	10
NEW YORK	5	4	3	3	3	3	3	3	3	2	2	1	2	2	2
PARIS	9	9	9	9	9	9	9	12	10	10	12	13	17	13	13

Elaborated by AD Slovic
Source: CETESB, Airparif, NYS DEC Bureau of Air Quality

4.3.5 O_3 trends in São Paulo, New York City and Paris: 2006 / 2014

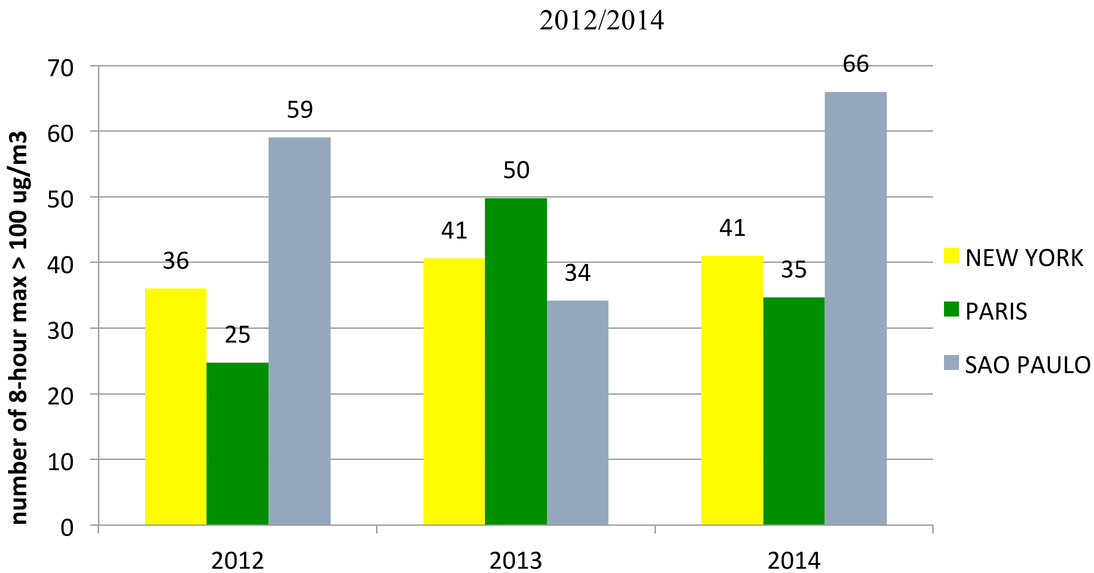
Ozone (O_3) is a secondary pollutant that is found both in nature and as a result of human activity. In the upper atmosphere or stratosphere (9-45 kilometers above the surface) ozone plays a critical role, absorbing a large percentage of ultraviolet rays that are emitted by the sun, acting as a filter. This "ozone layer" is critical for survival at Earth's surface, and has been the subject of countless studies over the last 30 years, as several man-made compounds were shown to deplete this stratospheric ozone (such as chlorofluorocarbons), putting life at the surface in significant risk.

Ground-level ozone is a result of man-made emissions, formed almost exclusively by the reaction of volatile organic compounds (VOCs) with nitrous oxides (NO_x), themselves man-made industrial and vehicular emissions. While ozone in the stratosphere has a beneficial impact on life at the surface, ground-level (tropospheric) ozone is very harmful. Ground-level ozone is the principal component of haze or smog and, due to its highly reactive nature, can cause severe respiratory problems independently from other pollutants. Short-term studies have shown respiratory effects such as lung inflammation and permeability, respiratory symptoms and increased use of medication in especially vulnerable populations such as children and the elderly. (WHO, 2008)

Ozone is typically reported either in parts per million (ppm), parts per billion (ppb) or ug/m^3. For the purposes of this document, all values were converted to ug/m^3. Ozone is also often reported as an 8-hour average and maximum value, wherein a running average of hourly data is calculated every 8 and either averaged or from which the maximum value is extracted. In addition, frequently the number of times that this 8-hour maximum value exceeds a reference standard (ex. 100 ug/m^3 for the WHO) is reported. For the purposes of this theses, both the average values of the hourly data for all three cities is shown, as is the number of days that each city's ozone exceeded the WHO standard (100 ug/m^3).

Graph 9 shows a comparison of the number of days that the 8-hour max exceeded the WHO limit of 100 ug/m^3 for the years 2012-2014. The data show a general increase in the number of days that exceeded the limit over the course of the three years, with São Paulo being the most pronounced of the three cities. Indeed, Carvalho et al. (2015) have identified that for São Paulo, ozone concentrations were higher on weekends than during week days and had not presented any significant reduction over the last years (different from the other studied pollutants). New York appears to have stabilized its Ozone levels from 2013 to 2014, having the same number of days in both years.

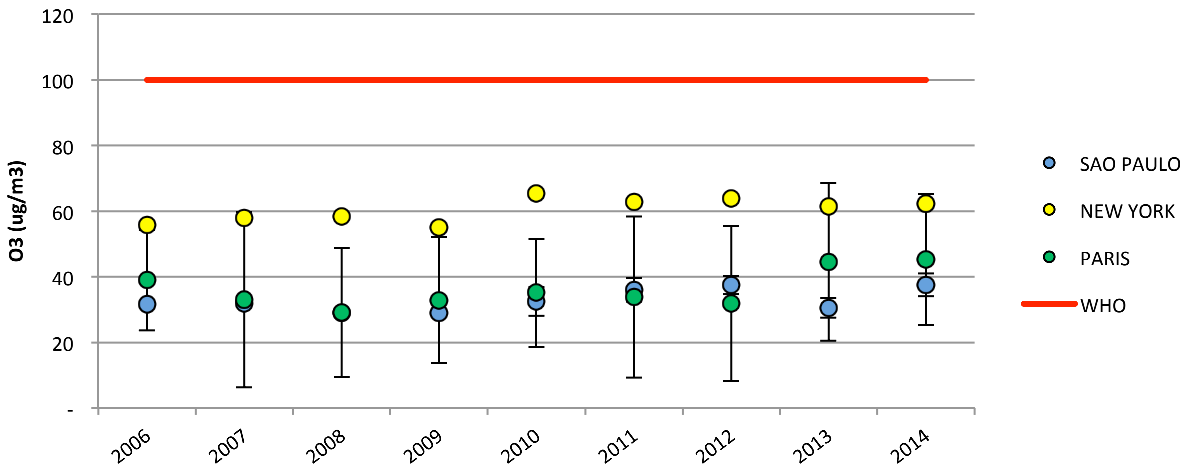
Graph 9 – Total number of days above WHO guidelines of O_3 in São Paulo, New York City and Paris:



Elaborated by A. Slovic
Source: Airparif, EPA, CETESB

Graph 10, in turn, shows the average O_3 values in the three cities for the years 2006 to 2014, with respective standard deviations where possible to calculate. The data show a relatively stable trend over the time period with all cities maintaining levels well below the WHO limit of 100 ug/m^3. New York appears to exhibit higher values than the other two cities, but due to the small number of measuring stations, it was not possible to calculate a standard deviation. In general, the data show little change over the period selected.

Graph 10 – O_3 (8-hour max) yearly average concentrations for São Paulo, New York City and Paris: 2006 / 2014



Elaborated by A. Slovic
Source: Airparif, EPA, CETESB

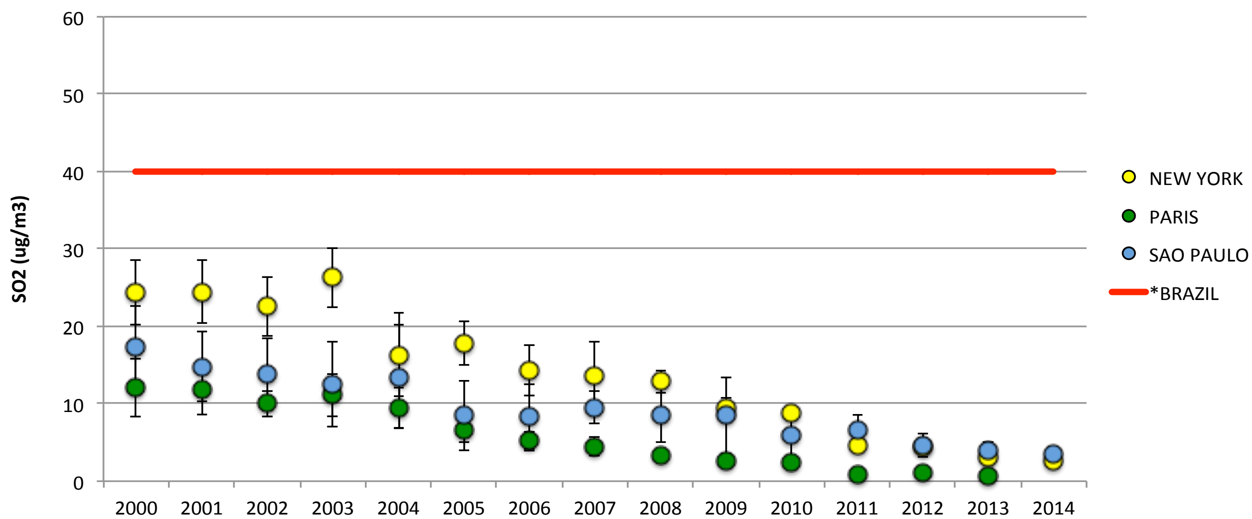
n stations	2006	2007	2008	2009	2010	2011	2012	2013	2014
SAO PAULO	7	10	10	10	10	9	10	10	13
NEW YORK	2	3	3	3	3	2	3	1	3
PARIS	3	3	3	3	3	3	3	3	4

4.3.6 SO_2 trends in São Paulo, New York and Paris

Sulfur dioxide (SO_2) is a member of a class of molecules called the oxides of sulfur (SO_x). These molecules are found in the atmosphere as a result of natural processes such as volcanic emissions and from burning sulfur-containing fossil fuels in the presence of oxygen. In the atmosphere, the highest man-made contributions of SO_2 come from power plants (73%) and other industrial facilities (20%) with the remainder coming from automobiles, non-road equipment, trains and freight ships. In general, inhalation of SO_2 is harmful and small doses may lead to respiratory failure and eventually death, with the current EPA having set a 1-hour standard of 75 ppb. There are several methods to reduce the sulfur content in fossil fuels, in addition to there being Calcium- and Magnesium-based additives that may be added to fuel to reduce SO_2 formation.

Graph 11 shows a consistent reduction in average SO_2 emissions since 2000, with all three of the studied cities considering the annual mean. The levels are below the stated limit of 40 ug/m^3 (CONAMA reference). Overall SO_2 levels in the three cities have experienced a decrease this last decade. In São Paulo, this reduction has been associated to the reductions of Sulfur content in vehicle fuels (CARVALHO et al., 2015). In Paris, since the year 2011 until 2014 there was only one station that monitored SO_2.

Graph 11 – SO_2 yearly average concentration – São Paulo, New York City and Paris: 2000 / 2014



Elaborated by A. Slovic
Source: Airparif, EPA, NYS DEC, CETESB
* Average standard value for secondary annual mean of SO2 by Brazilian standards

n stations	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
SAO PAULO	5	5	5	4	4	4	3	2	2	2	2	2	3	3	4
NEW YORK	2	2	1	1	4	4	4	4	4	3	3	2	3	3	3
PARIS	11	8	7	7	5	4	4	4	4	4	4	1	1	1	1

4.4 Urban mobility in São Paulo, New York City and Paris: preserving air quality and enabling people to commute

4.4.1 Characterizing transport modes in São Paulo, New York City and Paris

Understanding how people commute in each city is essential to capture the challenges and travel modes that can provide insightful support to policymakers. To do so, information was extracted from the different public transport agencies of each city and from major reports of mobility surveys:

- For São Paulo: *Pesquisa Mobilidade Urbana*, 2012
- For New York City: *Peripheral Travel Study*, 2010; 2010/2011 Regional Household Travel Survey
- For Paris, from the *Bilan des Déplacements*, 2012: *Enquête Globale des Transports*, 2013

The information has been combined in Table 6 to present the public transport network in the metropoles. Three modes of public transport were taken into consideration: bus, subway and light rail. Information on the choice of transport (public, active) was extracted from the different mobility surveys to magnify the alternatives offered to the use of public transportation. Few points can be highlighted from the information collected:

- Although Paris and New York City have an extensive subway transportation system (214 km for Paris, 337 km for New York City as opposed to 74,8 km in São Paulo), they also face air pollution challenges that, depending on the pollutant, can be similar to the city of São Paulo, which counts on a much smaller public transportation network (see graphs of air pollution in section 4.3.2).
- New York City counts on the largest rail network subway (337 km of subway and a total of 1,060 km of light rail that includes the Greater region of New York City) and the highest average of subway riders per day (8.7 million/day). However, considering the density per inhabitant and size of the city, the numbers for Paris show a saturated public transport network, particularly of the subway system.

