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Research article

Integrated modelling approach for the evaluation of low emission zones

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ABSTRACT

Low emission zones (LEZ) are areas where the most polluting vehicles are restricted or deterred from entering. In recent years, LEZ became a popular option to reduce traffic-related air pollution and have been implemented in many cities worldwide, notably in Europe. However, the evidence about their effectiveness is inconsistent. This calls for the development of tools to evaluate ex-ante the air quality impacts of a LEZ. The integrated modelling approach we propose in this paper aims to respond to this call. It links a transportation model with an emissions model and an air quality model operating over a GIS-based platform. Through the application of the approach, it is possible to estimate the changes induced by the creation of a LEZ applied to private cars with respect to air pollution levels not only inside the LEZ, but also, more generally, in the city where it is located. The usefulness of the proposed approach was demonstrated for a case study involving the city of Coimbra (Portugal), where the creation of a LEZ is being sought to mitigate the air quality problems that its historic centre currently faces. The main result of this study was that PM10 and NO_2 emissions from private cars would decrease significantly inside the LEZ (63% and 52%, respectively) but the improvement in air quality would be small and exceedances to the air pollution limits adopted in the European Union would not be fully avoided. In contrast, at city level, total emissions increase and a deterioration of air quality is expected to occur.

1. Introduction

1.1. Research context

Increased public concerns have recently elevated the role of air quality policies. According to the World Health Organization, air pollution is the largest single environmental health risk, contributing to around 7 million premature deaths worldwide in 2012, and traffic-related air pollution is the major factor in this respect (WHO, 2013, 2014).

In order to protect public health, the European Union (EU) has set forth directives to regulate ambient air quality by setting limit values for several pollutants, including particulate matter (PM10) and nitrogen dioxide (NO_2) (Directive, 2008/50/EC). However, despite these directives, air pollution limits are currently being infringed in many cities throughout Europe, and road transport is one of the main reasons for this problem to occur (Colvile et al., 2001; Giannouli et al., 2011; EEA, 2012; WHO, 2013).

Under European Directive 2008/50/EC, Member States must provide Action Plans for those areas that do not comply with air pollution limits. In the context of such plans, numerous European cities have established and implemented ambitious traffic management measures to reduce air pollution levels, focusing especially on road transport emissions. Examples of such measures include congestion charges, old vehicle scrapping programs, and biking and transit network improvements. However, one of the most frequent responses to the directive has been the creation of low emission zones (LEZ).

The concept of LEZ, which first appeared in Sweden in the late 1990s under the name of miljözon (environmental zone in English), designates an area where the most polluting vehicles are restricted or deterred from entering (EC, 2014). For this purpose, criteria based on Euro emission classes are used to select the vehicles to be banned from the LEZ or charged if they enter them. Such emission reduction scheme can take several forms depending on the geographical area they cover, the time period during which the LEZ is in force, and the type and emission class of the vehicles to which they apply. In the EU, over 150 cities in nine Member States have meanwhile implemented LEZ schemes, in most cases focusing on

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heavy vehicles and valid for 365 days and 24 h per day (EC, 2014).

Despite LEZ are generally considered to be an appropriate measure towards achieving the air pollution reduction targets of the EU, the evidence about their effectiveness is somewhat inconsistent, which makes their application debatable. Indeed, this type of measure has not always been successful in meeting European air pollution limits, notably with regard to PM10 and NO_2 levels (Boogaard et al., 2012; Ellison et al., 2013). In our view, there is not enough understanding on how the adoption of LEZ will help reducing air pollution in a given city, and there is consequently an urgent need for tools that can assist local authorities in the making of well-informed decisions on this important matter.

The research described in this paper aims to respond to this urgent need. Specifically, it consists in the development of an integrated modelling approach to evaluate (ex-ante) the air quality impacts of LEZ in urban areas. This approach is intended to be a key component of a decision-support tool for the complex decision-making processes concerning the impacts of LEZ. It encompasses three interconnected models: the first is a macroscopic transportation model that describes road traffic in the urban area where the approach is to be applied; the second is an emissions model that quantifies the amount of pollutants produced by line sources, thus by road traffic; and the third is an air quality model that describes the dispersion of pollutants in the air. The usefulness of the approach is demonstrated through a study involving the city of Coimbra (Portugal), where two large areas of the historic centre were recently classified as UNESCO World Heritage.

1.2. Literature review

The concept of LEZ is quite recent, and research about it is still rather scarce. In particular, there are only a limited number of studies dealing with the evaluation of LEZ as a tool to improve urban air quality. This literature can be divided in two streams: ex-post evaluation and ex-ante evaluation. On ex-post evaluation studies, the effectiveness of a LEZ is analysed after a certain period has passed since its implementation. Ex-ante evaluation studies are conducted prior to the implementation of a LEZ, to anticipate its outcomes and confirm whether this measure is effective. The insights gained from the review of this literature and its major gaps are described in this section. In Table 1, we enumerate the ex-post and ex-ante LEZ evaluation studies published in journals included in the ISI and/or SCOPUS bibliographic databases. Studies aimed solely to quantify the impacts of LEZ on pollutant emissions were not considered in the literature review.

