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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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**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

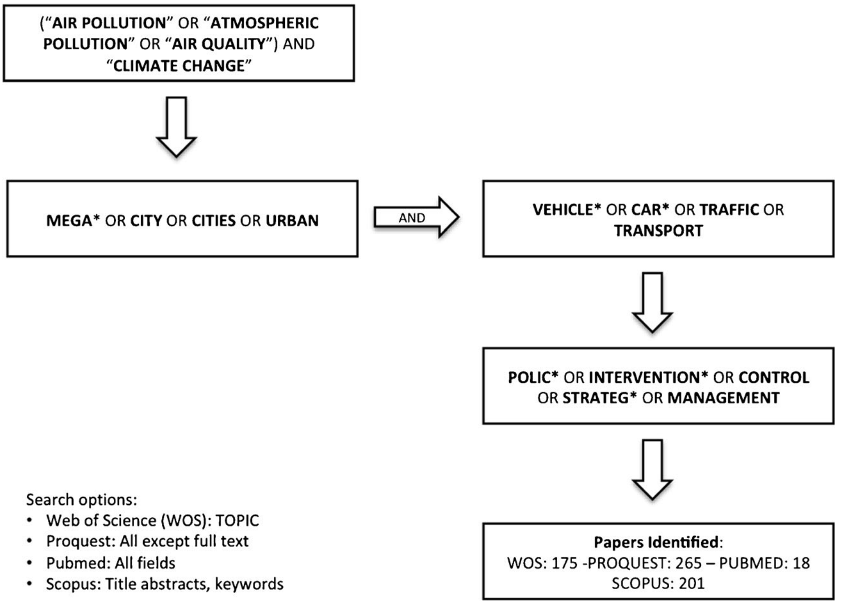


**FIG. 1** Overview of the search process.

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

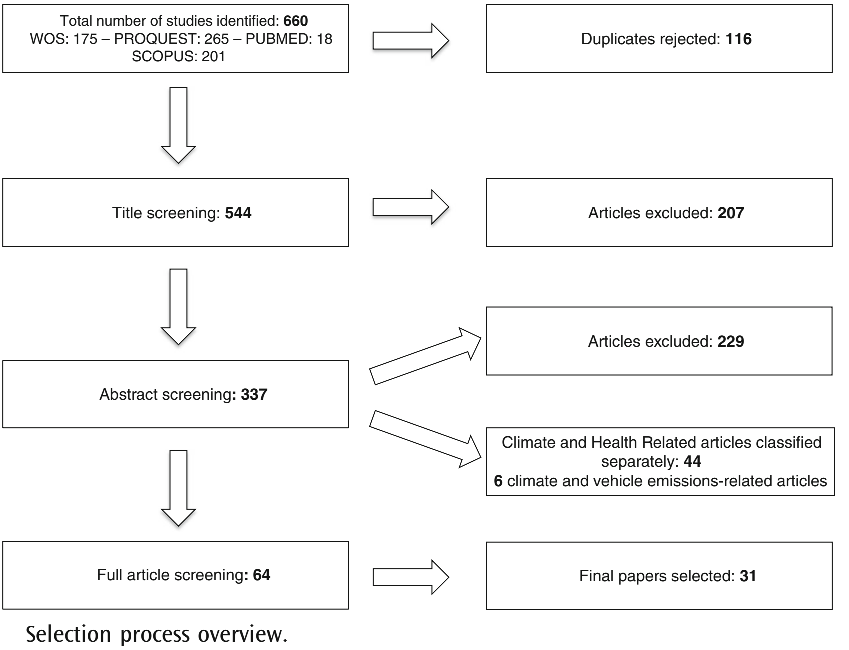


**FIG. 2** Selection process overview.

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 | | | | | Policy | | | Primary findings |
|---|---|---|---|---|---|---|---|---|---|---|
| | | C | N | S | PM | O3 | REG | ECO | OTH | |
| | | | | | | | | | | 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 | | | | | Policy | | | Primary findings |
|---|---|---|---|---|---|---|---|---|---|---|
| | | C | N | S | PM | O3 | REG | ECO | OTH | |
| | 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<br>•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.<br><br>•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.<br><br>•Lower emissions from Euro IV and CNG buses are effective in reducing overall vehicle emissions for pollutants studied.<br><br>•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: <br>•Reduction in $CO_2$ emissions (−19.5 %) apparently with little additional benefit from new vehicle technology <br>•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]