- São Paulo has the largest bus fleet, used by 32.9% of the population to commute, while Parisians and New Yorkers tend to favor the subway, despite the fact that Paris has, in proportion to the size of the city, an extensive bus fleet.

Table 5 – Overview of the current public transportation network – São Paulo, New York City and Paris

AVAILABLE PUBLIC TRANSPORTATION	SAO PAULO	NEW YORK CITY	PARIS
SUBWAY (KM)	74.8	337	214
Average riders million/day	3.2 million	5.6 million - week	4.25 million
LIGHT RAIL (KM)	260.7	1060	587 among which 76.5 are in Paris
Average riders million/day	2.1 million	8.7 million	2.7 million
BUS (NUMBER OF VEHICLES)	14 800	5710	4490
BUS LINES #	1390	307	65 (Paris only)
Average riders million/day	8 million or 32.9 %	2.5 million (NYC only)	1.14 million

Elaborated by AD Slovic
Sources: São Paulo (CPTM - SPTrans – Mêtro – *Pesquisa Mobilidade Urbana*), Paris (RATP, EGT, *Bilan des Déplacements* 2012, *Enquête Globale des Transports*, 2012, SNCF), New York City (MTA, NYC Dept. of City Planning – *Peripheral Travel Study, 2010*).

Modes of travels differ within cities. There are different factors that influence citizens to prefer one mode to another such as distance, socioeconomic conditions, purpose of a trip, public transport availability and efficiency. An indicator of transport efficiency can be reflected in the time of commute by mode of travel. For these purposes, information on the commuting time by bus, subway and privately owned vehicle was gathered for the three cities. Some trends can be perceived for each one.

When considering the average commuting time by motorized mode, São Paulo's is the highest if using public transport: 67 minutes with public transport, as opposed to 31 minutes in individual motorized vehicles as seen in Table 6. In average, time of commute by public transport, in São Paulo takes an additional 30 minutes as compared to Paris and New York. New

Yorkers and Parisians both have a similar commuting time of 38 to 48 minutes on average when using public transports. Another important change in the way "*paulistanos*" commute for work or educational-related trips is the increase from 2007 to 2012 in the number of travels by subway but it was offset by the increase from 2007 to 2012 in the use of vehicle trips.

The development of bus lanes over the years has improved the efficiency of time of commute for bus users. This is particularly essential in a city like São Paulo where buses remain the most important mode of travel for a vast majority of the population (7 passengers per m^2 per bus, according to Ernst & Young latest auditing report of SPtrans). Table 6 shows the number of km of bus lanes (corridors only) for the three cities. It is in the last years that São Paulo has focused on the implementation of these corridors. Although a major improvement for the fluidity of buses, its extension of 61 km continues being low compared to New York City and Paris (respectively 112.6 km and 172.6 km).

In these three cities a major change in the utilization of the public transport was the introduction of electronic passes, which simplified the payment of the network and offered some reductions. They were introduced:

- In 2004 in São Paulo by former mayor Marta Suplicy under the name of "*bilhete unico*" or unique ticket
- In New York the initiative started in 1993 with the introduction of the Metrocard
- In Paris in 2001 with the "Navigo" pass.

Theses passes have encouraged and facilitated the use of public transportation because of the cost reduction they provided (in particular one using more than one mode of transport). They have allowed many citizens that could not afford to take more than one mode of public transport to do so.

Thus, active transportation has been of special attention in the recent years, walking trips in the three cities still being a very important mode of travel. In São Paulo, 13.7 million walking trips are done per day for duration of 16 minutes on average (PESQUISA MOBILIDADE URBANA, 2012). In Paris, walking is the second main mode of travel after public transportation and is mostly done for distances of less than 400 and for non-work purposes (BILAN DES DÉPLACEMENTS A PARIS, 2013). In Paris, active travel time is the shortest one, with 12 minutes for walking and 19 for biking. In New York City, although this number is explained in percentage, 10.4% of the population walks to work (NYC DOT, 2010). However, these percentages vary tremendously from one borough to another.

Bicycle programs are another major change in these three centers over the last fifteen years. Goal Program for the city of São Paulo (2013-2016) promoted the installation of bicycle lanes that now account for 265 km. However, this number is very low as compared to the size of the city and still very much inferior to New York City´s network of 680 km. Paris, in proportion to its size, has a spread out bicycle network 55,5 km.

If the commuting time for privately owned vehicle is similar in the three cities (an average of 30-40 minutes), the use of privately owned vehicles differ according to purpose of the trip and access to alternative ways of transportation. For example, São Paulo Mobility's report of 2012 shows that privately owned vehicles and public buses are the main mode of transport while traveling for work and education. In Paris, the main mode of transport to work is public transportation and the use of vehicles is in majority done for recreational purposes (EGT, 2010).

Commuting times by mode of travel was non explicit for New York City, where the averages indicated in studies such as the Peripheral Travel Study did not exclusively measure the time of commute by individual motorized vehicle or walking, for example. The available information for New York City provided only data such as the percentage of mode of transportation to work. Results differ tremendously in New York City by borough and access to public transportation. The further away from public transportation the more likely New Yorkers were to use a car (MYERS et al., 2013). New York City presented another particularity in the sense that the use of cars for work-related trips was mostly done in the Bronx, Brooklyn and Queens, but the highest share of mode of travel was public transport when residents had to leave their borough to go to work (PERIPHERAL TRAVEL STUDY, 2010). This reflects the lack of accessibility to public transportation in some of the poorest parts of New York City where, like in São Paulo, the time of commute to work is one of the highest of their city. (ibid.).

Table 6 – Mode of travel indicators for São Paulo, New York City and Paris in 2010-2012

MODE OF TRAVEL INDICATORS	SAO PAULO	NEW YORK CITY	PARIS
PUBLIC TRANSPORT (TIME)	67 min	31.8 -43.3 min depending on the borough all modes*	38 min
IND. MOTORIZED VEHICLE (TIME)	31 min		32 min
MOTOS (TIME)	28 min		21 min
BICYCLE (TIME)	26 min Biking		19 min Biking - 12 min walking
WALKING (TIME)	16 min		12 min
# PASSENGERS/ M2	7/m2	n/a	n/a
BUS LANES (exclusive)	61 km	112.6 km	172.6 km
BIKE LANES	265.5 km	680 km	55.5 km
# WALKING TRIPS/ DAY	13.7 million	10.4 % walks to work*	4.9 million

Elaborated by AD Slovic
Sources: Pesquisa de Mobilidade, 2012; CET, SPTrans (São Paulo). Bilan des Deplacements, 2012 and Enquête Global de Transport, 2010 (Paris) and *Peripheral Travel Study, 2010, NYC Department of Transportation, Census. gov (New York City)*.
* Average commuting time data for New York City was not detailed by mode of transport and the averages on the Peripheral Study indicate only the average for all the boroughs with the exception of Manhattan. The percentage of walking trips for work was for the years of 2005 to 2007.

4.4.2 Overview of the vehicle fleet composition and emissions in São Paulo, New York and Paris

Vehicular emissions are a problem in urban centers. São Paulo, New York City and Paris are no exception to this worldwide issue. Indeed, if overall levels of air pollution have reduced in these cities, meaning that some policies were beneficial, they are coping with designing new policies that will discourage people from using privately owned vehicles to commute. Thus, policies in these three centers have been influenced by the contribution of vehicle emissions into the atmosphere and its costs to health. Comprehending the current information on the vehicle fleet in these three cities is fundamental to support policymakers in their decision-making process.

A similarity between the three cities is the average speed of automobiles in peak hours that turn around 16 km/h. However, the number of privately owned vehicles is greater in São Paulo but the car ownership/ 1000 inhabitants is the lowest, 212/ 1000 inhabitants (according to CETESB), out of the three cities. With the Pro-alcohol program, in 1979, Brazil's fleet changed, as compared to other parts of the world, and assumed the particularity of having flex cars for its vehicle fleet, mostly based on sugar-cane ethanol. Flex and ethanol vehicles are today a large component of the fleet, which ages an average of 9 to 8.6 years (CETESB, 2014). São Paulo, as previously mentioned, follows the PROCONVE standards which are in stage five. Nogueira et al. (2014) have found that in addition to the increase in the number of flex-fuel cars, technology and stricter emissions standards have positively impacted the reduction of pollutants such as aldehydes in the atmosphere (NOGUEIRA et al., 2014).

In New York City, the vehicle ownership, 3.7 million, decreases as compared to São Paulo but differ from borough to borough. When looking at Manhattan, this number falls considerably and car ownership drops. According to NYC DEC, Manhattan concentrates one of the highest traffic-related air pollution levels in the New York City area. This suggests that a large proportion of the vehicles in Manhattan are actually part of the circulating fleet. Indeed, 880,000 people commute each day to work in Manhattan (NYC DEPARTMENT OF CITY PLANNING, 2010).

According to the American Community Survey from the Census Bureau of 2010, only 23% of households in Manhattan have a car. This percentage increases and varies in other boroughs of New York City. For instance, in the Bronx, 51% of households have a car, 44% in Brooklyn, 66% in Queens 64% and 84% in Staten Island. In the Bronx, car ownership varies from the Northern to the Southern part. The farther from Manhattan the home, the most likely it is to have a car (15% in the Southern and 50% in the Northern part) (MYERS et al., 2013).

Table 7 – Car ownership in New York City by borough in 2010

BOROUGH	% of CAR OWNERSHIP/ household
Manhattan	23%
Brooklyn	66%
Bronx	51%
Queens	64%
Staten Island	84%

Adapted from Myers et al., 2013

In Paris, 628,000 of Parisians owned vehicles were less than 15 years old. Although as previously seen, Parisians use public transportation to go to work, the car ownership in the city has not lowered other the years. Vehicular emissions contribution accounted for 66% of NO_x, 56% of PM_{10} and 58% of $PM_{2.5}$ out of which 37% of these pollutants were concentrated on Paris' major circulation *boulevard périphérique* axis (AIRPARIF, 2013).

There are some particularities of the vehicle fleet in France such as diesel vehicles for automobiles. In its evaluation report of vehicular emissions in Paris, Airparif has identified that a decrease between 2002 and 2012 (AIRPARIF, 2013), they contribute to emissions of:

- 7 t on average /day of NO_x
- 0.7 t on average/ day of PM_{10}
- 2000 t on average/ day of $PM_{2.5}$

The introduction of new technologies into the vehicle fleet in France has positively contributed to improving the air quality but with the increase in diesel passenger cars some of these outcomes have offset (SCHMIDT, 2016). Motorcycles play an extensive contribution to emission in Paris (AIRPARIF, 2012).

Table 8 – Vehicle profile in the Municipality of São Paulo, New York City and Paris – 2011

VEHICLE FLEET PROFILE	SAO PAULO	NEW YORK CITY	PARIS
Number of vehicles*	4.6 million	3.7 million	632 000
Average speed on peak hours (morning and afternoon)	16 km/hour	15.3 km/ hour	15.4 km/hour

Elaborated by AD Slovic
Sources: São Paulo (Denatran, CETESB; Pesquisa de Mobilidade Urbana, 2012), Paris (*Enquête Globale des Transports*, 2012, SNCF), New York City (MTA, NYC Dept. of Transportation).
* 2011 was used for the number of vehicles – automobile only. For the metropolitan Region of São Paulo, the circulating fleet of automobiles was of 9 million. For The car ownership/ inhabitant for Paris was of 2006.

Paris follows the Euro Norm introduced in 1993. Currently, the EURO 6 norm applies to new vehicles. For diesel passenger cars, the current norm is of 0.080 g/km for NO_x and of 0.005g/km for PM. In 2002, the majority of passenger cars were equipped according to the EURO 2 norm (41.1%) while in 2012, 51.6% of the passenger car fleet was composed of vehicles that followed the EURO 4 norm (AIRPARIF, 2012).

