



A proposed methodology for impact assessment of air quality traffic-related measures: The case of PM_{2.5} in Beijing[☆]

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ABSTRACT

Air quality traffic-related measures have been implemented worldwide to control the pollution levels of urban areas. Although some of those measures are claiming environmental improvements, few studies have checked their real impact. In fact, quantitative estimates are often focused on reducing emissions, rather than on evaluating the actual measures' effect on air quality. Even when air quality studies are conducted, results are frequently unclear.

In order to properly assess the real impact on air quality of traffic-related measures, a statistical method is proposed. The method compares the pollutant concentration levels observed after the implementation of a measure with the concentration values of the previous year. Short- and long-term impact is assessed considering not only their influence on the average pollutant concentration, but also on its maximum level. To control the effect of the main confounding factors, only the days with similar environmental conditions are analysed. The changeability of the key meteorological variables that affect the transport and dispersion of the pollutant studied are used to identify and group the days categorized as similar. Resemblance of the pollutants' concentration of the previous day is also taken into account. The impact of the road traffic measures on the air pollutants' concentration is then checked for those similar days using specific statistical functions.

To evaluate the proposed method, the impact on PM_{2.5} concentrations of two air quality traffic-related measures (M1 and M2) implemented in the city of Beijing are taken into consideration: M1 was implemented in 2009, restricting the circulation of yellow-labelled vehicles, while M2 was implemented in 2014, restricting the circulation of heavy-duty vehicles. To compare the results of each measure, a time-period when these measures were not applied is used as case-control.

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1. Introduction

In the recent years, Beijing's population has been growing quickly. Between 1990 and 2015, it increased from 10.8 to 21.7 million people and, today, the city is one of the most populated cities in the world (BJSTATS, 2016). This fast growth, combined with stable atmospheric conditions and with the transport of regional

emissions, has led to a record-high number of heavy haze pollution days during the last years (Cai et al., 2017; Ding and Liu, 2014; Zhuang et al., 2014). As result, the high levels of PM_{2.5} concentrations (particulate matter with particle aerodynamic diameter smaller than 2.5 µm) in the atmosphere have been pointed out as the main reason for the poor air quality in the city (Batterman et al., 2016; Guo et al., 2017).

Several PM_{2.5} episodes observed in Beijing have been attracting the attention of researchers worldwide (e.g. Fontes et al., 2017; Huang et al., 2014; Zhao et al., 2011; Wang et al., 2013). Besides the impact on the climate (Maricp, 2013), this pollutant has also an important impact on human health. PM_{2.5} tend to penetrate into the gas exchange regions of the lung and blood streams causing permanent DNA mutations, cardiovascular diseases and premature deaths (Roy et al., 2012). Several studies conducted in China

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reported acute (Chen et al., 2013; Li et al., 2013) and chronic (Chu et al., 2015) human health problems. A recent study involving 312,944 people in nine European countries revealed that, for every increase of $5 \mu\text{g.m}^{-3}$ in $\text{PM}_{2.5}$, lung cancer rate rose by 18% (Raaschou-Nielsen et al., 2013). Although research studies revealed that no safe level of $\text{PM}_{2.5}$ concentrations can be defined to mitigate the impact on human health, the World Health Organization (WHO, 2005) proposed guidelines for this pollutant by defining an annual ($10 \mu\text{g.m}^{-3}$) and a daily ($25 \mu\text{g.m}^{-3}$) exposure limit. Three interim targets (IT) were also defined for $\text{PM}_{2.5}$ that must be achievable by each country with successive and sustained abatement measures. The most IT permissive levels were adopted by countries as China: $35 \mu\text{g.m}^{-3}$ for the annual exposure limit and $75 \mu\text{g.m}^{-3}$ for the daily exposure limit.

To understand the problems of $\text{PM}_{2.5}$, several source apportionment studies have been conducted in Beijing (e.g. Li et al., 2015; Yang et al., 2016). In a recent study, Li et al. (2015) explain that 40–60% of total $\text{PM}_{2.5}$ emissions in the city are from local emissions. Furthermore, it was also seen that road traffic emissions contribute between 10 and 20% of the overall $\text{PM}_{2.5}$ emissions of the city (Huang et al., 2014; Li et al., 2015; Yang et al., 2016). For the greater Beijing area, the contribution of local emissions can be even higher (Li et al., 2015). According to the literature, the hotspots of $\text{PM}_{2.5}$ concentrations in the cities are usually located near road traffic lanes (Huang et al., 2012) and such levels decrease when the distance to the main roads increases (Kimbrough et al., 2013; Barros et al., 2013). All the above together suggests that local controls deserve high priority and that the management of the road traffic sector may have here an important role.

Beijing is one of the cities with the highest private car ownership (Shen et al., 2014). In 2030, the number of vehicles is expected to be 10.4 million (Wu et al., 2011). Both commuting distance and time put the city in the top of Chinese cities with highest levels of traffic congestion. In 2014, the daily average commuting distance was 19.2 km, while the national average was 9.2 km (Chen, 2015). On top of that, the average commuting time has been rising continuously: from 38 min in 2005 to 45 min in 2010, and 97 min in 2014 (Xu et al., 2011; Lai, 2015).