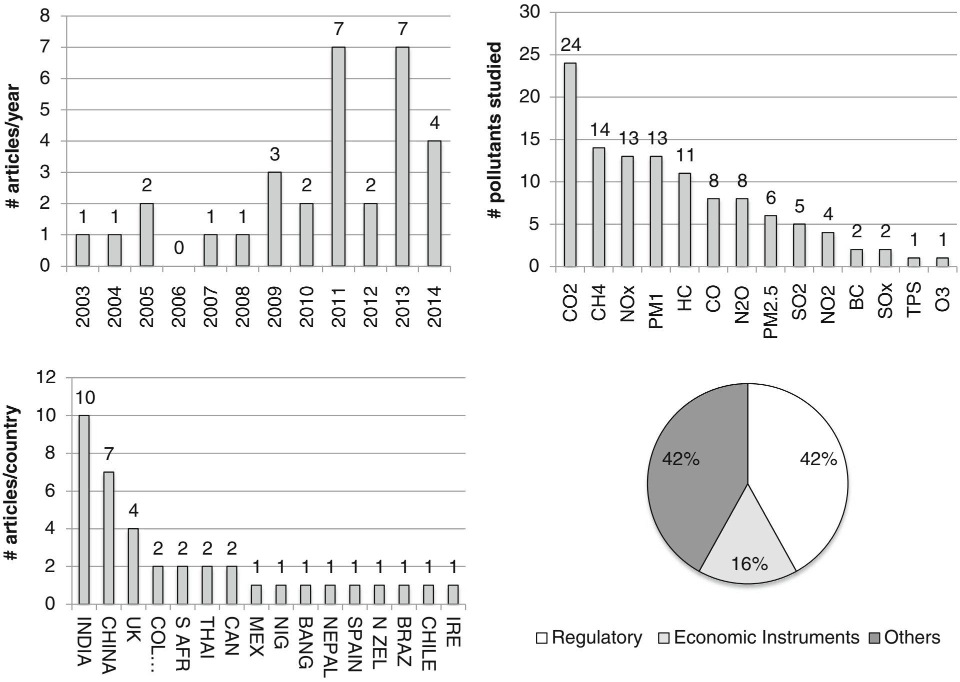


**FIG. 3** Overall trends.

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

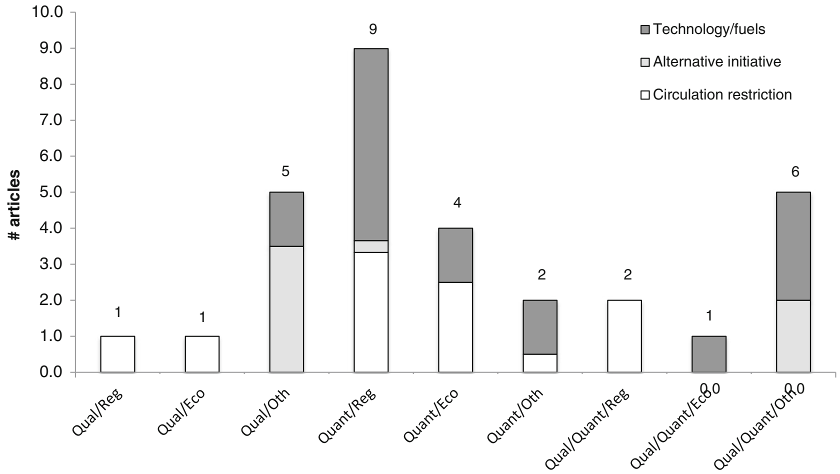


**FIG. 4** Air pollution policy management. *QUAL* qualitative, *QUANT* quantitative, *REG* regulatory approach, *ECO* economic incentives, *OTH* other.