New York City follows the ones established by the United States. The first federal standards for new non-road (or off-road) diesel engines were adopted in 1994 for engines over 37 kW (50 hp), and the phase-in was begun from 1996 to 2000. This standard, called Tier 1 was adopted on August 27, 1998, when the EPA signed the final rule reflecting the provisions. The 1998 regulation introduced the Tier 1 standard, applying to equipment under 37 kW (50 hp). More stringent were Tier 2 and Tier 3 standards for all engines, which were to be phased in from 2000 to 2008. In order to meet the requirements of Tier 1-3 standards, manufacturers would apply modern engine design principles, with little use of exhaust after-treatment (catalytic converters). In the Tier 3 standards, the limits for NO_x and HCs are similar to those from the 2004 standards. Tier 4 standards were established on May 11, 2004 by the EPA, and were phased in from 2008 to 2015. These standards mandate the reduction of PMs and NO_x by 90%, more than the levels established in Tier 3. (EPA, 2015)

Another important point to be considered is the sulfur content in fuels. Source of several regulations and programs in the three cities, it differs according to each city:

- São Paulo follows the norms implemented by the Federal Petroleum Agency that, in 2013, instituted that in gasoline the level of sulfur should be 10 ppm for commercial gasoline and 50 ppm for diesel (CETESB, 2015);
- New York City follows the federal regulation that mandates 30 ppm of sulfur both in diesel and gasoline fuel (EPA, 2014) (to be lowered to 15 ppm in 2017);
- Paris regulates its sulfur content by applying the EU Directive 2009/30, 10 ppm in diesel fuel (EURLEX, 2015).

Table 9 gives an overview of the NO_x, PM_{10} and $PM_{2.5}$ emissions from passenger cars only for the year of 2011 in São Paulo and New York City, and for 2010 in Paris. The data shows that largest vehicle emitters for this category were the diesel vehicles in Paris with 18,370 tons per year of NO_x and São Paulo gasoline vehicles with 16,565 t/year of NO_x. However, in which concerns gasoline vehicles, Paris only had 3,700 t/year, a much smaller figure than São Paulo because of less restrictive emissions standards applied in São Paulo. São Paulo fleet has some particularities. For instance, diesel heavy-duty vehicles are restricted to the outskirts of the city. Ethanol vehicles are also low in numbers and older than the rest of the vehicle fleet.

In terms of NO_x emissions of for ethanol and flex cars in São Paulo, their emission was much smaller than for gasoline. New York had the smallest value, with 1753 t/year of NO_x but the greatest one in PM_{10} of 280 t/year and of 71 t/year of $PM_{2.5}$ compared to Paris in the same category. São Paulo reports do not indicate $PM_{2.5}$ emissions.

Table 9 – Current estimates of vehicular emissions for automobiles of NOx, PM10 and PM 2.5 in t/year in New York, São Paulo and Paris for 2011

FUEL	POLLUTANT	SAO PAULO	NEW YORK CITY	PARIS
	NOx	16565	1753	3 700
	PM-10	71	280	20
Gasoline	PM-2.5	n/d	71	20
Ethanol	NOx	3102	n/a	n/a
	NOx	1980	n/a	n/a
Flex-Gasol.C	PM-10	37	n/a	n/a
Flex-Ethanol	NOx	2740	n/a	n/a
	NOx	n/a	n/a	18 370
	PM-10	n/a	n/a	1530
Diesel	PM-2.5	n/a	n/a	1530

Adapted from CETESB, NYC DMV and Airparif
Elaborated by AD Slovic
Source: São Paulo (CETESB), New York City (NYC Dept of Motor Vehicles), Paris (Airparif)
* this table does not include light-duty vehicle emissions - 2011 was the year where data was found for the three cities, although São Paulo has more recent data.

4.5 Programs and plans: applying the OECD air pollution management strategies to São Paulo, New York and Paris

Establishing the context between air pollution, meteorological, vehicle fleet and emission standards allows a thorough comprehension of the situation in which these cities have developed and implemented the programs that enforce their policies. As cited earlier in the Methodology section, programs and plans were considered part of the policies and the action plans that enabled meeting policy objectives. In addition, the methodology used to identify trends in air pollution control policies was the one applied in the approved manuscript from section 4.1. To this end, major programs and plans established in São Paulo, New York City and Paris were compiled starting with different timeframes because of their own historical context. For each year, the main programs and plans were mapped from the years:

- 1975 for São Paulo
- 1992 for Paris
- 1997 for New York City

The OECD classification strategies used in the article were applied to the selected policies, and the same classifications were applied:

- Regulatory approaches
- Economic Incentive
- Others

The Methodology section gives a more detailed explanation of the different approaches used. The number of surveys and reports collected along the research were compiled in Graph 10, presented previously in section 4.3.5. In the OECD classification, they would fall under the OTHER category. Setting them apart from the programs and plans has helped count the number of studies done to support policymakers and evaluate the outcomes of the chosen strategies. Similar to the article, each approach was divided into three categories:

- A: Circulation restriction initiatives
- B: Alternative initiatives
- C: Fuel / technology initiatives

Tables 7, 8 and 9 combine these initiatives using the classifications mentioned above, which divides them by location where the initiative were started (country level or local level), the name of the initiative and the OECD categories. Overall results for the three cities show the following tendencies for initiatives dealing with air quality:

- Over the last 35 years, 26 programs and plans were developed in São Paulo; over the last 23 years, 21 in Paris and over the last 27 years, 30 in New York City;

- The “regulatory” approach is the most commonly used strategy to address vehicular air emissions and tends to focus more on “fuels and energy initiatives”, followed by “circulation restrictions” and “alternative ones”;

- The last decade saw an increase in the number of initiatives in the “other” category, as compared with prior to 2000 (see annex for the programs and plans timeline) in the three cities. This category uses more alternative initiatives and fewer ones that impose “circulation restrictions” or focus on “fuels and energy”.

- "Economic incentive" is the least used strategy of the three and tends to be applied for "fuels and technology initiatives", Paris has the highest number of management approaches within this category.

When looking at the air pollution management strategies by countries, some additional points can be highlighted:

1. Decision-making level:

- In São Paulo, out of the 27 programs and plans, 16 were at the local level (state and city) and 11 at the country level;
- In Paris, out of the 21 programs, 17 were at the country level and 5 local ones;
- In New York City, out of the 30 programs, 6 were at country level and 24 local ones.

This result may point out a geographic disparity when designing and implementing air pollution strategies. For instance, New York City and São Paulo have developed a much higher number of local programs. On the other hand, Paris has had a smaller number of local programs indicating that air quality strategies from a political and governance perspective are seen as a country level priority. This said, the episode of high levels of air pollution in the years of 2013 and 2014 has made Paris develop actions that were not only the reflection of a federal intervention but exclusively developed for that city (MAIRIE DE PARIS, 2015). This brings to light the challenge of understanding the implications of urban governance and local authorities (BULKELEY, 2010).

4.5.1 Air pollution management approaches in São Paulo

In São Paulo, "regulatory" initiatives focusing the most implemented ones, among which 11 had an impact on fuels and technology and 8 on circulation restriction. This was aligned with the Brazilian government's choice of developing the Pro-Alcohol program in 1975. The Pro-alcohol program was a response to a world petroleum crisis in the context of the cold war. This choice, although not motivated by environmental issues, was of tremendous importance to the Brazilian agro sector, economy and energy Matrix (GIESBRECHT, 2013). It marked the early introduction of biodiesel in the Brazilian vehicle fleet in 2004 and the production of flex cars for Otto vehicles in 2003. As previously mentioned, the PROCONVE and PROMOT programs were

Brazil's main strategy to address vehicular emissions. The catalytic converter and the electronic injection were the two major technological improvements in which concerns emissions and air quality, but they were only introduced in 1992.

Another particularity of some of the programs in São Paulo was the implementation of the license plate-based restriction program "Rodizio", after which 20% of the vehicle fleet, according to a license plate's final digit could not circulate during peak hours. This measure introduced in 1997 had, at first, an environmental motivation, but in time, started to produce greater impact on the city circulation flow. In terms of regulatory management approaches, the sulfur reduction on the fuel content and the Inspection and Maintenance Program represented two milestones in the progress towards reducing emissions in the city. This said, it is important to highlight that the State of São Paulo started its Vehicular Emission Control Plan (PCPV) in 2011, as one of PROCONVE's requirements. Among other things, the plan helped to:

- Improve vehicle black smoke control
- Start the municipal inspection and maintenance program
- Contribute to the elaboration of emission inventories for the State of São Paulo

Of all the programs developed, only two managed to include an "economic incentive" aspect:

- The Federal Biodiesel production and use program of 2004, which also fits into the fuel and technology approach.
- The Brazilian government's decision to reduce the tax on the importation of electric and hydrogen vehicles in 2015.

The Brazilian government's intervention in the automobile industry is not new. In the last decade, taxes on industrialized products (IPI), such as automobiles, were reduced (2008-2010, 2012 and 2013) in order to boost the economy. Indeed, the vehicle fleet age has a significant impact on emission levels, but these measures were not necessarily motivated by air quality. However, this point will be reviewed in the discussion section.

Implementing alternative programs to address air quality has been a recent strategic choice in São Paulo, started around 2001 with the São Paulo Transport Master Plan. As part of a global rising consciousness to address urban mobility challenges, tackling air pollution began to also include more integrated approaches in different fields. Urban planning played an important role into re-thinking the city and the ways people commute. For example, in 1997 and 2007, two major surveys on origin–destination were performed by Metro (of the São Paulo department of transportation) aiming to evaluate how inhabitants of São Paulo commute. Some of these results were presented in section 4.4 as a contribution to the elaboration of later plans such as the 2006 São Paulo Metropolitan Urban Transport Integrated Plan (PITU). PITU followed the idea of the importance of improving public transportation, with initiatives like new bus corridors and the connection of different modes of transport. More recent programs such as São Paulo Strategic Plan of 2013 or São Paulo Mobility Plan of 2015 focus on developing more sustainable travel means, among which non-motorized transportation has been receiving particular attention.

To summarize, in the last fifteen years, 26 programs have been implemented, ten have fallen into the "other" category. Out of these ten, two have incorporated the three sub classifications and nine were focused on alternative initiatives. Circulation restrictions were mostly used under the regulatory category.

Table 10 – Outlook of main initiatives and OECD strategies applied in São Paulo: 1975 / 2015

YEAR	LOCATION	NAME	REGULATORY			ECONOMIC INCENTIVE			OTHERS		
			A	B	C	A	B	C	A	B	C
1975	BRAZIL	Federal Pro-alcool Program			✔						
1989	BRAZIL	Proconve (stages: 1992, 1997, 2005, 2009, 2014)	✔								
1992	BRAZIL	Catalizer and Electronic Injection are introduced in the vehicle fleet as part of the Proconve			✔						
1997	SAO PAULO	São Paulo Plate Restriction "Rodizio"	✔								
1998	SAO PAULO	Program for the Improvement of Diesel Vehicle Maintenance			✔						
2001	SAO PAULO	São Paulo Transport Master Plan	✔	✔						✔	
2003	BRAZIL	Introduction of Flexible Fuel Otto Vehicles			✔						
2003	BRAZIL	PROMOT (stages: 2003, 2006, 2009, 2014)	✔								
2003	SAO PAULO	VIGIAR Program on information on health effects of air pollution and climate								✔	
2004	BRAZIL	Federal Biodisel Production and Use Program			✔			✔			
2006	BRAZIL	SP Metropolitan Urban Transport Integrated Plan - PITU							✔	✔	✔
2009	SAO PAULO	São Paulo 1st Inspection and Maintance Program	✔		✔						
2009	BRAZIL	Brazilian National Air Quality Plan							✔	✔	✔
2009	BRAZIL	Program for the Improvement of Diesel Vehicle Maintenance	✔		✔						
2009	SAO PAULO	Circulation restriction of heavy-duty vehicles	✔								
2009	BRAZIL	Green Note Program on vehicle emission levels per brand for consumers								✔	
2011	SAO PAULO	São Paulo 1st State Vehicular Emissions Control Plan - 2011-2013							✔		
2012	SAO PAULO	São Paulo State Biofuels Program									
2012	SAO PAULO	São Paulo bycicle sharing program								✔	
2013	SAO PAULO	São Paulo State Emission Sources Reduction Stationary Plan - 2013			✔						
2013	BRAZIL	São Paulo State Vehicular Emission Control Plan 2014-2016			✔						
2013	SAO PAULO	Emergency Air quality Plan	✔								
2013	SAO PAULO	Goal Program for the City of São Paulo 2013-2016								✔	✔
2014	SAO PAULO	São Paulo Strategic Master Plan							✔	✔	
2014	SAO PAULO	São Paulo State new Air Quality Standards							✔		
2015	SAO PAULO	São Paulo Mobility Plan								✔	
2015	SAO PAULO	No tax on importation of electric and hydrogen vehicles						✔			

a) circulation restriction
b) alternative incentives
c) fuels/technology

Sources: São Paulo (CETESB, Metrô)

4.5.2 Air pollution management approaches in Paris

In Paris, the highest number of management strategies fall into the “regulatory” category but are closely followed by the “economic incentives” and “other” ones. One overall particularity in Paris is that most of the actions included alternative initiative approaches. Although some of these programs were developed at the same time as in São Paulo, such as the Urban Travel Plan of the Île de France region, many actions over the last fifteen years have included public transportation improvements and non-motorized transportation. Paris, for example, was one of the first cities in the world to develop the bicycle and electric automobile sharing programs that were later on duplicated in São Paulo and New York City.

