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# Tool for assessing health and equity impacts of interventions modifying air quality in urban environments

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ABSTRACT

*Background:* Urban outdoor air pollution (AP) is a major public health concern but the mechanisms by which interventions impact health and social inequities are rarely assessed. Health and equity impacts of policies and interventions are questioned, but managers and policy agents in various institutional contexts have very few practical tools to help them better orient interventions in sectors other than the health sector. Our objective was to create such a tool to facilitate the assessment of health impacts of urban outdoor AP interventions by non-public health experts.
*Methods:* An iterative process of reviewing the academic literature, brainstorming, and consultation with experts was used to identify the chain of effects of urban outdoor AP and the major modifying factors. To test its applicability, the tool was applied to two interventions, the London Low Emission Zone and the Montréal BIXI public bicycle-sharing program.
*Results:* We identify the chain of effects, six categories of modifying factors: those controlling the source of emissions, the quantity of emissions, concentrations of emitted pollutants, their spatial distribution, personal exposure, and individual vulnerability. Modifiable and non-modifiable factors are also identified. Results are presented in the text but also graphically, as we wanted it to be a practical tool, from pollution sources to emission, exposure, and finally, health effects.
*Conclusion:* The tool represents a practical first step to assessing AP-related interventions for health and equity impacts. Understanding how different factors affect health and equity through air pollution can provide insight to city policymakers pursuing Health in All Policies.


## 1. Introduction

Air pollution is a major contributor to the global burden of disease and mortality (Balakrishnan, Cohen, & Smith, 2014; Brauer et al., 2011) and is estimated to cause 1.3 million deaths worldwide each year (Smith et al., 2014). Urban ambient air pollution is a priority for action as the world population becomes increasingly urbanized (World Health Organization, n.d.-a) and as urban environments concentrate industrial and transport activities affecting air quality. Furthermore, interventions aiming at improving health may paradoxically increase health inequities and it is now recognized both should be addressed in order to maximize the positive impacts of policies and interventions (Benach, Malmusi, Yasui, & Martínez, 2012). It is therefore still necessary to include the assessment of equity in policy evaluation. The recognition that policies and interventions, in sectors other than the health sector, have an important effect on air quality and ultimately health, increases the need to provide managers and policy agents, in various occupational sectors, with tools and information to help them better assess the impact of interventions. In fact, public health is becoming more deeply integrated within city policymaking and programming, and is likely to gain even more importance in the coming years with such movements as Health in All Policies (HiAP) (World Health Organization & Government of South Australia, 2010) and the WHO's Healthy Cities networks (World Health Organization, n.d.-b) emphasizing the need for increasing positive impacts on health but also on social inequities. Both movements push for greater intersectoral collaboration within governments in order to achieve health objectives, and guidance is needed to help anticipate and assess the

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impact of interventions on air quality and health in urban environments (Benmarhnia et al., 2014). Some academic literature has highlighted different policies that can be implemented to reduce air pollution levels in urban areas. The policies that have been documented include for instance pollutant regulations (e.g. lead banning), low emission zone implementation, or speed limitation. Yet there is still a lack of studies evaluating the health and equity impacts related to policies aiming to reduce air pollution (Giles et al., 2011; Henschel et al., 2012; Wang, Xing, Zhao, Jang, & Hao, 2014) and further evidence in relation to the effectiveness of policies described above is still needed.

The objective of this article is to propose a tool, designed primarily for non-health experts (though public health experts may also find it useful), to support them in the health and equity assessment of policies and interventions affecting air pollution. This tools aims at identifying the various modifiable factors that can be mobilized to increase positive impacts of policies and interventions. It can be used by urban planners, health policy decision makers, and other municipal authorities who may not necessarily have or need sophisticated epidemiological models.

Three domains of research were mobilized to build the tool: public health, with its long standing analysis on health determinants; air pollution research, which analyzes contributors to pollution and their impacts on health and equity; and evaluation, with its important work on logic analysis. The tool has been tested on to two interventions: the Low Emission Zone in London, and the public bike sharing system in Montreal.

## 2. Methods

To build the tool, the authors first conducted a scoping review of the literature of air pollution with a broad perspective, including sources of air pollution, air pollution interventions, and complementary subjects such as exposure measurement, green spaces, and behavior. Keywords, titles, and abstracts were searched in PubMed, Cochrane Library and Embase to identify relevant publications (see Supplemental material for keywords). The abstracts of all studies were reviewed to determine inclusion. In addition, the reference sections of studies identified in this way were hand-searched for additional studies. No restrictions were put on date, geographical location, or language of publication.