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.

## REFERENCES


1. Cifuentes L, Borja-Aburto VH, Gouveia N, Thurston G, Davis DL. Assessing the health benefits of urban air pollution reductions associated with climate change mitigation (2000–2020): Santiago, Sao Paulo, Mexico City and New York City. *Environ Health Perspect*. 2001; 109: 419. doi:10.2307/3434790.
2. Strefler J, Luderer G, Kriegler E, Meinshausen M. Can air pollutant controls change global warming? *Environ Sci Pol*. 2014; 41: 33–43. doi:10.1016/j.envsci.2014.04.009.
3. Worden HM, Cheng Y, Pfister G, Carmichael GR, Zhang Q, Streets DG, Worden JR. Satellite-based estimates of reduced CO and CO2 emissions due to traffic restrictions during the 2008 Beijing Olympics. Geophys Res Lett. 2012; 39(14). doi: 10.1029/2012GL052395.
4. United Nations. World urbanization prospects, the 2014 revision. doi: 10.4054/DemRes.2005.12.9.
5. Stern N. The economics of climate change. Climate Stern Rev 2007. doi: http://doi.org/9780521700801.
6. Harlan SL, Ruddell DM. Climate change and health in cities: impacts of heat and air pollution and potential co-benefits from mitigation and adaptation. *Curr Opin Environ Sustain*. 2011; 3(3): 126–34. doi:10.1016/j.cosust.2011.01.001.
7. Castán Broto V, Bulkeley H. A survey of urban climate change experiments in 100 cities. *Glob Environ Chang*. 2013; 23(1): 92–102. doi:10.1016/j.gloenvcha.2012.07.005.
8. D'amato G, Baena-Cagnani CE, Cecchi L, Annesi-Maesano I, Nunes C, Ansotegui I, et al. Climate change, air pollution and extreme events leading to increasing prevalence of allergic respiratory diseases. *Multidiscip Respir Med*. 2013; 8(1): 12. doi:10.1186/2049-6958-8-12.
9. Dominici F. Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. *JAMA*. 2006; 295(10): 1127–34. doi:10.1001/jama.295.10.1127.
10. Ribeiro H. Queimadas de Cana-de-açúcar no Brasil: efeitos na saúde respiratória. *Rev Saude Publica*. 2008; 42(2): 370–6. doi:10.1590/S0034-89102008005000009.
11. Tseng RY, Li CK, Spinks J. Particulate air pollution and hospitalization for asthma. *Ann Allergy*. 1992; 68(5): 425–32.
12. Vanos JK, Hebbern C, Cakmak S. Risk assessment for cardiovascular and respiratory mortality due to air pollution and synoptic meteorology in 10 Canadian cities. *Environ Pollut*. 2014; 185: 322–32. doi:10.1016/j.envpol.2013.11.007. **Barking, Essex□: 1987.**