Driven by European Commission directives, the French government has also fostered the implementation of Atmosphere Protection Plans that aimed to guide and give authority to local administrations to develop local action plans in municipalities greater than 250,000 inhabitants where air quality was not meeting required standards or was threatening to. Such measures include speed limitation of vehicles, evaluation tools and authorization to launch the alert air pollution plan, among some of them. The Plan has been reviewed three times (2005, 2010 and 2013) and had to respect the Regional Climate, Air and Energy Plan (SRCAE) result of the Grenelle laws on rational use of energy and environmental protection. The SRCAE has the particularity of addressing energy, air pollution and climate change, and of incorporating other plans such as the local urban travel plans, recently reviewed (2014). Another measure that had a strong emphasis on urban vehicular emissions and resulted of the Grenelle law was the creation of priority zones – the ZAPAS. The Zapas's main goals were the reduction of particulate matter and nitrogen, enabling local administration to act within their own context and helping reduce the costs associated with air pollution in French cities.

Economic incentive strategies are among the main particularities of the approaches used in Paris. Strong emphasis has been given in the last few years to the development of hybrid and electric vehicles.

The air pollution episodes of 2013 and 2014 in Paris have also motivated the city to revise its air pollution strategies and to acknowledge the remaining air quality challenges. In 2015, the city authorities launched new sets of measures in which regulatory measures were re-implemented (circulation restrictions, plate restriction circulation in case of critical air pollution episodes, for example). However, while the last two years saw the "return" of restrictive measures, they also offered economic incentives to the adoption of alternative ways to commute and non-motorized ways. A re-organization of the public space and the closing of circulation axes for pedestrian use accompanied these measures. A 2015 innovative action, for example, has been set to provide financial support for Parisians to use the bicycle and electric automobile sharing programs. Another significant one has been the monthly fee reduction of public transportation fees.

Table 11 – Outlook of main air quality initiatives and OECD strategies applied in Paris: 1992 / 2015

YEAR	LOCATION	NAME	REGULATORY			ECONOMIC INCENTIVE			OTHERS		
			A	B	C	A	B	C	A	B	C
1992	FRANCE	Inspection and Maintance Program			✔						
1996	FRANCE	Creation of Acredited Assoc. for Air Quality Surveillance and Monitoring							✔		
2000	PARIS	Urban Travel Plan - Ile de France Region		✔						✔	
2003	FRANCE	National Plan of Pollutant Emission Reduction (PREPA)	✔						✔		
2005	FRANCE	1st Atmosphere Protection Plan	✔	✔	✔				✔	✔	✔
2007	FRANCE	Ecological bonus for greener vehicle purchase						✔			
2007	PARIS	Paris bike sharing service "Velib"					✔			✔	
2007	PARIS	Regional Climate, Air and Energy Plan									
2010	FRANCE	Federal Inventory System of Air Pollutant Emissions			✔						
2010	FRANCE	2nd Atmosphere Protection Plan	✔	✔	✔				✔	✔	✔
2011	PARIS	Paris car sharing service					✔			✔	✔
2012	FRANCE	Automobile Plan						✔			
2012	FRANCE	Regional Climate, Air and Energy Plan		✔						✔	✔
2012	FRANCE	Priority Zones of Action for Air	✔		✔						
2013	FRANCE	3rd Atmosphere Protection Plan	✔	✔	✔				✔	✔	✔
2013	FRANCE	Biofuels Aid Policy						✔			
2014	PARIS	Urban Travel Plan of the Ile de France Region								✔	✔
2014	FRANCE	Particulate Matter Plan - 2014	✔								
2014	FRANCE	Info. and warning in case of air pollution episode and the measures							✔	✔	
2014	FRANCE	Action plan for active mobility								✔	
2014	FRANCE	Plan for the development of hybrid and electric vehicles			✔			✔			
2015	PARIS	Launching of accompanying measures to fight air pollution	✔				✔				

a) circulation restriction
b) alternative incentives
c) fuels/technology

Sources: Paris (*Ministere de l'écologie et du développement durable et de l' énergie*, DRIE, Airparif, Mairie de Paris)

4.5.3 Air pollution management approaches in New York City

New York City reflects São Paulo's tendency in that it mostly follows "regulatory approaches" under the fuel and technology initiatives. The same trend appears in the economic incentive strategy, in which the focus is also on fuel and technology. Programs from 1997 to 2005 were mainly designed to improve fuels such as the ultra-low sulfur content, best retrofit technology and fuel mixtures. The reduction of fuel content appeared earlier in New York than in São Paulo, in 2005, with an economic incentive under the emission reduction grant program. New York bears four major characteristics:

- The first one is the “late” development of an environmental plan for the city, focused on air quality. Indeed, PlanNYC was only launched in 2007.
- The second one is that economic incentives at the local and federal levels target the private sector industry, such as the Smart Way Program, as opposed to Paris, that has developed initiatives oriented to the users or consumers. The smart way program, a public-private partnership specifically targeted at the transport freight industry and the improvement of its supply chain. It aimed to reduce fuel cost and lower environmental impacts from emissions;
- New York City strategies have the particularity of having designed plans that were more neighborhood-focused or targeted at specific problems. For example, in 2009, legislation was voted to regulate the amount of time of vehicle idling near a school or the different air toxics and noise monitoring actions focused on some specific places of the cities;
- The inclusion of environmental justice aspects into air quality with the *One New York plans for a strong and just city*.

Alternative incentives, specifically ones that are related to public transportation, appeared later in comparison to the other two studied cities. Indeed, transportation plans are really enhanced in 2013 and the change in the New York City vehicle administration fleet (police vehicles for example and buses) only happened in the last five years. Even so, studies have demonstrated that many neighborhoods are scarce in access to public transportation (MYERS, 2013).

Non-motorized initiatives were motivated by some actions such as the development and spread of bicycle lanes and pedestrian spaces, but it is only in 2013 that New York City started its first bicycle sharing program, six years later than Paris.

Table 12 – Outlook of main air quality initiatives and OECD strategy choices applied in New York City: 1997 / 2015

YEAR	LOCATION	NAME	REGULATORY			ECONOMIC INCENTIVE			OTHERS		
			A	B	C	A	B	C	A	B	C
1997	NEW YORK	NYS Chemical and Pollution Control Programs			✔						
1998	NEW YORK	Fuels Program: Alternative, Mixture and Nitrogen			✔						
2003	NEW YORK	Assessing and Mitigating Impacts of PM10 Program - 2003			✔						
2004	USA	Smart Way Program									✔
2005	USA	Diesel Emissions Reduction Program Grants			✔			✔			
2005	NEW YORK	Ultra low sulfur diesel fuel (“ULSDF”) and the best available retrofit technology (“BART”) for vehicles program			✔						
2005	USA	Renewable Fuel Standard (RFS) program						✔			
2005	NEW YORK	Bicycle Data Collection Program								✔	
2005	NEW YORK	2005-2030 Regional Transportation Plan								✔	
2006	NEW YORK	NYSDEC Guidelines on Dispersion Modelling Proc. for Air Quality Impact Analysis								✔	
2007	NEW YORK	1st Plan NYC	✔	✔	✔				✔	✔	✔
2008	NEW YORK	NYC Strategic Plan " Sustainable Streets"							✔	✔	
2009	NEW YORK	Reg. on the amount of time of vehicle iddling near a school	✔								
2009	NEW YORK	Mobile Source Civil Penalty Policy - 2009	✔								
2010	USA	Diesel Emission Reduction Act Grants						✔			
2010	NEW YORK	Car Sharing Zoning Tax Amendement					✔				
2011	NEW YORK	2nd Plan NYC	✔	✔	✔				✔	✔	✔
2011	NEW YORK	NYC Air toxics Monitoring Begins			✔						
2012	NEW YORK	NYC Noise Monitoring Starts								✔	
2012	NEW YORK	New York City Department of Transportation's Mobility Management Program							✔	✔	
2013	USA	Fuel Economy Label			✔						
2013	NEW YORK	Regional Transportation Plan -2013								✔	
2013	NEW YORK	Coordinated Public Transit Human Service Transportation Plan - 2013		✔							
2013	NEW YORK	Transportation Enhancements Programs - 2013							✔	✔	✔
2013	NEW YORK	Economic and Technical Analysis for Reasonable Available Control Technology			✔						
2013	NEW YORK	Bycicle Share Program "Citi Bike"								✔	
2015	NEW YORK	Thrid Plan NYC: One New York the Plan for a Strong and Just City	✔	✔	✔				✔	✔	✔
2015	USA	EPA Clean Power Plan		✔	✔						
2015	NEW YORK	Regional Freight Plan		✔	✔						

a) circulation restriction
b) alternative incentives
c) fuels/technology

Sources: New York (NYS DEC, EPA and DOT)

4.5.4 Monitoring and evaluating programs and plans within the city: São Paulo, New York City and Paris

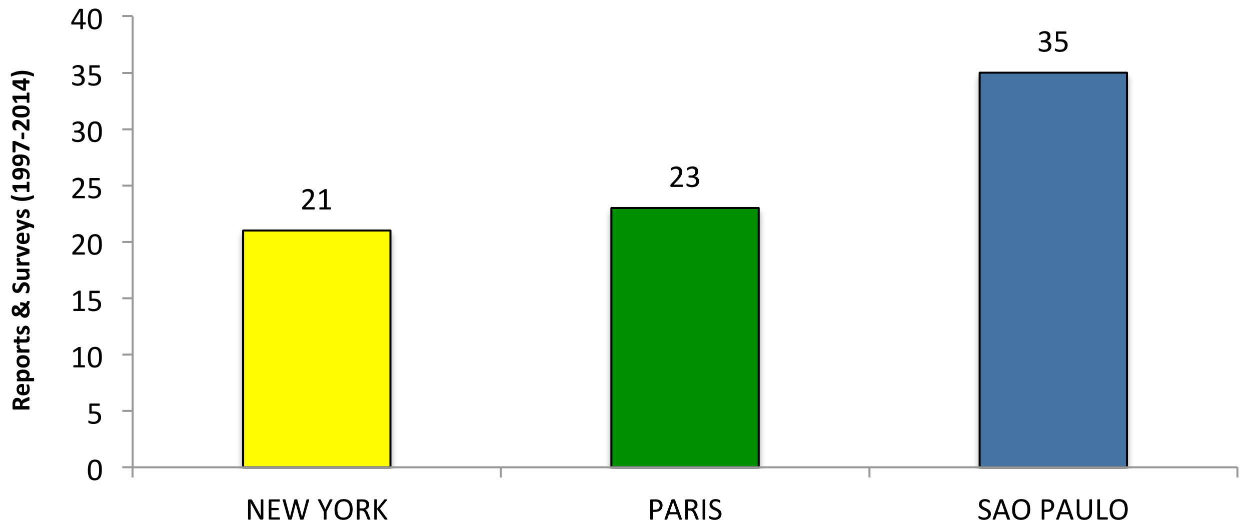
When looking at reports from 1997 onward, Graph 12 shows São Paulo with the highest number of reports, totaling 35 (air quality, surveys, emission inventories), followed by Paris with 23 and New York City with 21 reports. Out of these data, air quality reports were only provided from 2000 to 2014 on Paris and São Paulo. New York City air quality reports were only found after the start of the 1st PlanNYC. Yet, this was the only city that had reports linking air pollution and health (NYC DEC, 2011 / 2013) and that had a report on noise monitoring. São Paulo and Paris had better emission inventory reports while New York City's such reports were not available.

