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Review

Review of the efficacy of low emission zones to improve urban air quality in European cities

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HIGHLIGHTS

- Most studies of LEZs have not taken confounding factors into account adequately.
- German LEZs may have reduced PM_{10} and NO_2 concentrations by a few percent.
- Elsewhere no clear effects on PM_{10} and NO_2 observed.
- Carbonaceous particle concentrations may be reduced significantly.

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ABSTRACT

Many cities still exceed the European Union (EU) air quality limit values for particulate matter (PM_{10}, particles with an aerodynamic diameter less than 10 μm) and/or nitrogen dioxide (NO_2). In an attempt to reduce emissions approximately 200 low emission zones (LEZs) have been established in 12 EU countries. These restrict the entry of vehicles based on the emission standard the vehicles were originally constructed to meet, but the restrictions vary considerably. This paper reviews the evidence on the efficacy of LEZs to improve urban air quality in five EU countries (Denmark, Germany, Netherlands, Italy and UK), and concludes that there have been mixed results. There is some evidence from ambient measurements that LEZs in Germany, which restrict passenger cars as well as heavy duty vehicles (HDVs), have reduced long term average PM_{10} and NO_2 concentrations by a few percent. Elsewhere, where restrictions are limited to HDVs, the picture is much less clear. This may be due to the large number of confounding factors. On the other hand there is some, albeit limited, evidence that LEZs may result in larger reductions in concentrations of carbonaceous particles, due to traffic making a larger contribution to ambient concentrations of these particles than to PM_{10} and $PM_{2.5}$. The effects of day to day variations in meteorology on concentrations often mask more subtle effects of a LEZ. In addition, separating the direct effects of a LEZ from the effects of other policy measures, the economy and the normal renewal of the vehicle fleet is not easy, and may give rise to false results.

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1. Introduction

A large proportion of the European population continues to be exposed to poor air quality despite the significant reduction in emissions over the last few decades. The last evaluation by the European Environmental Agency (2014) has estimated that, during 2012, 21–33% of the urban population live in areas where the PM_{10} limit value is exceeded, and 64–83 and 91–93% where the WHO PM_{10} and $PM_{2.5}$ guidelines are exceeded. Whilst the adverse health effects of particulate matter (PM) are well documented (WHO,

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2005, 2013) there is increasing evidence of the health effects of long term exposure to NO_2 (WHO, 2013).

The European Union (EU) air quality Directive (2008/50/EC) requires the limit values for PM_{10} and NO_2 to be achieved by 2005 and 2010 respectively, but also allows the compliance to be delayed until 2010 and 2015 respectively subject to the Member State submitting an acceptable air quality action plan for non-compliant agglomerations and zones. Most EU member states have sought time extensions for one or both these pollutants.

In an effort to comply with the air quality limit values, and to protect human health, a number of European cities have introduced low emission zones (LEZs). In the nearly two decades since the first one was established LEZs have become regarded as an important measure to improve urban air quality, and there are thought to be approximately 200[2] currently in existence in Europe (Sadler Consultants Ltd, 2014a).

Whilst there are a large number of LEZs there have been few good quality studies quantifying their impact on air quality using monitored data. As the ultimate aim for many LEZs is to contribute towards compliance with the EU limit values, which are largely assessed thorough monitoring ambient concentrations, this is perhaps surprising. Many cities have assessed the cost-effectiveness of introducing a LEZ pre-implementation using emissions modelling and, in some cases, dispersion modelling to assess their potential impact, but there have been few post-implementation studies published.

The aim of this review is to describe the types of LEZ in the EU and to assess the evidence of their efficacy, focussing largely, but not exclusively, on ambient air quality measurements. It reviews studies undertaken in five EU countries (Denmark, Germany, Netherlands, Italy and the UK), and is based on a literature search of peer reviewed papers using a range of relevant terms and databases. To identify reports commissioned by city and Government agencies a Google search was also undertaken. As the searches where undertaken mainly in the English language and it is probable that some relevant studies were missed. In addition not all relevant studies may be available on the internet.

It discusses the evidence from the London LEZ in more detail than other LEZs as it is probably the most extensively studied and certainly Europe's largest LEZ. Both modelled and measured data has been discussed, to provide an insight into the often optimistic results of modelling studies. For other LEZs the evidence is limited to ambient monitoring data.