We used an iterative process to identify a basic causal path for air pollution in urban areas from sources to health and then to equity effects, incorporating all types of pollutants and for both acute and chronic health effects. The tool can be assimilated to a conceptual framework in direct logic analysis (Brousselle & Champagne, 2011; Rey, Brousselle, & Dedobbeleer, 2012; Tremblay, Brousselle, Richard, & Beaudet, 2013). Logic analysis usually encompasses three steps: (1) the building of the logic model of the intervention; (2) the building of the conceptual framework based on scientific knowledge; (3) the comparison of the logic model to the conceptual framework, with the objective to improve the intervention and to orient the evaluation. Therefore, the tool, which corresponds to step 2 of logic analysis (i.e. building the conceptual framework), represents the causal path from emitting sources to health effects and the modifying factors. This process was iterative as we drafted, based on our first readings, a framework that was used to analyze the next articles. There was an iterative process of brainstorming among the three researchers and review of the literature to improve the model through several cycles. We also identified, during our readings, various interventions affecting air quality. An analysis of these interventions was systematically conducted to challenge and complement the categories that were identified in the causal path as having an influence on health and equity (see Table 1).

**Table 1**
Classification of various urban interventions affecting outdoor air pollution-related health, according the factors they target and the level of their action.

| Levels of action | Factors targeted | Interventions |
|---|---|---|
| Sources | Regulatory context | - Ban on ingredients or technologies<br>- Ban on energy source (e.g. coal) |
| | Demand | - Energy pricing<br>- Fuel pricing<br>- Ecotaxes |
| | Urban design | - Limiting sprawl (mixed-use neighborhoods)<br>- Developing public transport |
| | Behavior | - Car buyback incentives<br>- Low emission zones |
| Emissions | Regulatory context | - Air quality monitoring<br>- Air quality standards<br>- Fuel emission standards<br>- Industrial emission standards<br>- Engine retrofitting |
| | Urban design | - Limiting sprawl<br>- Low emission zones |
| | Behavior | - Car pools, walking, biking, public transport initiatives<br>- Discourage engine idling<br>- Low emission zones<br>- Speed limits |
| Concentration | Topography/ weather | |
| | Architecture | - Build lower buildings<br>- Set buildings back from roads |
| | Green spaces | - Increase density of green spaces<br>- Favor shrubs and trees |
| Spatial distribution | Urban design | - Traffic routing/calming measures<br>- Zoning |
| | Green spaces | - Situate green spaces in highly polluted areas |
| | Behavior | - Restrict solid fuel burning in densely populated zones |
| Exposure | Behavior | - Voluntary information systems<br>- Walking/biking paths separated from routes |
| Vulnerability | Age | |
| | Comorbidities | - Physical activity interventions<br>- Nutrition interventions |
| | SES | - Employment/education interventions |
| | Other exposures | - Occupational interventions |
| Health effects (endpoint) | | - Secondary prevention<br>- Health care interventions |

This tool can be used first, to design the logic model of the intervention (step one of logic analysis); second, to identify relevant questions for the evaluation of the intervention; and third, to identify awareness-provoking questions for the improvement of the intervention. In order to test its applicability, the tool was applied to two interventions in urban areas. The first, the London Low Emission Zone, covers most of Greater London and imposes a daily charge on heavy vehicles that do not meet emission standards (Transport for London, n.d.). Its principal objective is to reduce air pollution. The other intervention, whose principal objective is encouraging active transport but which could have an indirect impact on air pollution, is the Montreal bicycle-sharing program "BIXI" (BIXI, n.d.). BIXI allows subscribers to borrow and return bicycles from stands located throughout the city. These interventions were chosen because there was sufficient documentation for analysis, and because they are representative of the kinds of interventions that are currently being put into place in urban settings in developed countries (Giles et al., 2011). Using the tool, the interventions were analyzed in order to identify relevant evaluation questions and elements that could help in fostering their positive impacts on health and equity. A dialectic process questioning each of the amenable elements was used to identify further pertinent questions for improving the intervention. The tool and the analyses were presented to and improved by two public health experts. We present the results here to illustrate the interest and applicability of the tool.