Paris had the highest number of mobility studies and reports, followed by São Paulo and New York City. Although the Peripheral Travel Study in New York City provided insightful information on the use of passenger cars and on how people commute, it did not give a full profile of the commuters and preferences as the mobility studies in Paris (*Plan des deplacements* and *Enquete Globale des Transports*) and São Paulo (*Pesquisa origem destino* and *Pesquisa Mobilidade*) did.

These figures show that although the number of reports demonstrates the intention of evaluating the programs that does not necessarily imply that new programs or plans are being developed, and suggests that there might be a gap to fulfill between the evaluation stage and its findings or improvements on air pollution. Yet, this information needs further research.

In the transport sector, there is a literature gap to better comprehend how local transport policies, in particular those aiming to address the impact of policies on active transportation and the use of vehicle, can produce a positive impact on health and climate change mitigation (SHAW et al., 2014)

Graph 12 – Number of Reports and Surveys produced by local governmental agencies in São Paulo, New York and Paris from 2000 to 2014



Sources: Paris (Municipal and Federal agencies) São Paulo (Municipal and Federal agencies), New York City (Municipal and Federal agencies)

5 DISCUSSION

5.1 Bringing the SWOT analysis to detect policy trends in São Paulo, New York City and Paris

This study is the first of its kind, offering a qualitative analysis and comparison of the air pollution emission policies in three of the world's most important metropolitan regions. The approach taken was the analysis of the context in which each set of policies evolved, including fleet data, fuel standards and air pollution trends. Describing each city's legal framework was essential to understand what strategies were most used in each of them to cope with air pollution, particularly due to vehicular emissions.

This said, there are some central points that deserve special attention from the findings described in the Results section. Given the magnitude of this study, choosing the right methodology to underline initiative trends in the three cities required the application of a system that had the potential to summarize findings. To this end, a SWOT analysis (Strengths, Weaknesses, Opportunities and Threats) was undertaken in the discussion section. The SWOT analysis consists of a matrix commonly used in strategic management, aiming to identify in an industry or organization:

- Its potential "know how"
- Areas of enhancement
- Factors that could help developing strengths
- Factors that could potentially harm it

Developed by Weihrich in 1982, the SWOT methodology has the particularity of including internal (strengths and weaknesses) and external (opportunities and threats) factors to evaluate a given project or organization. Ghazinoory et al. identified in a literature review the areas where SWOT analysis was most utilized and have concluded that in recent years it has been used in the health policy and environmental field by research practitioners (GHAZINOORY et al., 2013). In Malaysia for instance, the SWOT analysis has helped study the palm-based biofuel and biomass sector as a renewable source of energy expansion; and identify the potential challenges to implement policies towards it (DARSHINI, 2013). Diakaki et al. have applied SWOT to look at different proposals of available vehicle automation and communication systems (VACS) and found that it was beneficial to traffic flow and efficiency (DIAKAKI et al., 2015).

Other examples of environmental studies that are running SWOT analyses included, for example, the observation of industry's relocation as a tool to decrease air pollution in cities in the developing world. That study has highlighted what main decision factors will encourage firm´s decision makers to move. They discovered that decision makers view relocation as a weakness factor when it comes to leaving a large market, but consider it a strength for "relief from government pressure", emphasizing the need for stronger government intervention in air pollution management (ESLAMIPOOR, 2014). A similar initiative was performed in the mining industry in Greece, to identify the good practices to be adopted for better environmental purposes and concluded with some recommendations to enhance performance and protect the environment (NIKOLAOU, 2010). In the automobile sector, Andersson et al., based on the SWOT analysis and simulation results for the Swedish and German market, have demonstrated what would be the ideal regulation for plug-in hybrid electric vehicles (ANDERSSON et al., 2010). In Iran, Talaei et al. have conducted a SWOT analysis to develop policy packages that could contribute to foster low carbon technology and mitigate climate change (TALAEI et al., 2014).

The SWOT analysis was applied to combine the findings from the three cities and offer some support to policymakers in other urban centers. To this end, it has been included in the discussion part of this research.

STRENGTHS	WEAKNESSES
Emphasis on non-motorized mode of transport such as bicycle sharing program Enhancement of the public transportation network Capacity to develop strategies at the neighborhood level Vehicle technology improvements Focus on clean and renewable fuel development Capability to develop emission inventories and air quality reports Legal structure that enable the development of new strategies	Data gathering and terminology Location/ lack of air pollution monitoring stations Local governance challenges Disparity between local and global air quality standards Difficulties of local population to embrace certain programs and plans Disparities in the access to public transportation Social differences of exposure and private vehicle ownership Increase in the number of vehicles and fleet age Use of space allocation and government´s intervention Private-public sector interaction
OPPORTUNITIES	**THREATS**
Possibility to develop interdisciplinary approach to air quality Develop studies that incorporate social determinants of health Human-rights based approach to air pollution Incorporate quality of life and well-being to air pollution policies Mobility and air quality interactions Fostering further research and collaboration on the effects on air pollution and health Existing academic potential Technology transfer Integration of air pollution control policies into climate change mitigation	Consistent high levels of ozone and particulates Health costs associated to air pollution Climate change Unbalance between local and global scales Lack of interaction between health policy and environment Political instability and fuel market variations Economic factors that offset environmental advancement

Figure 3 – SWOT analysis matrix of combined air pollution initiatives – São Paulo, New York City and Paris
Elaborated by AD Slovic

The SWOT matrix points out the summarized findings of the internal factors that have demonstrated air pollution strategies’ strengths and weaknesses. However, out of the three studied cities, some have revealed a higher potential in certain strategies as opposed to others. As previously stated, Paris was one of the first cities in the world to foster bicycle sharing programs and electric vehicle sharing programs at the same time as it worked in giving back public spaces to its inhabitant. Paris also has constantly improved its public transportation network – already extent – as compared to a city like São Paulo, and very early (compared to the other cities) fostered public transportation and non-motorized modes of travel. These initiatives, implemented by former Parisian Mayor Delanoe (2001-2014), were the results of a local administration that had the re-appropriation of the public space and the decrease of air pollution as a primary objective.

A comparative study between London and New York City on climate change initiatives found that there were more similarities between the two cities in regards to achieving sustainable goals. Differences found relied on the approaches taken and on the interactions between government and citizens (SUFIYAN, 2013). To the same extent, this point is valid in the three studied cities that have shown common strengths, as seen in Figure 3. There are points from the SWOT analysis that deserve mention:

- The need to better monitor the interaction between government´s regulations and their application to the private sector. The recent events with Volkswagen´s fraud have demonstrated a lacuna that has yet to be fulfilled (SCHMIDT, 2016).
- How to include citizen´s behavioral changes and government transfer of information on the importance of a policy to locals. The Inspection and Maintenance program in São Paulo did not win the support of the local population. This raises the question for policymakers to re-evaluate air pollution perception and understanding by the local population. When Parisians were faced with the re-introduction of the rotation vehicle program in case of air pollution alert, they claimed to social injustice, although Airparif demonstrated the positive impact in lowering PM_{10} emissions (15%) and NO_2 (20%) in Paris major circulation axes (AIRPARIF, 2014). Although all important, these points constitute an area for further research
- The importance of further encouraging the development of cleaner fuels of public transport and to reduce vehicle emissions (ANDRADE et al., 2012) that can be made possible throughout technology improvements.

5.2 Limitations of the study

This research has encountered some challenges worth highlighting to better encourage further research on cited aspects below and comprehend the limitations of the study.

For instance:

- The opted timeframe differed at times for each city. The reason for this choice was the importance of some policies and programs to more recent ones;
- Being a qualitative and descriptive case study, this research did not include statistical analysis, using only the standard deviation to look at the air pollution trends in each city;
- Data gathering gaps. Finding similar information for each city was challenging and reflected policy choices. For example, in New York City, finding data on vehicles (emission, fleet composition, ownership, etc.) and different policies was troublesome. São Paulo and Paris had the best available data on air pollution levels and air quality reports. São Paulo, since 2011, has been combining emission inventories in reports that are extremely helpful for understanding the vehicle emission contributions to air quality in the city. Thus, it is worth citing that although not studied in this research, the number of air pollution monitoring station plays an important role on the available data for each city as well as in the average calculation of air pollutant levels.
- Air pollutant composition, especially Particulate Matter, varies in the three cities, having a direct impact on their health effects. This point wasn't accessed in this study.
- Terminology disparities for policies and government actions (policies, legislation, interventions, initiatives).
- Accessing the urban sprawl of cities contributes to understanding how the city was designed and can provide some insightful information on the development of public transportation and the design of major highways, such as the *Rodoanel*[3] in São Paulo.

5.3 The human-rights-based approach of air pollution policies

[3] Rodoanel is a major highway, which aims to alleviate São Paulo's traffic through the construction of a highway surrounding São Paulo. Started in 2003, the road is today 75% build

Some of the main findings of this study are that, following world's trends and despite structured air pollution control policies, São Paulo, New York City and Paris experience significant disparities when related to commuting and exposure and their environmental health effects. For instance, this is particularly true regarding where inhabitants of each city live and when they commute. Some of the variables that play a major role include:

- Households' and work places' geographic location
- Available public or active transport network and accessibility
- Household socioeconomic status.

These variables point out to a growing field of study of pollution in the cities that encompasses environmental justice aspects. Environmental justice means the inclusion of aspects such as race, ethnicity and economic class to better foster knowledge on air pollution disparities within a city context (MOHAI et al, 2009). From one neighborhood to another, in the same city, the health effects of air pollution differ. Better consideration of these local inequities is essential to elaborate and plan efficient policies. Incorporating air quality dimensions in local contexts, where geography, political and social economic conditions, access to health care, and technology play such an important role, are real challenges faced in their unique ways by cities.

In the city of São Paulo, for example, the population with the highest socioeconomic status also lives in some of the most polluted parts of the city (HABERMANN et al, 2014). As Habermann argues, the place of residence does not necessarily reflect the exposure. Moreover, Toledo et al. point out that, in São Paulo, disparities start at the monitoring level. Indeed, there are gaps to be fulfilled into better distribute monitoring stations throughout the city. This problem is seen as a deficiency to truly measure people´s exposure to, for example, traffic-related air pollution (TOLEDO et al, 2012 and LÉPICIER et al., 2013).

In New York City, Maroko et al. (2013) found in the South of Bronx that stressors at the neighborhood level, such as traffic volume, poverty, safety, play a major role in environmental injustices. Studies geared towards including such factors could be beneficial and foster long-term evidence based policy changes. The MESA study (multi-ethnic study of atherosclerosis) is another example of understanding disparities at the neighborhood level. It was found that when looking at associations between ambient air pollution, exposure with race/ ethnicity and racial segregation exposure levels differed by ethnicity in American cities. Indeed, low levels of exposure were associated to white neighborhoods, while Hispanic neighborhoods were associated to higher levels of exposure (MIRANDA et al., 2014).

Similar studies to the MESA have not been available in Paris or São Paulo. Thus, Leygonie et al. (2013) found in a study of 55 greatest French cities that taking into consideration geographic scale was essential to capture variations in health disparities (respiratory), environment and socioeconomic dimensions. Deguen et al. (2015) discovered that, in Paris, when looking at residence, NO_2 concentrations, socioeconomic status and all cause of morbidity, low-income residencies were more at risk and more vulnerable than the ones of higher social levels.

Thus, task remains in comprehending how to integrate and develop policies that can fit and benefit all. The complexity of environmental issues raises awareness on how to think about new approaches of urban air quality, which could be reproduced. An option to foster a universal concept that could fulfill this gap would be to incorporate human rights-based approaches (HRBA) to air quality policies in urban centers. Human rights-based approaches have the particularity to bridge the differences that can prevent some concepts from being successful from one place to another.