13. Clancy L, Goodman P, Sinclair H, Dockery DW. Effect of air-pollution control on death rates in Dublin, Ireland: an intervention study. *Lancet*. 2002; 360(9341): 1210–4. doi:10.1016/S0140-6736(02)11281-5.
14. Pope CA, Ezzati M, Dockery DW. Fine-particulate air pollution and life expectancy in the United States. *N Engl J Med*. 2009; 360(4): 376–86. doi:10.1056/NEJMsa0805646.
15. Chen YL, Shih YH, Tseng CH, Kang SY, Wang HC. Economic and health benefits of the co-reduction of air pollutants and greenhouse gases. *Mitig Adapt Strateg Glob Chang*. 2013; 18(8): 1125–39. doi:10.1007/s11027-012-9413-3.
16. Ebi K. Health in the new scenarios for climate change research. *Int J Environ Res Public Health*. 2013; 11(1): 30–46. doi:10.3390/ijerph110100030.
17. West JJ, Fiore AM, Horowitz LW, Mauzerall DL. Global health benefits of mitigating ozone pollution with methane emission controls. *Proc Natl Acad Sci U S A*. 2006. doi:10.1073/pnas.0600201103.
18. Molina MJ, Molina LT. Megacities and atmospheric pollution. *J Air Waste Manag Assoc*. 2007; 54(6): 644–80. doi:10.1080/10473289.2004.10470995.
19. Bell ML, Davis DL, Gouveia N, Borja-Aburto VH, Cifuentes LA. The avoidable health effects of air pollution in three Latin American cities: Santiago, São Paulo and Mexico City. *Environ Res*. 2006; 100(3): 431–40. doi:10.1016/j.envres.2005.08.002.
20. Fang Y, Mauzerall DL, Liu J, Fiore AM, Horowitz LW. Impacts of 21st century climate change on global air pollution-related premature mortality. *Clim Chang*. 2013; 121(2): 239–53. doi:10.1007/s10584-013-0847-8.
21. Walsh MP. Ancillary benefits for climate change mitigation and air pollution control in the world's motor vehicle fleets. *Annu Rev Public Health*. 2008; 29: 1–9. doi:10.1146/annurev.publhealth.29.091307.183257.
22. Wright L, Fulton L. Climate change mitigation and transport in developing nations. *Transp Rev*. 2005; 25(6): 691–717. doi:10.1080/01441640500360951.
23. World Health Summit. 2015 yearbook. Available from http://www.worldhealthsummit.org/fileadmin/downloads/2015/WHS/Documents/WHS_2015_Yearbook.pdf
24. Douglas MJ, Watkins SJ, Gorman DR, Higgins M. Are cars the new tobacco? *J Pub Health*. 2011; 33(2): 160–9. doi:10.1093/pubmed/fdr032.
25. Parrish DD, Singh HB, Molina L, Madronich S. Air quality progress in North American megacities: a review. *Atmos Environ*. 2011; 45(39): 7015–25. doi:10.1016/j.atmosenv.2011.09.039.
26. Benmarhnia T, Rey L, Cartier Y, Clary CM, Deguen S, Brousselle A. Addressing equity in interventions to reduce air pollution in urban areas: a systematic review. *Int J Pub Health*. 2014; 59(6): 933–44. doi:10.1007/s00038-014-0608-0.
27. Thambiran T, Diab RD. The case for integrated air quality and climate change policies. *Environ Sci Pol*. 2011; 14(8): 1008–17. doi:10.1016/j.envsci.2011.08.002.
28. Grant MJ, Booth A. A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Inf Libr J*. 2009; 26(2): 91–108. doi:10.1111/j.1471-1842.2009.00848.x.
29. Fajersztajn L, Veras M, Barrozo LV, Saldiva P. Air monitoring coverage in low-income countries: an observational study. 2014.
30. OECD. OECD environmental outlook to 2050: the consequences of inaction. *Outlook*. 2012. doi:10.1787/9789264122246-en.
31. Ahmad SS, Aziz N. Spatial and temporal analysis of ground level ozone and nitrogen dioxide concentration across the twin cities of Pakistan. *Environ Monit Assess*. 2013; 185(4): 3133–47. doi:10.1007/s10661-012-2778-7.
32. Goswami P, Baruah J. Simulation of daily variation of suspended particulate matter over Delhi: relative roles of vehicular emission, dust and domestic appliances. *Mon Weather Rev*. 2008; 136(9): 3597–607. doi:10.1175/2008MWR2386.1.
33. Ho KF, Lee SC, Louie PKK, Zou SC. Seasonal variation of carbonyl compound concentrations in urban area of Hong Kong. *Atmos Environ*. 2002; 36(8): 1259–65. doi:10.1016/S1352-2310(01)00570-2.