1.2.1. Ex-post evaluation

To the best of our knowledge, Boogaard et al. (2012) contains the first ex-post evaluation of LEZ from the viewpoint of air quality. Based on a measurement campaign in five Dutch cities including Amsterdam, the authors concluded that the introduction of LEZ for heavy-duty vehicles has produced non-significant reductions in PM10 and NO_x concentrations. In contrast, focusing specifically on the effects of the LEZ in Amsterdam, Panteliadis et al. (2014) reported a significant decrease in PM10 and NO_x concentrations (7.7% and 5.9%, respectively) in the vicinity of roadside environmental monitoring stations. Instead of measured air pollution concentrations, Keuken et al. (2012) used modelled concentrations to estimate the effects of this same LEZ on elemental carbon (EC) levels. Actual traffic data, meteorological parameters and emission factors were used as input for a street-canyon model (URBIS model) to characterize the spatial distribution of EC concentrations. However, the model was only applied to roads inside the LEZ (with a traffic volume exceeding 7500 vehicles in 24 h), and therefore the city-wide impact of the LEZ was not addressed. Specific EC emission factors were determined for heavy-duty vehicles in this study, but no distinction was made regarding the EC emissions relating to the various Euro classes. The conclusion stated by the authors was that the LEZ led to a negligible reduction of EC concentrations due to the low proportion of highly polluting heavy-duty vehicles (1% of traffic volume) circulating in the urban area.

In the United Kingdom, Ellison et al. (2013) carried out an ex-post evaluation study on the impacts of a LEZ created in London for heavy diesel vehicles, buses and coaches. This study concluded that London's air quality improved marginally with respect to PM10 concentrations. Indeed, ambient air quality measurements showed that concentrations of PM10 within the LEZ have dropped by 2.5–3.1% compared to just over 1% for areas in its vicinity. In contrast, no discernible differences were found for NO_x concentrations.

A first ex-post evaluation study of a LEZ in Munich has been conducted by Qadir et al. (2013) based on PM2.5 measurements made before and after its creation. These measurements were analysed for elemental carbon (EC) and particulate organic compounds (POC). The authors evidenced that the average daily concentration of EC from traffic decreased 60%, from 1.1 $\mu g/m^3$ before to 0.5 $\mu g/m^3$ after the implementation of the LEZ, and no significant differences were noticed in POC concentrations. More recently, also evaluating the effects of the LEZ in Munich, Fensterer et al. (2014) reported a substantial decrease of PM10 levels at the traffic-monitoring site analysed, especially in summer (19.6%) but also in winter (6.8%). However, it should be noted that Fensterer et al. (2014) considered not only the impact of the LEZ but also the impact of a transit ban for all trucks on Sundays. Therefore, the authors did not assess the effects that can be specifically attributed to the implementation of the LEZ.

The most recent ex-post evaluation study we encountered in the literature was performed by Da Silva et al. (2014) to assess the effectiveness of the LEZ established in 2012 in the most polluted area of Lisbon (Baixa and Avenida da Liberdade). The conclusion was that its implementation led to reductions of 16% and 6% in annual average PM10 and NO_2 concentrations, respectively. However, the air pollution levels achieved outside the LEZ were not addressed by the authors, therefore the citywide impact of the LEZ was not fully appraised.

Globally, as evidenced by the studies reviewed, it remains unclear how successful LEZ have been with respect to the fulfilment of EU air pollutant limit values and what improvements in air quality levels can be attributed to such traffic management measures. To clarify the situation, ex-post evaluations can certainly be very useful, but need to be made considering also what is happening outside the LEZ, as well as separating their impacts from those of other measures that may likewise be affecting air pollution levels in the city where they are being applied.

1.2.2. Ex-ante evaluation

Despite the important information that can be obtained through the ex-ante evaluation of the air quality impacts of a LEZ, only two studies were found in the literature where such impacts have been estimated.

The first of these studies was performed for London by Carslaw and Beevers (2002). Using NO_2 as air pollution indicator, two main types of potential LEZ schemes were analysed: the reduction of vehicle flows and the restriction of higher polluting vehicles. For this purpose, the COPERT II model (HA, 1999) and the CAR International model (Eerens et al., 1993) were used to calculate the emissions and near-road concentrations of NO_2, respectively. Considering the most effective scenario, the authors predicted an overall reduction between 3.6% and 11.1% in NO_2 concentrations. However, it should be noted that traffic data for all major roads in