Historically most used on climate change, this approach finds its foundations in the Stockholm declaration of 1972, where the link between human rights and environment was established. One of the first applied cases started with indigenous rights and climate change. The Inuit tribes, in 2005, were able to do a petition to the Inter-American court of Human Rights (IACHR) stating that climate change was injuring the rights of indigenous people in the Artic region (CLARKE et al, 2010). In 2007, a similar case was made in the Small Island Developing States. It is only in 2008, that the Human Rights council voted the 7123 council resolution explaining that climate change poses a threat to people, community and human rights[4] and was then mentioned in the IPCC. The HRBS brings to light the threat posed by global warming and the poorest countries that will be most affected. Furthermore, as Bell states: “there is a human right to a stable and adequate environment” (BELL, 2013) that is essential today and to future generations. As air quality is seen as an ally for coping with climate change mitigation, there is a window of possibilities to include this approach to air quality.

[4] Available at: <http://ap.ohchr.org/documents/E/HRC/resolutions/A_HRC_RES_7_23.pdf>. Access Jan 2016

Scholars have proposed, over the last years, ways in which HRBA could be incorporated into the environmental health field. Gruskin et al. (2012) have pointed out to the importance of highlighting first the differences and benefits that HRBAs could bring to policies and programs (GRUSKIN et al., 2012). Another point that could be reproduced would be to develop studies that combine risk assessments and household's vulnerability with exposure sensitivity and risk management strategies (HELTBERG, 2009). The goal, as Samet points out, should be to "provide a universal rationale and approach for action, even in the face of widely varying legal and regulatory schemes" (SAMET, 2015), which implies to accept that a safe environment and health are universal concepts that should be assimilated in air pollution design and management.

There are several other aspects to the application of HRBAs including determining who is responsible for the costs of the environmental damage while the focus is individual: who pays and who suffers from it (BELL, 2013). Bell proposed to share evenly the costs of climate change mitigation, an idea that could be extended to pollution control. Another point brings back to mobility in urban centers and the idea that available for all, decent quality and efficient modes of transports are essential at the urban level to the success of the HRBAs. Understanding what is happening in each city at the neighborhood level and fostering communication between academics and communities will be key to foster research that could turn into more inclusive air pollution policies (KINNEY et al, 2000). As individual motorized transportation tends to rise in some of the most developing cities, incorporating these aspects will continue being key to successful air pollution policies and strategies.

5.4 Manuscript 2: Clean air matters: an overview of traffic-related air pollution and pregnancy

Manuscript approved by the Revista de Saúde Pública and expected to be published by September 2016.

The manuscript brings a new research perspective to linking the issue of a safe pregnancy to the quality of air. Indeed, as researchers have demonstrated the relationship between pregnancy outcomes and air pollution exposure, in particular related to low weight of newborns, a safe environment has been strongly linked to delivery conditions. Importantly, a growing number of researchers have used epigenetics and exposome studies to demonstrate the impact of air pollution at different stages of pregnancy. This article focuses on the topic of including clean air as a human right for pregnant women.

MS6652 Tipo: Comentário

Clean air matters: an overview of traffic-related air pollution and pregnancy

A relevância do ar puro: a poluição atmosférica decorrente do trânsito e a gravidez

Título resumido: Clean air and Maternal Health

ABSTRACT:

The right to a healthy pregnancy and to giving birth in a safe environment is source of comprehensive research. Decent birth facilities, respect and no discrimination are already recognized as fundamental rights, but an accurate look at the outdoor environment is required. Air pollution is a dangerous factor to pregnant women and newborns, many of whom highly exposed to traffic-related atmospheric pollutants in urban areas. Such exposure can lead to major health problems like low birth weight as well as long-lasting effects like respiratory diseases and premature death. Thus, this commentary, based on the analysis of literature, presents the importance of the exposome concept and epigenetics in identifying the role of the environment for better health conditions of pregnant women and newborns. In the final considerations, this paper proposes the deepening of the subject and the mobilization in this regard, with a human rights-based approach to environmental health and to the increased awareness of pregnant women on the risks of air pollution and related outcomes.

DESCRIPTORS: Maternal health, environment, air pollution, rights

RESUMO:

O direito a uma gestação saudável e ao parto em local seguro é tema de amplas pesquisas. Instalações adequadas, respeito e não-discriminação já são reconhecidos como direitos fundamentais, mas falta um olhar acurado para o ambiente externo. A poluição do ar é danosa para a saúde da mãe e dos recém-nascidos, muitos deles sujeitos a elevados graus de poluentes atmosféricos na urbe, como aqueles decorrentes do trânsito. Tal exposição pode causar impacto como baixo peso ao nascer

e efeitos duradouros à saúde, como doenças respiratórias e morte prematura. Este comentário, baseado em análise de literatura, introduz a relevância do conceito de expossoma e da epigenética na identificação do papel do meio-ambiente na garantia de condições de saúde dessa população. Nas considerações finais, o estudo propõe o aprofundamento do tema e a mobilização nesse sentido, com uma abordagem baseada nos direitos à saúde ambiental e maior consciência das gestantes quanto aos riscos associados à poluição do ar e seus efeitos na saúde.

DESCRITORES: Saúde materna, meio-ambiente, poluição do ar, direitos

INTRODUCTION:

Maternal health studies have demonstrated the importance and the right of women to safe and healthy pregnancy and delivery. Mistreatment during pregnancy, in particular during labor, has been associated with discrimination, abusive procedures,[5,6] and lack of communication of the multiple dimensions of intervention risk,[7] resulting in violation of women´s right to decent health care during pregnancy and safe labor.[8,9] The World Health Organization has acknowledged and emphasized women´s rights to assistance and respect during pregnancy and labor, calling for better practices and women´s empowerment and participation in the decisions related to their body and to their

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5. Gruskin S. Rights-based approaches to health: something for everyone. *Health and Human Rights*. 2006; 9(2): 5–9. DOI:10.2307/4065399

children.[10] In addition, research has shown that the environment plays an important role in maternal health and birth outcomes either via the mode of delivery on the baby's immune system and health, [1,11] or by environmental degradation, such as air pollution. This said, there is still a gap in including the right to a healthy environment, in particular clean air, as a major component of a safe pregnancy and delivery. This commentary aims to highlight the issues related to air pollution, in particular in urban centers, and how it is essential to develop more exposure assessments to include the environment into a healthy pregnancy agenda.

AIR POLLUTION AND MATERNAL HEALTH:

Air pollution is defined by the World Health Organization (WHO) as "the contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere" [12] and constitutes one of today's major global environmental challenges. Furthermore, the WHO has recently published that air pollution is at the origin of 7 million premature deaths, among which 3.7 million are attributed to outdoor air pollution.[6] The Organization for Economic Co-operation and Development (OECD) has projected that particulate matter, one of the major air pollutants, will be the second cause of premature deaths by 2050.[13]

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6. World Health Organization. Declaração da OMS. Prevenção e eliminação de abusos, desrespeito e maus-tratos durante o parto em instituições de saúde. 2014. Available on: <http://apps.who.int/iris/bitstream/10665/134588/3/WHO_RHR_14.23_por.pdf>. Accessed: June 30, 2015.
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In general, outdoor pollutants are generated by natural phenomena (volcanos for example), industries (fixed sources) or by internal combustion vehicles (mobile sources). In cities, atmospheric pollution is today one of the major environmental health issues facing populations. It is of great importance to understand the overall effects of air pollution on human health. For instance, research has linked changes in life expectancy with changes in the levels of air pollution particulates in North American cities between the 1980s and 1990s,[14] when a decrease on particulate levels was associated with higher life expectancy. In urban areas, one of the most important primary sources of atmospheric pollution is car emission; posing a challenge as vehicle fleets are rapidly increasing [15] and emission restrictions are sparse. Research has demonstrated that harm is bigger in regions where heavy traffic is concentrated and points to the consequences on the respiratory and circulatory systems.[16,17,18]

In addition to respiratory and cardio-vascular diseases, birth outcomes, diabetes and arteriosclerosis are also known to be associated to the exposure to atmospheric

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pollution. However, some populations carry a burden of disease,[19,20,21] more than others. This vulnerability is particularly found in children [12,22,23] and elderly people.[24,25,26]

Increasing numbers of studies also correlate air pollution with women´s health and birth outcomes. Indeed, pregnant woman who are exposed to air pollution during the first trimester of pregnancy are more likely to have low weight or pre-term newborns.[16,27,28,29] In a systematic review and meta-analysis of 60 studies, a relation was found between pregnancy outcomes and particulate matter, nitrogen dioxide and carbon dioxide, pointing out however, that the time and levels of exposure were major components to better understand consequences on health.[30] The exposure to air

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pollutants is today explored at the fetus stage via the mother, suggesting that reducing this exposure could be beneficial to the infant. Indeed, this early life exposure is linked to birth outcomes previously mentioned.[31] For pregnant women, some studies also suggest that air pollution is related to hypertension during pregnancy [32] and pre-eclampsia during labor [33,34] – one of the main causes of maternal and fetal death. Asthma is another important outcome of air pollution during pregnancy in exposed women, but also in children,[12] who are more likely to develop asthma in their early life.

Research opportunities

Another approach to understanding the correlation between humans and the environment is the *exposome* concept. This concept underlines the idea of adding all the different sorts of exposure in the life of a human being.[35] As stated by Wild,[31] this exposure implies taking into consideration general external, internal and specific internal factors. For instance, according to Wild[31], “it is important to highlight the particular environment of the child, namely the body of its mother”. In this concept, the overlapping of the different exposures is an essential component into assessing and measuring the exposure´s impact. One of the most useful tools to measure the *exposome* while understanding maternal health and air pollution are “biomarkers” (genetics among them) and sensor technologies such as air pollution monitoring stations. Epigenetic effects on prenatal and infant periods are well studied, but recent analyses have demonstrated the

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31. Wild CP. The exposome: from concept to utility. *International Journal of Epidemiology.* 2012; 41(1): 24–32. DOI:10.1093/ije/dyr236

role of epigenetics using an *exposome* approach on labor or birth outcomes.[36] As explained by Dahlen et al.,[32] this research is promising in helping understand how some procedures used during labor, such as oxytocin, caesarean delivery can actually affect the epigenetic processes of the mother and the child.

The Helix project, a European initiative, has carried on the objective to study pregnancy and early stages in life as a major component to understand "lifetime consequences" on health, considering this period as the "starting point for development of exposome".[37]

FINAL CONSIDERATIONS:

As the link between maternal health and birth outcomes is of growing concern to a large body of researchers, some aspects remain of great importance to further analysis. The effects of air pollution on health are known, as well as the perspective of how problematic they can be to pregnant women and their babies. However, despite all the evidence, there is still no inclusion of the right to clean air and healthy environment as a major component of women´s right to a safe pregnancy and delivery; and some questions remain open to better comprehend what could be other measurements to evaluate these outcomes. In this sense, *exposome* and epigenetics could constitute an important field of study. Furthermore, as the human rights-based approach is integrated to health and environment, it will be essential for pregnant women to fully understand the environmental risks associated to unsafe pregnancy. As women are more empowered to understand the effects of air pollution during pregnancy and health outcomes, they will be able to make better choices. Scholars, environmentalists, policymakers, families and healthcare providers have a very important role to play to ensure that environmental equity and a right-based approach are taken into account.

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6 CONCLUSION

This research was quite ambitious in that it incorporated more than 20 years of policies and programs in three of the world's most renowned cities. As seen in the first published manuscript, studying air pollution policies in urban centers constitutes an important factor in climate change mitigation. In this sense, the main objective of this study was to identify and analyze air pollution management strategies implemented in São Paulo, New York City and Paris and to foresee to what extent a local government´s action could serve as a model for other cities facing critical air pollution issues. From the description and analysis of these major actions, it was revealed that choosing the right policy is a complex task which requires knowledge, access to technology and policymakers' convictions to enforce strategies and programs.

The examples of São Paulo, Paris and New York City have shown that even with chronic levels of exposure to air pollutants, air pollution standards and levels continue to be above recommended WHO guidelines despite an extensive public transportation system in New York City and Paris. The literature also demonstrated that the implementation of stricter vehicle emission standards in each urban center was not enough to improve air quality, unless it was followed by technological improvements and cleaner fuels. São Paulo and New York City both focused their air pollution control efforts on regulation strategies while Paris focused on public and active transportation strategies from the beginning. Thus, the three cities over the past five years have attached particular importance to linking mobility aspects to air quality. Out of the three cities, Paris was unique in having the most programs with an economic incentive. However, they were driven by fuel and technological improvements. In São Paulo and New York City, economic incentives were linked to the automobile industry, which left unanswered questions about the environmental motivations behind such measures. However, the introduction of better vehicle technologies have been of tremendous importance to reduce vehicular pollution emissions but not enough as seen in São Paulo due to the continuous growing number of vehicles in the city.