34. Liang MS, Keener TC, Birch ME, Baldauf R, Neal J, Yang YJ. Low-wind and other microclimatic factors in near-road black carbon variability: a case study and assessment implications. *Atmos Environ*. 2013; 80: 204–15. doi:10.1016/j.atmosenv.2013.07.057.
35. Megaritis G, Fountoukis C, Charalampidis PE, Pilinis C, Pandis SN. Response of fine particulate matter concentrations to changes of emissions and temperature in Europe. *Atmos Chem Phys*. 2013; 13(6): 3423–43. doi:10.5194/acp-13-3423-2013.
36. Mohan M, Kandya A. An analysis of the annual and seasonal trends of air quality index of Delhi. *Environ Monit Assess*. 2007; 131(1–3): 267–77. doi:10.1007/s10661-006-9474-4.
37. Rutty M, Matthews L, Andrey J, Matto TD. Eco-driver training within the city of Calgary's municipal fleet: monitoring the impact. *Transp Res Part D: Transp Environ*. 2013; 24: 44–51. doi:10.1016/j.trd.2013.05.006.
38. Dirgahayani P. Environmental co-benefits of public transportation improvement initiative: the case of Trans-Jogja bus system in Yogyakarta, Indonesia. *J Clean Prod*. 2013; 58: 74–81. doi:10.1016/j.jclepro.2013.07.013.
39. Doll CNH, Balaban O. A methodology for evaluating environmental co-benefits in the transport sector: application to the Delhi metro. *J Clean Prod*. 2013; 58: 61–73. doi:10.1016/j.jclepro.2013.07.006.
40. Garg A. Pro-equity effects of ancillary benefits of climate change policies: a case study of human health impacts of outdoor air pollution in New Delhi. *World Dev*. 2011; 39(6): 1002–25. doi:10.1016/j.worlddev.2010.01.003.
41. Li J. Decoupling urban transport from GHG emissions in Indian cities—a critical review and perspectives. *Energ Policy*. 2011; 39(6): 3503–14. doi:10.1016/j.enpol.2011.03.049.
42. Reynolds CCO, Kandlikar MM. Climate impacts of air quality policy: switching to a natural gas-fueled public transportation system in New Delhi. *Environ Sci Technol*. 2008; 42(16): 5860–5. doi:10.1021/es702863p.
43. Woodcock J, Edwards P, Tonne C, Armstrong BG, Ashiru O, Banister D, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. *Lancet*. 2009; 374(9705): 1930–43. doi:10.1016/S0140-6736(09)61714-1.
44. Yedla S, Parikh JK, Shrestha RM. Sustainable urban transportation: impact of CO2 mitigation strategies on local pollutants. Int J Environ Pollut. 2003. 19(5), 475–482. Available from http://www.scopus.com/inward/record.url?eid=2-s2.0-0141650411&partnerID=tZOtx3y1.
45. Becerra JM, Reis RS, Frank LD, Ramirez-marrero FA, Welle B, Arriaga Cordero E, Paz FM. Transport and health: a look at three Latin American cities. Cadernos de Saúde Pública. 2013. 29(4), 654–66. Available from http://www.ncbi.nlm.nih.gov/pubmed/23568296
46. Creutzig F, He D. Climate change mitigation and co-benefits of feasible transport demand policies in Beijing. *Transp Res Part D: Transp Environ*. 2009; 14(2): 120–31. doi:10.1016/j.trd.2008.11.007.
47. Wang X, Westerdahl D, Hu J, Wu Y, Yin H, Pan X, et al. On-road diesel vehicle emission factors for nitrogen oxides and black carbon in two Chinese cities. *Atmos Environ*. 2012; 46: 45–55. doi:10.1016/j.atmosenv.2011.10.033.
48. Wang X, Westerdahl D, Wu Y, Pan X, Zhang KM. On-road emission factor distributions of individual diesel vehicles in and around Beijing, China. *Atmos Environ*. 2011; 45(2): 503–13. doi:10.1016/j.atmosenv.2010.09.014.
49. Geng Y, Ma Z, Xue B, Ren W, Liu Z, Fujita T. Co-benefit evaluation for urban public transportation sector—a case of Shenyang, China. *J Clean Prod*. 2013; 58(SI): 82–91. doi:10.1016/j.jclepro.2013.06.034.
50. Atkinson RW, Barratt B, Armstrong B, Anderson HR, Beevers SD, Mudway IS, et al. The impact of the congestion charging scheme on ambient air pollution concentrations in London. *Atmos Environ*. 2009; 43(34): 5493–500. doi:10.1016/j.atmosenv.2009.07.023.