A number of other urban scale traffic measures have been introduced into European cities, such as parking restrictions, road and bridge charges, and bus lanes that discriminate in favour of low emission vehicles. Another measure that is favoured in some European countries is the use of short term vehicle restrictions to reduce emissions during pollution events. These measures, whilst mentioned in passing, have not been included in the main part of this review, as these are not strictly LEZs, although there are similar or greater difficulties in assessing the success or otherwise of these measures.

2. Low emission zones

In broad terms LEZs are areas where access is restricted due to the emissions of certain road vehicles. The restriction is generally based on the emissions standard the vehicle was constructed to and may be a complete ban or there may be a charge to enter the LEZ. It may cover a few roads or a large inner city area.

[2] This assumes that the approximately 1550 mainly small LEZs in the Lombardi region of Italy count as one LEZ.

European emission standards apply to passenger cars and vans (i.e. light duty vehicles; LDVs), two/three wheeled vehicles and the engines used in heavy duty vehicles (HDVs). Each type of vehicle has different emission limits and test procedures. For LDVs there are separate requirements for gasoline and diesel vehicles. For LDVs Arabic numbers (Euro 1, Euro 2, etc.) and HDVs Roman numbers (Euro I, Euro II, etc.) are used to identify the emission standards. This convention has been used in this paper.

A LEZ essentially introduces a step change in the normal fleet turnover, resulting in lower emissions than would have occurred without the LEZ. Over time the fleet emissions will become similar to those that would have occurred without the LEZ. For further benefits it is necessary to periodically tighten the scheme's criteria.

The LEZs are mainly aimed at reducing exhaust emissions of PM, although some also aim to reduce nitrogen oxides (NO_x). These emissions are greater from diesel vehicles than from conventional gasoline vehicles (assuming, for NO_x, a three-way catalyst is fitted). HDVs, which are almost all diesel fuelled in Europe, have the greatest emissions per vehicle kilometre. For example, Wang et al. (2010) suggests that in an urban area in Copenhagen HDVs emit about 30 times more $PM_{2.5}$ and 26 times more NO_x than LDVs. Therefore many LEZs restrict these vehicles.

2.1. Brief history of LEZs

The first LEZs in Europe were established in 1996 in Stockholm, Göteborg and Malmo in Sweden, where they are known as Environmental Zones (Miljözon). The oldest HDVs were banned, and middle aged HDVs had to be fitted with a certified emission control device or new engine (Göteborgs Stad, 2006). In 2002 the entry criteria were modified to include restrictions on NO_x emissions. In 2006 the Swedish Government established a national LEZ scheme. The current requirements are that Euro II and III HDVs can be driven in a LEZ for eight years from first registration, Euro IV until 2016 and Euro V until 2020 (Göteborgs Stad et al., 2009).

The first LEZ outside Sweden, established in 2002, was in the Mont Blanc Tunnel between France and Italy. HDVs are banned from entering unless they meet at least the Euro III standard.

2.2. Summary of European LEZs requirements

Table 1 summarises the LEZ requirements. Only HDVs are restricted in most countries, but in Germany LDVS are included as are cars in Athens (Greece) and Lisbon (Portugal). The Italian LEZs also restrict 2-wheeled vehicles.

There are a large number of LEZs in Italy and Germany, but other countries have been less enthusiastic. In France, according to Charleux (2014), legislation was passed in 2010 to allow large urban communities to introduce LEZs, but following a change in government, the policy was abandoned. However, the Mayor of Paris (2015) has announced the establishment of a LEZ in the capital from the summer 2015.

According to Sadler Consultants Ltd. (2014a) most LEZs are permanent and apply 24 h a day, seven days a week. Some, however, only apply on weekdays (Athens and Budapest LEZs) and the Lisbon LEZ only applies for 12 daytime hours on Monday to Saturday. Some Italian LEZs only restrict passenger cars in the winter, but restrict 2-stroke motorcycles and mopeds, and diesel public transport buses all year. Athens LEZ applies from September to July each year, with different requirements within the city centre and the rest of Athens. Vehicles up to 2.2 t are allowed to enter the city centre on alternative days depending on the last digit of the license plate. In the whole of Athens vehicles over 2.2 t and first registered before 1 January 1991 are banned. The date increases by one year, every year. LEZ restrictions are enforced by manual techniques or

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