Furthermore, the different management approaches to air pollution also raise several question in the sense that regulatory approaches are mandatory while economic incentives and others are optional, which in turn, raises the question of policy adhesion and its importance to air quality. When the city of Paris experienced high levels of air pollution in 2014, a set of regulatory measures was re-installed, a discontinuation from its primary focus on public transports initiatives. The example of the vehicle inspection in São Paulo also showed that scale was an important factor to a successful policy. Indeed, the initiative was city wide, which might have prevented it from succeeding. The case of Paris has also demonstrated how meteorological factors, in the case of the 2014 air pollution episode can affect air pollution levels but has also showed that air pollution management approaches also vary according to the gravity of the different levels of air pollution. Indeed, there are several factors to be included when defining programs and initiatives to improve air quality. Among some of them, we understand today that command and control (regulatory) are not enough anymore to cope with air pollution and should be combined with programs that foster active transportation, promote green spaces and considers scale and governance as important aspects of efficient policies.

SWOT analysis was the most effective way to summarize findings and bring together information to support policymakers' efforts and to encourage a more in-depth application of this methodology. Indeed, a SWOT analysis can help cities looking to replicate models implemented elsewhere understand the internal and external factors that can improve strategy as well as key factors for success.

Some external factors, though, could be offset by incorporating a human-rights perspective into air pollution control policy, in particular when mitigating inequity in cities.

To conclude, some recommendations can be drawn from the study of São Paulo, New York City and Paris:

- The energy matrix choice has to encompass vehicle technology and clean fuels. As energy scarcity has become a contemporary reality, the search for clean energy should be a policy priority.
- It is important to foster various modes of travel within a city, which are available to the greatest number of people. Integrated modes of transport have proven to be efficient in many cities around the world but can only work if there is an understanding by the local government that encouraging active transportation is an environmental tool, not an economical driver.
- Additional tools to monitor and evaluate the efficiency of implemented policies must be developed. In many ways, all three cities have achieved a long-term vision of a

sustainable city but have failed to develop further tools that could measure the real impact of these programs and strategies.

- The interdisciplinary challenge of improving air quality by encouraging more interactions between different fields and their impact on environmental health must be overcome. For instance, it would be important to develop and encourage more dialogue between environmental agencies, transportation, health and urban planning departments (especially regarding housing and work location) in order to develop policies that can incorporate a greater number of urban issues.
- Technology transfer to overcome gaps in data gathering between cities around the world must be encouraged. This is particularly important for air pollution and emission levels monitoring.
- More research must be executed on a neighborhood scale. Both New York City and Paris had literature on this type of approach, but in São Paulo, it was scarce. Indeed, cities are the reflection of society inequities and incorporating neighborhood-level research is essential to understanding the disparities and particularities of air pollution in each city.

This study has emphasized the potential that the human rights-based approach (HRBA) offers in lowering the impacts of air pollution and works toward urban equity. The second manuscript on maternal health, air pollution and human rights attempted to open the dialogue on a recent research field. Furthermore, the HRBA has the potential to work towards a global solution that could outreach to a greater number of urban centers and advance a global common goal: improving air quality and mitigating climate change. While this research has touched on several major points on air pollution control in urban centers it could not go into greater detail on some other aspects; however, further research on cross-city studies is strongly encouraged.

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ANNEX 1 Geographical Map of São Paulo, New York City and Paris

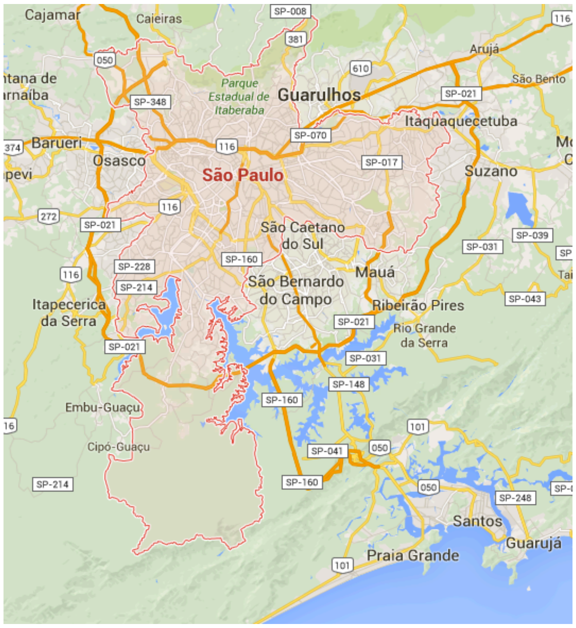


Figure 4 – Map of the Municipality of São Paulo
Source: google maps

Figure 5 – Map of the Municipality of New York.
Source: google maps

Figure 6 – Map of the Municipality of Paris
Source: google maps

ANNEX 2 Evolution of the legislation on sulfur content in diesel in Brazil

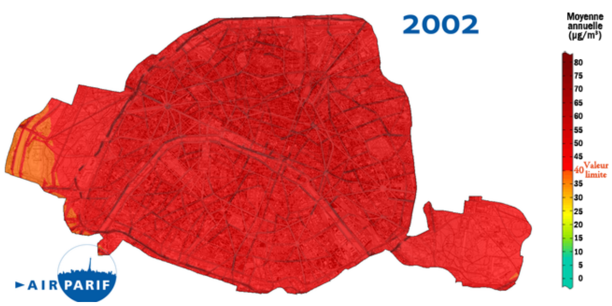
Dispositivo Legal		Diesel				
Nº	Data Edição	Enxofre Máximo Limite (mg/kg)				Início da Comercialização
Resolução CNP nº 7	22/01/1980	13.000 (1)				-
Portaria DNC nº 28	20/12/1993	A	B		D	-
		10.000	5.000		10.000	
Portaria DNC nº 9	23/03/1996	A	B	C	D	-
		10.000	5.000	3.000	10.000	
Portaria DNC nº 32	04/08/1997	A	B	C	D	-
		10.000	5.000	3.000	2.000	
Portaria ANP nº 310	27/12/2001	Metropolitano		Interior		-
		2.000		3.500		
Resolução ANP nº 12	22/03/2005	Ônibus Urbano	Metropolitano		Interior	-
		500	2.000		3.500	
Resolução ANP nº 15	17/07/2006	Metropolitano		Interior		-
		500		2.000		
Resolução ANP nº 32	16/10/2007	Fase P6 - S50				-
		50				
Resolução ANP nº 41	24/12/2008	Metropolitano		Interior		S-1800: a partir de 1º de janeiro de 2009
		500		1.800		
Resolução ANP nº 31	14/10/2009	Fase P7 - S10				-
		10				
Resolução ANP nº 42	16/12/2009	S-50	S-500		S-1800	
		50	500		1800	
Resolução ANP nº 65	09/12/2011	S-10	S-50	S-500	S-1800	S-50: a partir de 1º de janeiro de 2012
		10	50	500	1.800	
		Metropolitano		Interior		S-10: a partir de 1º de janeiro de 2013
		10/500		500/1800		
		Metropolitano		Interior		S-500: a partir de 1º de janeiro de 2014
		10/500		500		
Resolução ANP nº 50	23/12/2013	S-50		S-500		01/01/2014
		50		500		

(1) Flexibilizado tendo em vista a crise do petróleo de 1973

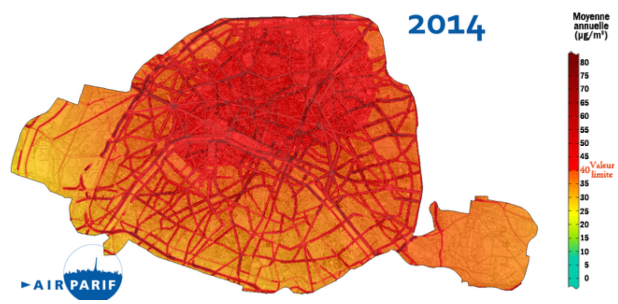
Extracted from CETESB Emission inventory – State of São Paulo, 2014

ANNEX 3 Maps of evolution of Air quality in Paris showing roads and air pollution concentrations