## 3. Results

### 3.1. The tool

In the tool (see Fig. 1) are factors that act on the emitting sources of pollution, factors that can modify the concentration of air pollutants once emitted, factors that can modify the spatial distribution of pollutants, and finally, the factors that modify the relationship between exposure and health effects, otherwise known as vulnerability. Factors that are amenable to intervention are shaded while un-modifiable factors are left white. We have also interpreted some factors as being either very difficult to intervene

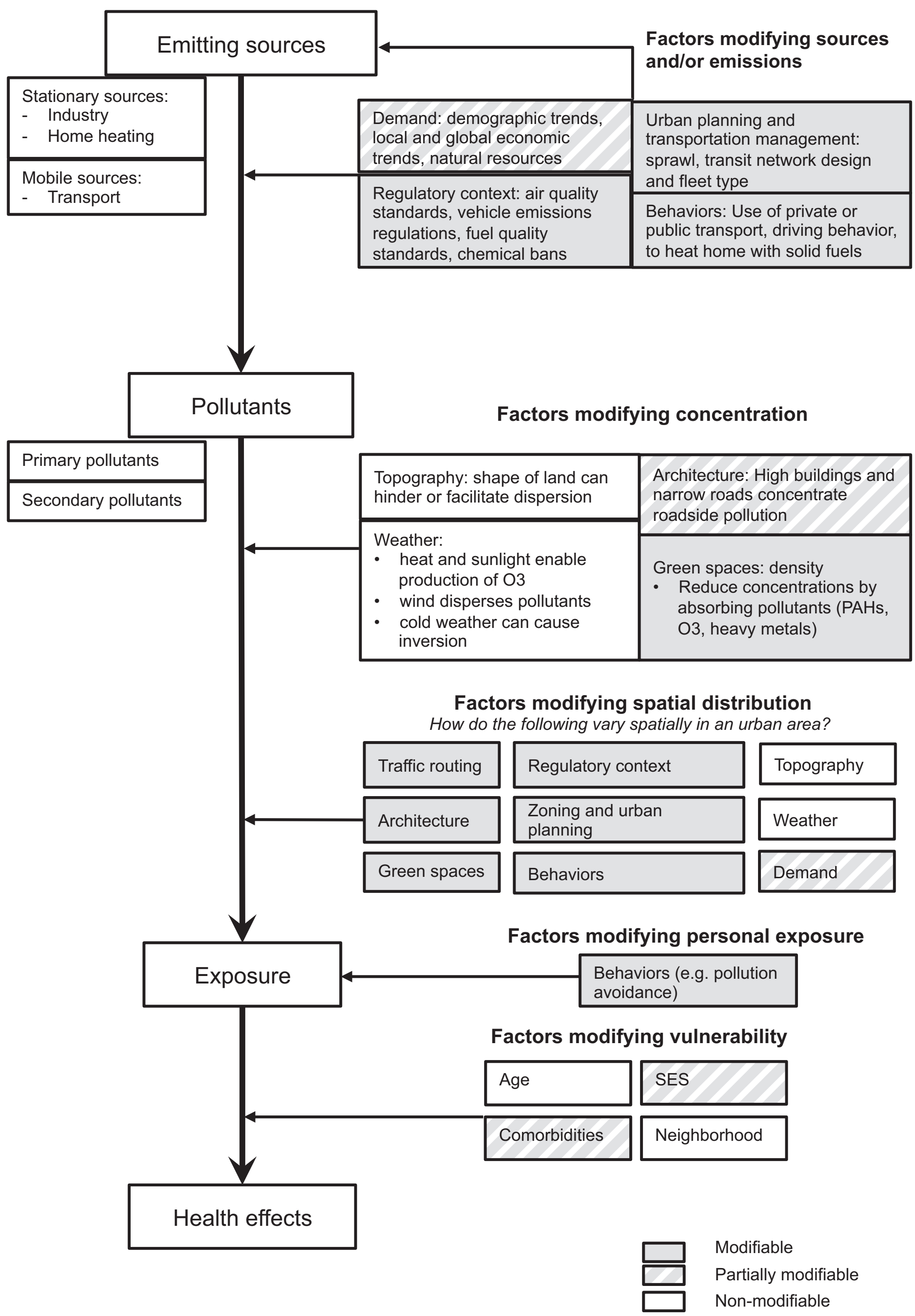


**Fig. 1.** Tool for assessing health and equity impacts of interventions and policies affecting air quality.

upon or that can only be intervened upon in certain contexts; they are presented in stripes.