In Beijing, to minimise the impact of road traffic, high investments have been done in public transport. Having exceeded 500 km of lines in 2015, the effort to build a metro network with 1000 km of lines until 2020, one of the longest metro networks in the world (Yanan, 2015), does not seem to relieve the burden related to high $\text{PM}_{2.5}$ concentrations in the atmosphere of the city. Such investments are not new. Over the last 25 years, the Beijing government has implemented many vehicle control strategies in order to minimise the effects of the fast growth (Wu et al., 2011; Zhou et al., 2010). Figure S1 (in the Supplements section) shows an overview of the main air quality traffic-related measures implemented between 1990 and 2015.

The air quality traffic-related measures introduced in Beijing during the last few decades have been mostly focused on controlling the total number of vehicles and the quality of their engines. As a result, measures for new and in-use vehicles have been defined. In 1994, a study conducted by the State Environmental Protection Administration of Beijing explained that more stringent emission standards were required and, in 1997, a dramatic increase in new light-duty vehicles was underway (Wu et al., 2011). As a result, Beijing started to implement emission standards in 1999 in an accelerated mode and Euro 6 emission standards are expected to be implemented until the end of 2023 (DieselNet, 2018).

As for in-use vehicles, in 1998, an environmental labelling measure was implemented. The vehicles registered in Beijing were issued with a yellow or green label indicating their emission standard. Since 2003, the yellow-labelled vehicles (also known as

high-emitting vehicles) are not allowed to circulate in the Second-Ring Road ($\approx 60 \text{ km}^2$, inside the urban area) and later this restriction was expanded to the Sixth-Ring Road ($\approx 2000 \text{ km}^2$, inside the urban area) (BENDIBAO, 2013). In 2014, the yellow-labelled vehicles registered outside of Beijing were also forbidden to run within Beijing administrative area (BJLZJ, 2014).

Similar measures to the labelling policy were implemented in Beijing for specific vehicle categories, namely motorcycles and heavy trucks. Motorcycles were first banned in 2001 and freight vehicles in 2004 (during daytime 06:00 a.m.–23.00 p.m.). Both vehicle categories were initially bann from driving within the Fourth-Ring Road ($\approx 300 \text{ km}^2$, inside the urban area), but later these restrictions were enlarged for some of the classes of these categories until the Sixth-Ring Road ($\approx 2000 \text{ km}^2$, inside the urban area) and Fifth-Ring Road ($\approx 700 \text{ km}^2$, inside the urban area), respectively (BJJTGL, 2009; BJLZJ, 2014; BJGOV, 2014). For freight vehicles, the restrictions were even higher, since the number of allowed hours to circulate also decreased. Such restrictions were applied for all vehicles; among them, non-Beijing vehicles were severely restricted both spatially and temporally. In spite of all the efforts, these measures were not enough to reduce traffic congestion and control the air pollution. Therefore, to remove the oldest and poorly maintained vehicles available in the city, car-scrapping incentives were introduced in 2009 (Minghao, 2011).

Fuel quality and alternative fuel type's policies were also implemented in Beijing city. Restrictions on the lead, sulphur and benzene contents on gasoline were some of those policies. After that, the introduction of alternative fuel vehicles and advanced vehicles brought a new hope to the city. The use of natural gas in the public bus fleet was being promoted since 1999 and, since 2009, hybrid electrical-diesel buses started to be used in Beijing. Retrofit programs to convert gasoline taxis to Flexible-Fuelled Vehicles (FFV) with either gasoline or Liquefied Petroleum Gas (LPG) were implemented as well.

Recently, advanced vehicles, also known in China as new-energy vehicles, are the main focus of the air quality traffic-related measures. The 2008 Olympic Games was used to launch this policy. During the event, more than 50 hybrid electric vehicles, pure electric vehicles and fuel cell vehicles were used (Wu et al., 2011). Also, several temporary measures were implemented during this time (e.g. Wang et al., 2010b). Private cars could only operate on odd or even days based on the last digit of their license plate and trucks could only operate inside the Sixth-Ring Road at night (12 a.m.–06 a.m.). A demo program restrict drivers on one day a week depending on what number the license plate ends with. This last measure, implemented in 2008, was extended until 2011 with huge social protest and economic losses. Nonetheless, other similar measures additionally were applied (Zhou et al., 2010; Wu et al., 2011).

With the Clean Air Act Plan for 2013–2017, more stringent emission controls were defined. The implementation of Euro 6 emission standards and the improvement of the fleet of public buses and taxis were two of the main goals of this plan. The government also plans to phase out all yellow-labelled vehicles, setting a target of no more than 6 million vehicles at the end of 2017 (Zhao, 2015; Zhang et al., 2014).

The environmental impact of traffic restriction measures implemented in Beijing, namely on $\text{PM}_{2.5}$ emissions, has been studied by several researchers. Hao et al. (2006) concluded that, despite the rapid increase in the number of vehicles, total vehicular emissions have not increased, and traffic measures as the retrofit programs showed little emission benefits. More recently, Zhang et al. (2014) reported two decades trend of vehicle emissions in the city. The results show that traffic control is playing an essential role in mitigating urban vehicle emissions. This is particularly

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