51. Chong U, Yim SHL, Barrett SRH, Boies AM. Air quality and climate impacts of alternative bus technologies in Greater London. *Environ Sci Technol*. 2014; 48(8): 4613–22. doi:10.1021/es4055274.
52. Iglesias MM, Apsimon HH. Alternative vehicle technologies and fuels in scenarios for atmospheric emissions in London. *J Environ Assess Pol Manag*. 2004; 6(2): 213–43. doi:10.1142/S1464333204001638.
53. Komolafe AA, Abdul-Azeez AS, Biodun AAY, Omowonuola AF, Rotimi AD. Air pollution and climate change in Lagos, Nigeria: needs for proactive approaches to risk management and adaptation. *Am J Environ Sci*. 2014; 10(4): 412–23. doi:10.3844/ajessp.2014.412.423.
54. Macmillan A, Connor J, Witten K, Kearns R, Rees D, Woodward A. The societal costs and benefits of commuter bicycling: simulating the effects of specific policies using system dynamics modeling. *Environ Health Perspect*. 2014; 122(4): 335–44. doi:10.1289/ehp.1307250.
55. Lindsay G, Macmillan A, Woodward A. Moving urban trips from cars to bicycles: impact on health and emissions. *Aust N Z J Public Health*. 2011; 35(1): 54–60. doi:10.1111/j.1753-6405.2010.00621.x.
56. Thambiran T, Diab RD. Air pollution and climate change co-benefit opportunities in the road transportation sector in Durban, South Africa. *Atmos Environ*. 2011; 45(16): 2683–9. doi:10.1016/j.atmosenv.2011.02.059.
57. Moodley KG, Singh S, Govender S. Passive monitoring of nitrogen dioxide in urban air: a case study of Durban metropolis, South Africa. *J Environ Manag*. 2011; 92(9): 2145–50. doi:10.1016/j.jenvman.2011.03.040.
58. Shrestha SR, Kim Oanh NT, Xu Q, Rupakheti M, Lawrence MG. Analysis of the vehicle fleet in the Kathmandu valley for estimation of environment and climate co-benefits of technology intrusions. *Atmos Environ*. 2013; 81: 579–90. doi:10.1016/j.atmosenv.2013.09.050.
59. Kantor I, Fowler MW, Hajimiragha A, Elkamel A. Air quality and environmental impacts of alternative vehicle technologies in Ontario, Canada. *Int J Hydrog Energy*. 2010; 35(10): 5145–53. doi:10.1016/j.ijhydene.2009.08.071.
60. Brady J, O'Mahony M. Travel to work in Dublin. The potential impacts of electric vehicles on climate change and urban air quality. *Transp Res Part D: Transp Environ*. 2011; 16(2): 188–93. doi:10.1016/j.trd.2010.09.006.
61. Vedrenne M, Pérez J, Lumbreras J, Rodríguez ME. Life cycle assessment as a policy-support tool: the case of taxis in the city of Madrid. *Energ Policy*. 2014; 66: 185–97. doi:10.1016/j.enpol.2013.10.07.
62. Jiang P, Chen Y, Geng Y, Dong W, Xue B, Xu B, et al. Analysis of the co-benefits of climate change mitigation and air pollution reduction in China. *J Clean Prod*. 2013; 58: 130–7. doi:10.1016/j.jclepro.2013.07.042.
63. Wadud Z, Khan T. Air quality and climate impacts due to CNG conversion of motor vehicles in Dhaka, Bangladesh. *Environ Sci Technol*. 2013; 47(24): 13907–16. doi:10.1021/es402338b.
64. Mazzi EA, Dowlatabadi H. Air quality impacts of climate mitigation: UK policy and passenger vehicle choice. *Environ Sci Technol*. 2007; 41(2): 387–92. doi:10.1021/es060517w.
65. Labriet M, Caldes N, Izquierdo L. A review on urban air quality, global climate change and CDM issues in the transportation sector. *I J Glob Warm*. 2009; 1(1/2/3): 144. doi:10.1504/IJGW.2009.027086.
66. Li Y, Crawford-Brown DJ. Assessing the co-benefits of greenhouse gas reduction: health benefits of particulate matter related inspection and maintenance programs in Bangkok, Thailand. *Sci Total Environ*. 2011; 409(10): 1774–85. doi:10.1016/j.scitotenv.2011.01.051.
67. Beevers SD, Carslaw DC. The impact of congestion charging on vehicle emissions in London. *Atmos Environ*. 2005; 39(1): 1–5. doi:10.1016/j.atmosenv.2004.10.001.