### 3.2. Factors modifying sources and/or emissions

To the extent that air pollution's origins are mostly man-made, the factors that affect the sources and emissions of air pollution are also related to how people and institutions govern the use of technology, natural resources, and space. These factors are classified in terms of regulations, demand, urban planning, and behaviors, but it is important to note that the categories are flexible and factors within different categories can influence each other.

#### 3.2.1. Regulatory context

Most industrialized nations have a set of regulations in place to insure adequate air quality (Giles et al., 2011) that can vary for different sources of pollution (transport, industry, heating, etc.). These regulations can take the form of a ban on certain agents (Kuhlbusch et al., 2013), such as lead in gasoline; (Von Storch et al., 2003) or a technical requirement, such as three-way catalytic converters in cars (Farrauto & Heck, 1999; Merget & Rosner, 2001). There are also standards set by governmental agencies for levels of pollutants (Bell, Morgenstern, & Harrington, 2011). The most important of these is the Clean Air Act in the United States (Lawrence, 1971), regulation initially passed in 1970 and amended periodically ever since (Samet, 2011) that requires states to adopt and enforce plans to achieve and maintain pollution levels below federal standards (United States Environmental Protection Agency, n.d.). Lastly, the choice of a metropolitan area of one or more main sources of energy also plays a large part in the emission of pollutants (Mena-Carrasco et al., 2012).

#### 3.2.2. Demand

Economic, political, and cultural factors can shape the needs of an urban area in terms of transport, heating, or industry (Lioy & Georgopoulos, 2011). For example, a city that is highly dependent on tourism may prioritize public transportation, green spaces and walkability in its center and push industry to the outskirts. Cultural values associated with car ownership, for example, can generate high demand for cars in proportion to other methods of transportation. Global economic trends like the increasing reliance on imported goods can also impact emissions over time (Perez et al., 2009).

#### 3.2.3. Urban planning

Urban sprawl, which in and of itself is dependent on factors like topography, demographic shifts, and values can lead to increased demand for cars and longer journeys in cars (Frumkin, 2002). The design of the public transportation system in a city will also affect demand for private transportation (Mena-Carrasco et al., 2012). Different public transportation systems will be more or less polluting depending on their energy sources.

#### 3.2.4. Behavior

The behavior of residents within an urban area is conditioned by all of the preceding factors. Residents may have several options for transportation (bicycle, motorcycle, bus, train, or car) or for heating and the frequency with which they use each will affect the total emissions from each source (Krizek, 2003; Litman, 2005).

In the schematic the above factors are linked both to the source and to emissions, in the sense that they are determinants for the very existence of the source, or they can modify the quantity of air pollutants emitted. For example, policies banning fuel additives work on the source, while dense multi-use neighborhoods, by minimizing car use, work on the emissions.

### 3.3. Factors modifying concentrations

Once pollutants are emitted, they disperse in the atmosphere. There are several natural and man-made factors that influence how pollutants are dispersed, trapped, or absorbed.

#### 3.3.1. Topography and meteorology

The shape of the land in an urban area can help or hinder the dispersion of pollutants into the atmosphere, often working in conjunction with the weather (Wallace, Corr, & Kanaroglou, 2010). Valleys lower wind speed, slowing down dispersion, while a coastal location benefits from higher wind speeds (Hertel & Goodsite, n.d.). In particular, cold weather in a valley can create inversion, trapping air pollution near to the ground. Heat and sunlight enable the transformation of $NO_x$ and subsequent production of ozone (Ran et al., 2009).

#### 3.3.2. Green spaces

Vegetation absorbs some pollutants like PAHs and ozone, and foliage is capable of trapping and absorbing suspended particulate matter (Vida, 2011). The surface area devoted to green spaces in a city can thus affect the concentrations of these pollutants. However, not all green space is equal. For example, Peng, Ouyang, Wang, Chen, and Jiao (2012) found that the type of vegetative cover plays a role in how much pollution is absorbed; woodland and tree–shrub–herb settings trapped more PAH than grassland.

#### 3.3.3. Architecture

Architectural factors can include (but are not limited to) building materials, shape and size, distance from roads or road width. Colvile and colleagues (Colvile, Hutchinson, Mindell, & Warren, 2001) mention that narrow roads bordered by high buildings mitigate wind speeds, raising concentrations of pollutants from vehicle emissions. By contrast, open roads disperse vehicle emissions more effectively.