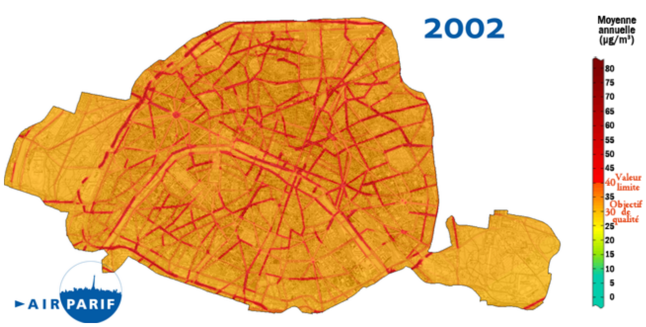
NO_2 2002



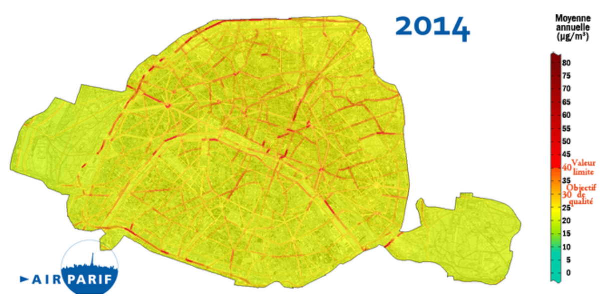
NO_2 2014



PM_{10} 2002

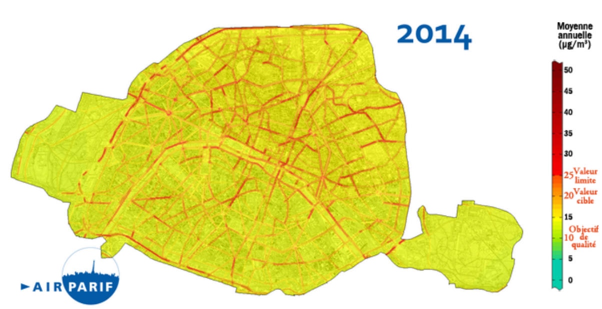


PM_{10} 2014

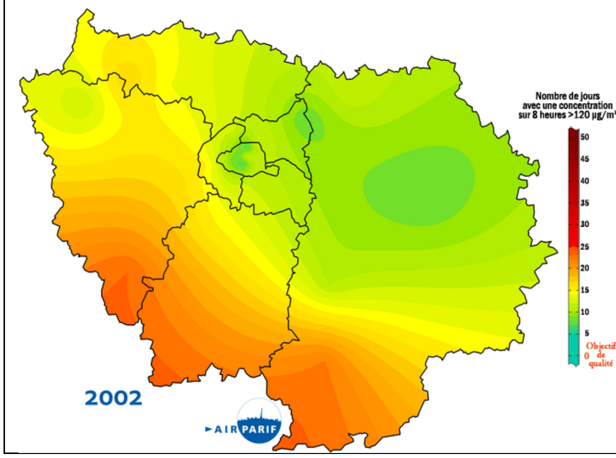


$PM_{2.5}$ 2007

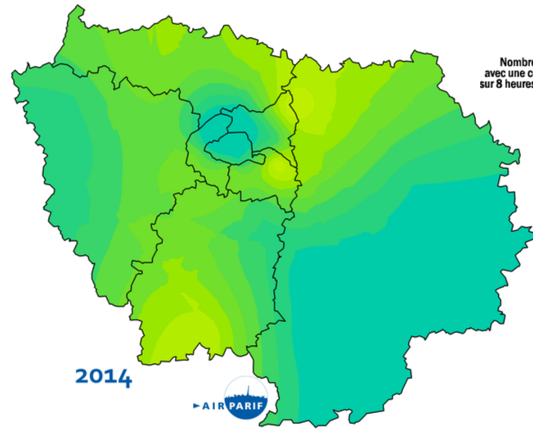
$PM_{2.5}$ 2014



Ozone Paris- Ile de France 2002

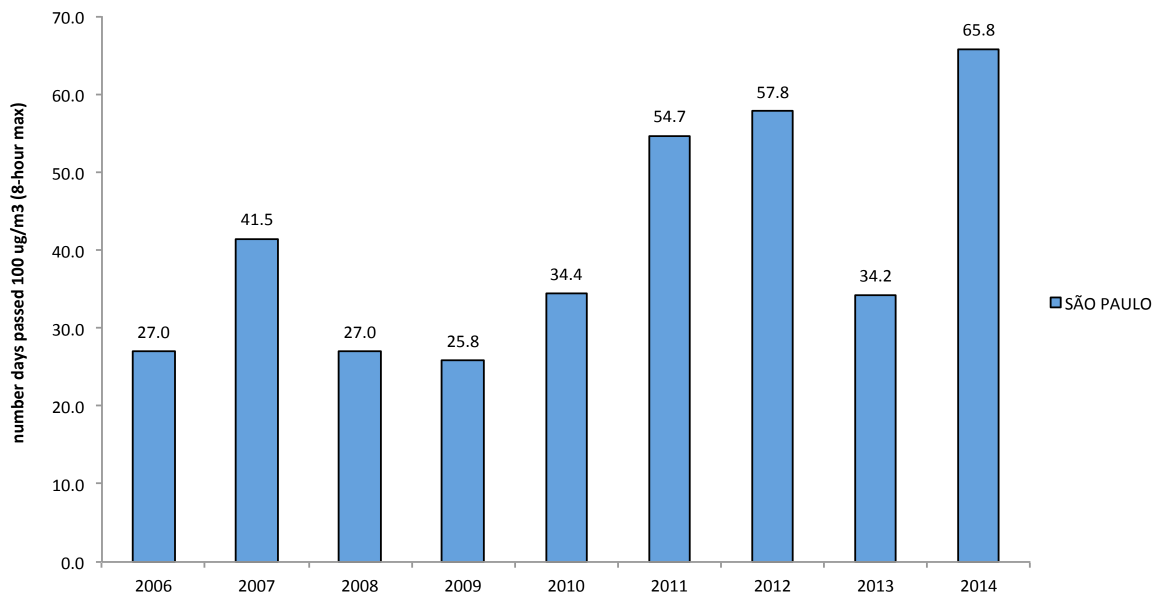


Ozone Paris – Ile de France 2014



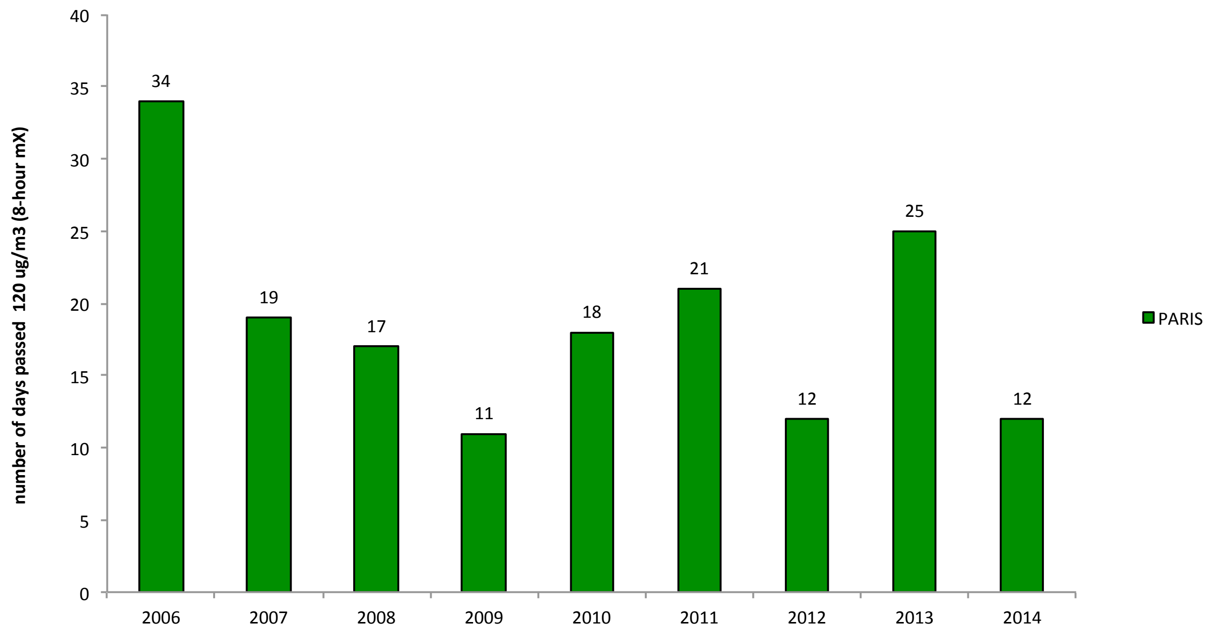
Source: Airparif

ANNEX 4 Number of days exceeding $100ug/m^3$ in São Paulo: 2006-2014



Adapted from Qualar online database – CETESB

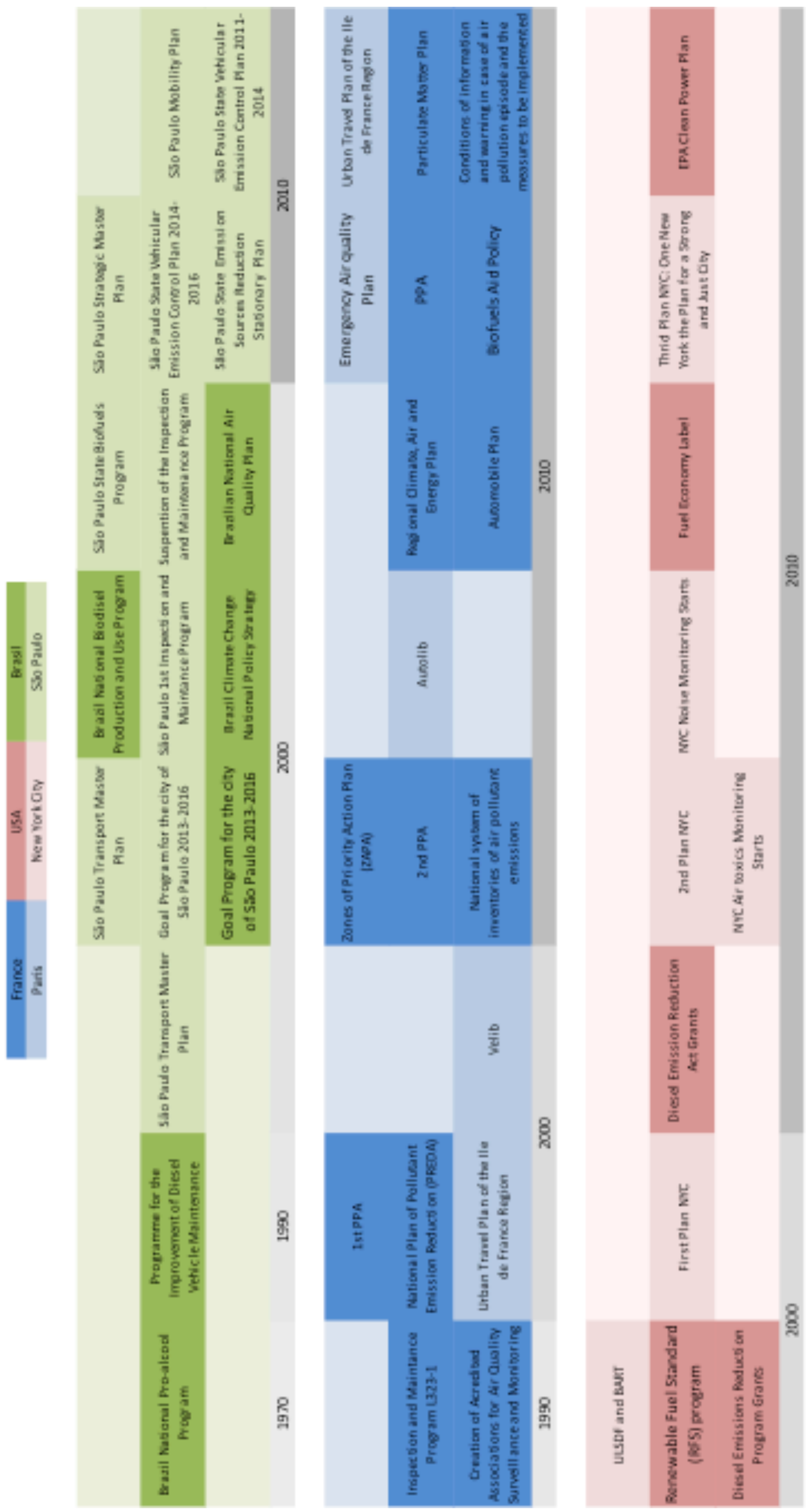
ANNEX 5 Number of days exceeding 120ug/m^3 in Paris: 2006-2014



Adapted from Airparif 2014 air quality report

ANNEX 6 Chronological background of main implemented programs in Sao Paulo, New York City and Paris: 1975 – 2015

Table 13 – Chronological background of main implemented programs in Sao Paulo, New York City and Paris: 1975 – 2005



Elaborated by AD Slovic
Source: New York (EPA, NYS DEC, NYC DEC, NYC Dept of city planning, NYMTC) – São Paulo (MMA, ANP, CETESB, Secretaria de Transporte, SVMA – Paris (DRIEE, Mairie de Paris, DRIEA, Airparif)

CURRICULA LATTES
AUTHOR

Anne Dorothee Slovic

Bachelor's of Arts in International Areas Studies from Drexel University (2002) Philadelphia, USA and Master's in International Affairs from the School of International and Public Affairs - Columbia University (2005) New York, USA. Currently, Phd candidate at the School of Public Health/ Environmental Health at the University of São Paulo, Brazil.
(Text informed by the author)

17/05/2016

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Formal Education/Degree

2012 - 2016 Ph.D. in Saúde Pública .
Universidade de São Paulo, USP, Brasil.
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Advisor: Helena Ribeiro.
Grantee of: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior ,CAPES ,Brasil .
Keywords: Saúde Ambiental; poluição do ar; políticas públicas; populações vulneraveis; controle de poluição do ar; mobilidade.
Major Area: Health Sciences.

2003 - 2005 Master´s in Negocios Internacionais - SIPA .
Columbia University, COLUMBIA, Estados Unidos. *Year of degree*: 2005.
Advisor: Eric Hershberg.
Keywords: Sustentabilidade; Desenvolvimento econômico; Moçambique; castanha de cajú; Geração de renda.
Major Area: Humanities.
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Activities Sectors: Other International Organizations; Activities related to associative organizations.

1998 - 2002 Graduation in Bachelor of Arts in International Areas Studies .
Drexel University, DREXEL, Estados Unidos.

Complementary Education

2014 Programa Bolsa Sanduiche. (Credit Hours: 640h).
Princeton University, PRINCETON, Estados Unidos.

2012 - 2012 Continuing education in Tópicos Especiais em Transporte e Qualidade do Ar. (Credit hours: 40h).
Universidade de São Paulo, USP, Brasil.

2007 - 2007 Avaliacao de Projetos Sociais. (Credit Hours: 80h).
Universidade de São Paulo, USP, Brasil.

Professional Experience

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Última atualização do currículo em 17/11/2015

bachelor's at Geography from Pontifícia Universidade Católica de São Paulo (1972), master's at Geography from University of California Berkeley (1981) and doctorate at Physical Geography from Universidade de São Paulo (1988). Has experience in Geosciences, focusing on Geographical Climatology, acting on the following subjects: environmental health. urban health, medical geography, air pollution, climate changes and environmental education. Professor of the Environmental Health Department of the School of Public Health of the University of São Paulo. Former professor of Pontifícia Universidade Católica de São Paulo. Former Environmental advisor to the Mayor of São Paulo Former Member of the Executive Commitee of ICLEI - International Council for Local Environmental Initiatives. **(Texto informado pelo autor)**

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Formação acadêmica/titulação

1984 - 1988	Doutorado em Geografia (Geografia Física) (Conceito CAPES 5). Universidade de São Paulo, USP, Brasil. Título: Poluição do ar e doenças respiratórias em criança da Grande São Paulo: um estudo de geografia médica, Ano de obtenção: 1988. Orientador: José Roberto Tarifa. Bolsista do(a): Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, CAPES, Brasil.
1977 - 1981	Mestrado em Geografia. University of California Berkeley, UCB, Estados Unidos. Título: Sequent land use and environmental issues in a subtropical milieu: the case of São Simão, in the State of São paulo, Brazil,Ano de Obtenção: 1981. Orientador: Hilgard O'Reilly Sternberg. Palavras-chave: agricultura sustentável; Cobertura Vegetal; Degradacao Ambiental.