68. Bell D. Climate change and human rights. *Wiley Interdiscip Rev Clim Chang*. 2013; 4(3): 159–70. doi:10.1002/wcc.218.
69. Maantay J. Asthma and air pollution in the Bronx: methodological and data considerations in using GIS for environmental justice and health research. *Health Place*. 2007; 13(1): 32–56. doi:10.1016/j.healthplace.2005.09.009.
70. Swart R, Amann M, Raes F, Tuinstra W. A good climate for clean air: linkages between climate change and air pollution. An editorial essay. *Clim Chang*. 2004; 66(3): 263–9. doi:10.1023/B:CLIM.0000044677.41293.39.
71. Boyce JK, Pastor M. Clearing the air: incorporating air quality and environmental justice into climate policy. *Clim Chang*. 2013; 120(4): 801–14. doi:10.1007/s10584-013-0832-2.
72. O'Neill MS, Kinney PL, Cohen AJ. Environmental equity in air quality management: local and international implications for human health and climate change. *J Toxic Environ Health A*. 2008; 71(9–10): 570–7. doi:10.1080/15287390801997625.
73. Moellendorf D. Climate change and global justice. *Wiley Interdiscip Rev Clim Chang*. 2012; 3(2): 131–43. doi:10.1002/wcc.158.
74. Bulkeley H, Betsill M. Rethinking sustainable cities: multilevel governance and the "urban" politics of climate change. *Environ Politic*. 2005; 14(1): 42–63. doi:10.1080/0964401042000310178.
75. Ostrom E. A polycentric approach for coping with climate change. World bank policy research working paper 5095. 2009. 56.
76. Becerra JM, Reis RS, Frank LD, Ramirez-Marrero FA, Welle B, Cordero EA, Paz FM, Crespo C, Dijon V, Jacoby E, Dill J, Weigand L, Padin CM. Transport and health: a look at three latin american cities. Cad. *Saúde Pública*. 2013. doi:10.1590/S0102-311X2013000400004.
77. Rayle L, Madhav P. Scenarios for Furture urbanization: carbon dioxide emissions from passanger travel in three indian cities. Transportation research record: *J Transp Res Board*. 2010. doi:10.3141/2193-15.