### 3.4. Factors modifying spatial distribution

All of the factors that affect sources, emissions, and concentrations have the power to affect the spatial distribution of pollutants (Gilbert, Goldberg, Beckerman, Brook, & Jerrett, 2005; Ragettli, Ducret-Stich, et al., 2014; Ross, Jerrett, Ito, Tempalski, & Thurston, 2007), depending on how these factors act across an urban area. Spatial distribution here refers to intra-urban exposure heterogeneity and does not encompass the differential distribution that can occur between a city and its surroundings (Ragettli, Tsai, et al., 2014). The following is a selection of examples to illustrate how these determinants may be acted upon in order to modify the spatial distribution.

#### 3.4.1. Traffic routing

Highways and other roads with high traffic density may not be evenly distributed throughout the city (Ducret-Stich et al., 2013). The question of where tunnels and overpasses are built also alters the distribution of pollution concentrations in a city. Trucks, for example, may only be authorized to pass through certain routes and this, too, will mean vehicle emissions will be higher in certain zones.

#### 3.4.2. Green spaces

Neighborhoods may have differential surface areas of green spaces (Lakes, Brückner, & Krämer, 2013), differential proximity of green spaces to roadways, or different types of land cover in such spaces (De Ridder et al., 2004; Wolch, Byrne, & Newell, 2014). Any of the aforementioned variations will reduce concentrations of pollutants to a greater or lesser extent as discussed above.

#### 3.4.3. Zoning and urban planning

Residences, nursing homes, or schools may be sited far away or close to industrial areas or densely trafficked roads. They may be well- or ill-served by public transportation routes.

#### 3.4.4. Behavior

As with behaviors affecting the source, behaviors here are highly constrained by the more upstream factors listed above. Different neighborhoods may have access to different modes of transportation or heating sources (Cohen, Boniface, & Watkins, 2014), leading for example to distribution of wood-burning-related pollution that is centered in neighborhoods without access to gas heating.

### 3.5. Factors modifying personal exposure

*Behavior.* An individual's exposure to air pollution depends on their behaviors in time and space, also known as time-activity patterns (Blangiardo, Hansell, & Richardson, 2011; Dons et al., 2011). Additionally, individuals with increased vulnerability to air pollution (such as asthmatics) may change their behaviors to avoid exposing themselves to high levels of air pollution (Buonanno, Stabile, & Morawska, 2014).

### 3.6. Factors modifying vulnerability

As research on social determinants of health and environmental justice have demonstrated, the most socially and materially deprived are also those who will experience a larger impact on their health for the same exposure (O'Neill et al., 2003). Indeed, two individuals may be exposed to similar air pollution levels but the health effects for one may be more pronounced, due to other social determinants of health such as co-morbidities, age, or socioeconomic position. Vulnerability refers to individual and contextual factors that modify the relationship between a given person's exposure and the health effects they may have (Forastiere et al., 2007).

It also must be noted that the health effects associated with air pollution can be caused by many other factors, at least some of which are addressed by other interventions. For example, exposure to PM is linked to a short-term increase in heart attacks (Peters, Dockery, Muller, & Mittleman, 2001) but there are several other determinants of heart attacks, including one's level of physical activity (Ahmed, Blaha, Nasir, Rivera, & Blumenthal, 2012), so a successful physical activity intervention may reduce a person's vulnerability to suffering an air pollution-related heart attack.

In order to integrate vulnerability factors documented in the epidemiologic literature, existing frameworks such as the PROGRESS framework (National Collaborating Centre for Methods and Tools, 2014) can be used. This framework proposes a range of vulnerability factors (e.g. place of residence, education, social capital...) which can help to analyze how various health and non-health interventions affect health equity.

The onus is thus on interventions targeting spatial distribution to take vulnerability into consideration, as this will play a role in determining the spatial distribution of health benefits from the intervention—a spatially homogenous intervention could offer disproportionately small health benefits to the more vulnerable.

The tool is used to identify relevant questions for the evaluation of the intervention, to identify questions for the improvement of the intervention (see Table 2) in general and for the two following case studies, the LEZ and the BIXI.

### 3.7. Two case studies

Two interventions are analyzed using the tool, one that explicitly aims to reduce air pollution (the London Low Emission Zone), and one intervention whose principal aim is not to reduce air pollution but which may have an impact on it (BIXI, Montreal's public bicycle sharing system).

#### 3.7.1. London Low-Emission Zone

In 2008 London launched a Low Emission Zone (LEZ), which covers most of the area known as Greater London. The zone, which is in effect 24 hours a day, imposes a daily charge for all larger vehicles (excluding cars and motorcycles) that do not meet Euro IV emission standards. The charges are designed to discourage non-compliant vehicles from entering into the zone: £100 for vans and

**Table 2**
Questions to be aware of for intervention evaluation and improvement, illustrated for two interventions.

| | General questions | BIXI | LEZ |
|---|---|---|---|
| Sources to pollutants | Question for intervention evaluation: Does the intervention have an impact on sources of emissions? | Does BIXI reduce the use of cars? | Within the geographical area defined by the LEZ, has the number of prohibited vehicles decreased? Are there some behavior changes that are more effective at achieving these impacts than others? |
| | Question for intervention improvement: Is it possible to modify the intervention so as to further reduce emissions? | What partners or areas should be targeted in order to further reduce car use? | How can the most favorable behaviors be encouraged by the intervention? |
| Pollutants to exposure | Questions for intervention evaluation: Are some groups more exposed to pollutants, due to the intervention? Does the intervention reduce exposure for those groups who previously had the highest levels of exposure? | Are BIXI users more exposed to pollutants? | Which groups would be more exposed to pollutants? Is the decreased exposure in the city center offset by an increased exposure at the limits of the Zone? |
| | Question for intervention improvement: What can be done so that reductions in exposure to pollutants are greater for those areas with higher initial exposure? | Is it possible to build bike paths away from major roads in order to minimize cyclists' exposure to roadside pollutants? | Can mechanisms be put in place in areas along the borders of the Zone in order to minimize population impacts? |
| Exposure to health effects | Question for intervention evaluation: Does the intervention affect the most vulnerable populations? | Not pertinent for BIXI | Where are vulnerable zones located with respect to major routes? How are they affected by the LEZ? |
| | Question for intervention improvement: What can be done to reduce the burden for vulnerable zones and populations? | Not pertinent for BIXI | What can be done to reduce the burden for vulnerable zones? |

BIXI: Montreal bicycle-sharing system; LEZ: London Low Emission Zone.

minibuses and £200 for trucks and buses. Parallel to the LEZ, there is a filter scheme. Non-compliant vehicles can be fitted with an approved filter and subsequently undergo a certification process to be approved for free entry into the LEZ. In targeting only larger vehicles, the intervention affects businesses and organizations and puts a limited burden on individuals. However, the benefits have the potential to be enjoyed by everyone in the LEZ.

The LEZ aims to incentivize the phasing-out of the oldest and most polluting heavy goods vehicles so that the remaining vehicles on the road emit lower levels of air pollution, specifically particulate matter and NOx. It is thus an intervention that affects one source of air pollution. Allowing vehicles to retrofit their exhaust pipes with filters acts on the emissions. Finally, this intervention acts upon the spatial distribution of pollution by aiming to lower roadside pollutants, with the greatest impact being on the most highly trafficked roads. Furthermore, the intervention's favorable impact on emissions has the potential to extend beyond the geographical boundaries of the LEZ, unless companies with fleets of these vehicles opt exclusively to reorganize routes so that non-compliant vehicles remain in circulation outside of the LEZ. Doing so would alter the spatial distribution of pollutants by concentrating the heavily polluting vehicles outside of the LEZ and potentially increasing exposure to pollution for populations residing just inside its boundaries.

*3.7.2. Application for evaluation and intervention*

For each question there are implications for intervention depending on the response that is found. The regulatory component (filter retrofitting scheme) and the urban planning component (daily charge scheme) of the LEZ both aim to change behavior. To what extent do they do so? Do behavior changes affect the number of heavy goods vehicles on the road and how much pollution is emitted from heavy goods vehicles? When faced with the intervention, we consider that organizations and businesses have five choices: they can replace their vehicles, retrofit their existing vehicles, reorganize their fleet so that non-compliant vehicles stay out of the zone, abandon their vehicles without replacing them, or enter the zone with the old vehicles and pay the charge. The progressively tightening standards mean that these decisions must be made each time new requirements emerge. Are there some behavior changes that are more effective at achieving these impacts than others? If so, how can the most favorable behaviors be encouraged by the intervention?

How are the benefits of the LEZ, air pollution-wise, spatially distributed? In particular, what is the comparative reduction of air pollution for vulnerable vs. non-vulnerable areas? In order to answer this question, it is necessary to locate zones where populations are vulnerable. Where is traffic in and around these zones? It might be conceivable to raise the daily charges for entry points in the LEZ where routes pass through vulnerable areas, in order to encourage drivers who choose to enter the LEZ with the older vehicles to take an alternate route that would have a lower impact on health. Do lowering the number of and the emissions from heavy goods vehicles improve health outcomes for the London population? What is the distribution of this improvement; is it equitable? What other factors concurrent to the intervention could have an impact on people's vulnerability?

*3.7.3. BIXI Montreal*

The Montreal public bicycle sharing system BIXI was introduced in 2009. From April to November, BIXI makes bicycles available at docking stations for a checkout fee of $7 for 24 h, $15 for 72 h, $31.25 for 30 days, and $82.50 for the year. Payment of the check-out fee entitles the user to 30 min free of charge for each ride, with additional hourly fees thereafter. The intervention is thus designed for frequent short-term use, consistent with its stated purpose as a "real means of urban transport" (bixi.com).

Built environment interventions such as BIXI often have the principal aim of improving health through the pathway of increasing physical activity (Fishman, Washington, & Haworth, 2012; Fuller, Gauvin, Kestens, Morency, & Drouin, 2013) but may also have an effect through the reduction of outdoor air pollution, which is also of interest for decision makers. In fact, both pathways contribute to reducing cardiovascular and respiratory disease. It is thus appropriate for us to analyze the intervention within the framework of our causal model.

The primary mechanism of the BIXI intervention operates on the sources of emissions, through behavior change. It is hypothesized that opting for the BIXI over one's car or motorcycle prevents emissions by these vehicles on the roads that users would take. This, in turn, would reduce exposure to roadside pollutants for those living or working in proximity to said roads. Consequently, one could hypothesize a decrease in air pollution-related disease and death, although the decrease may be differential according to people's vulnerability.

This pathway is the only way for BIXI to have an impact on air pollution itself and it is limited specifically to those who switch from cars and motorcycles. However, the intervention can also have effects on exposure and vulnerability for its users. BIXI users risk higher exposure to roadside pollutants (though the evidence is not conclusive, Kingham, Meaton, Sheard, & Lawrenson, 1998; Rank, Folke, & Homann Jespersen, 2001), negatively impacting health. As stated earlier, using BIXI also increases levels of physical activity, which has direct beneficial impacts on cardiovascular and respiratory health, thereby lowering vulnerability to air pollution's negative effects on cardiovascular and respiratory health.

*3.7.4. Application for evaluation and intervention*

Does BIXI change behavior? A modal shift from private transport to BIXI, if fulfilled, will have a positive impact on levels of air pollution, vulnerability, and health. There is no air pollution impact when other modal shifts occur, especially when the shift is from walking or privately owned bicycles; therefore, it is essential for evaluators to determine to what extent the intervention is meeting this objective. Who adopts it most—cyclists, motorists, people who take public transportation, pedestrians? There is some data to indicate that the modal shift to BIXI is occurring in higher proportions from public transportation than from cars (Fuller et al., 2013). How can motorists, the people who would bring the greatest benefit to the intervention in terms of air pollution reduction, be encouraged to switch to BIXI? New docking stations could be placed in areas where people are likely to commute by car for relatively short distances, perhaps due to inconvenient transport links. Another possibility is to engage universities and workplaces as partners in order to normalize a mass change from cars to BIXI each year at the start of the season (mid-April). However, bicycle redistribution services will need to be coordinated with such measures, or else the lack of docking spaces on arrival in the morning and of bicycles in the evening will discourage users. This raises the question of how we can redistribute bicycles so that both bicycles and docking stations are available, and how we can do so in such a way that does not increase pollution, since redistribution is done using large trucks. How can we lower exposure to pollution for BIXI users? While not within the purview of the intervention, the city may wish to take measures like building bike paths away from major roads in order to minimize cyclists' exposure to roadside pollutants.

## 4. Discussion

This tool may be useful at different levels: for intervention planning and evaluation. Teasing apart the different mechanisms that comprise an intervention's effects along the causal path enables the development of questions for evaluation and potential recommendations for action in a thorough and systematic manner.

While both modifiable and non-modifiable factors are included in the tool, we consider that the most important factors listed are those that can be targeted by interventions. Indeed, any intervention to reduce air pollution should be acting on at least one of the factors in this model. Those focusing on reducing overall exposure will act mostly on those upstream factors classified under sources, emissions, and concentrations. Interventions acting on factors that modify spatial distribution and vulnerability, on the other hand, are particularly relevant to equity concerns, because they are rarely uniform and this differential nature generates inequalities (Benmarhnia et al., 2014). In particular, interventions acting on spatial distribution should consider both equity of exposure as well as equity of health benefits related to population vulnerabilities, because an intervention that succeeds in decreasing the heterogeneity in exposure experienced over an urban area may still reap unequal health benefits due to differential vulnerabilities (Cesaroni et al., 2012).

Two interventions were used as case studies. Previous work has conducted evaluation related to both LEZ and BIXI. For example, about the London LEZ, some studies assessed its effects on air pollution reduction (Ellison, Greaves, & Hensher, 2013) and some studies about health effects are expected (Kelly et al., 2011). Evaluation studies related to the health effects of LEZ around the world are greatly growing in recent years (Morfeld, Groneberg, & Spallek, 2014) and our work is timely to conceptually help further empirical evaluation studies and intervention improvements as well.

In addition, further work could extend our approach to broader public policy analysis that consider the whole process of public decision making (Howlett, 2010; Knill & Tosun, 2012; Knill, Schulze, & Tosun, 2011; Sabatier & Weible, 2014) by setting a policy agenda, identifying challenges for implementation evaluation studies and discuss uncertainty issues (Manski, 2013) for example.

This tool has some limitations that affect its generalizability and transferability. First of all, it addresses urban outdoor air pollution within a developed country context. While the epidemiological burden of air pollution is higher in developing countries, the majority of the literature found was in the North American or European context. Intervening on air pollution in the context of a developing country could also benefit from the construction of a specific tool like that which we present here, taking the local evidence base as the starting point. Secondly, spatial distribution is accounted for, but not temporal distribution, which can also affect exposure (Brunekreef & Holgate, 2002). Evidence on temporal distribution may be incorporated into local adaptations of the tool, again depending on the availability of data. Lastly, for the purposes of this model, the city is a space with clearly defined boundaries. This is a necessary simplification given that interventions (especially policies) are carried out within an administrative subdivision, but the reality is admittedly more complex and other external factors can affect air pollution within a city.

## 5. Conclusion

The growing need to integrate health into city policymaking necessitates a thorough and effective way of examining how urban interventions can be evaluated and planned to maximize health and equity. People have the means to influence the way interventions are designed in order to increase the intervention's positive influence on health and equity. In fact, urban environments are major determinants of population health. Nevertheless, those who have the power to influence the way interventions are designed are not necessarily public health experts and there is a need to help them think through and conceptualize the health and equity aspects of interventions in urban environments. The tool we designed is meant as an assessment aid for municipal decision makers and program planners.

Air pollution has been a public health issue since the dawn of the industrial age, and has since undergone significant evolutions. Extensive legislation and technological innovations have contributed to improving air quality and associated health in developed countries, but the remaining gains to be made in this area depend on tackling inequalities in exposure and vulnerability to pollution.

## 6. Lessons learned

The building of this tool is at the crossing of various emerging and consolidating movements. First, population health intervention research (PHIR) (Hawe & Potvin, 2009), which propounds the idea that public health research should reorient its efforts from analyzing determinants of health toward finding ways to have an influence on population health. Second, theory-based evaluation, with the growing recognition that working on theories of intervention can provide important insights for the design and the evaluation of interventions. We wanted to propose a pragmatic tool, useful for non-public health experts. This objective led us to build a tool largely inspired from step 2 of logic analysis. We had to make compromises between its simplicity and the exact representation of complex causal paths, which would include several links and feedback loops. Nevertheless, we believe that, in its current form, it meets our expectations in that it will help raise pertinent questions that will enable better design and evaluation of interventions modifying air quality in urban environments.

## Conflict of interest statement

The authors declare that they have no conflict of interest.

## Financial disclosure

The authors have no financial disclosures.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.evalprogplan.2015.07.004.

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