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# Quantifying the impact of low- and zero-emission zones: Evidence Review

for the Clean Cities Campaign

17 October 2022

Commissioned by
the Clean Cities Campaign

CleanCities

## Document Control

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# Contents

# 1 Executive Summary

The European Commission has been undertaking a review of the Ambient Air Quality Directive (Directive 2008/50/EC, abbreviated as AAQD), with a view to publishing proposals for a revised Directive in October 2022. A key measure enacted by Member States and cities to comply with the existing air quality Limit Values, particularly for nitrogen dioxide ($NO_2$), has been the introduction of Low Emission Zones (LEZs). Zero Emission Zones (ZEZs), that do not allow vehicles powered by internal combustion engines to enter, have also started to be introduced. Currently, there are around 320 LEZs in place in European cities and more than 500 expected by 2025, with 35 ZEZs planned.

However, it is understood that the impact assessment to accompany the proposals for a revised Directive does not take into account the potential impacts of further LEZs and ZEZs in Europe. As a result, the Clean Cities Campaign has commissioned Air Quality Consultants (AQC) to collate and evaluate the available evidence in terms of the maximum potential impact of both existing and planned LEZs and ZEZs in Europe.

This report draws on recent review studies, a search of selected national and EU databases and the expert knowledge of the authors, to identify potential candidates for "maximum impacts", and then reviews the evidence relating to these. The main findings are:

- **Well-designed, carefully implemented and stringently enforced LEZs can make a significant contribution to improving air quality in urban areas.** $NO_2$ concentration reductions of around 40% are not only theoretically possible but have been demonstrated in practice. Reductions of around 20% have already been achieved and may be more achievable in a wider set of circumstances. ZEZs could have a greater effect (e.g. a greater than 95% reduction in traffic-related NOx emissions is projected for ZEZs in Oxford and Amsterdam), but this depends on when they are introduced, the relative change in the fleet, and the proportion of the fleet they cover.
- **In terms of Particulate Matter ($PM_{10}$ and $PM_{2.5}$), the potential for reduction by LEZs and ZEZs is smaller.** This is related to both the fact that the proportion of locally measured PM concentrations associated with exhaust emissions is much smaller than for $NO_2$ and also that a larger proportion of the diesel fleet will already have Diesel Particulate Filters (DPFs) fitted, due to earlier Euro standards. However, in some circumstances, such as in countries with older vehicle fleets (and especially, e.g. municipal buses), LEZs will still have a significant positive impact on reducing PM emissions. In addition, there is an ongoing debate on the importance of reducing not only the particle mass (PM) but also particle numbers (PN), which have been found to still be emitted in large quantities by tested Euro 6 petrol and diesel vehicles.
- **LEZs can positively improve air quality in areas outside the Zone and prior to full implementation (pre-compliance).** Significant preparatory work, in terms of technical design, financial support and social outreach, are beneficial for the Zone to be both implemented successfully, and to achieve the forecast benefits.

It should be noted that the impacts of LEZs and ZEZs on air quality are difficult to assess with precision. This is mainly due to the problems of constructing a robust counter-factual, and in isolating the effect of the Zone from the wider changes to the vehicle fleet and driver/operator behaviours (as well as wider societal changes).

Due to the small number of ZEZs either in operation or planned, there is limited information on their current or future use. However, the impact of a LEZ inevitably reduces over time, as older vehicles are naturally replaced. This offers the opportunity to tighten the standards of the LEZ so that new benefits can be accrued. However, there are currently no tighter standards than as defined by Euro 6/VI, and so a ZEZ currently offers the main route to obtaining additional air quality benefits (above and beyond Euro 6/VI). ZEZs also provide a key link point between air pollution and climate policy and will be a crucial step towards obtaining both net zero carbon emissions and zero pollution cities. ZEZs will therefore need to become a key policy instrument for urban areas in Europe, just as LEZs are now.

# 2 Introduction

## 2.1 Purpose of this study

The European Commission has been undertaking a review of the Ambient Air Quality Directive 2008/50/EC, abbreviated as (AAQD), with a view to publishing proposals for a revised Directive in October 2022. The publication of the WHO's updated Air Quality Guidelines in 2021 gave additional impetus to the review and underlined that there is still some way to go to achieve "safe" air quality levels in European towns and cities.

A key component of Member States' and their cities' efforts to comply with the existing air quality Limit Values, particularly for $NO_2$, has been the introduction of Low Emission Zones. The concept is not new – the first LEZs were set up in Sweden in 1996[1] and Berlin's Low Emission Zone (Umweltzone) has been in place since January 2008 – and encompasses many different types of zone, both in terms of area covered and vehicle types affected. More recently, the concept of Zero Emission Zones has been introduced, building on the availability of zero tailpipe emission vehicles. Currently, there are around 320 LEZs in place in European cities and more than 500 expected by 2025, with 35 ZEZs planned.

However, it is understood that the impact assessment to accompany the proposals for a revised Directive do not take the potential impacts of further Low- and Zero Emission Zones into account. As a result, the Clean Cities Campaign, a network of over 70 NGOs and grassroots groups campaigning for zero-emission transport in cities, has commissioned AQC to address two key questions:

1. What does the available evidence show in terms of the maximum potential impact of LEZs and ZEZs, both operating and planned, in Europe, and
2. How could more, or more stringent LEZs and ZEZs, contribute to improving urban air quality in Europe, thus allowing tighter Limit Values to be set.

This report addresses the first of those questions. Due to the time constraints on the project, it does not represent a fully exhaustive evidence review. Rather, it draws on recent review studies, a search in selected national and EU databases (see section 1.3) and the expert knowledge of the authors to identify potential candidates for "maximum impact" and reviews the evidence relating to these. As such, it takes both formal, peer reviewed literature and "grey" literature, often written or commissioned by the city authorities in question. The evidence quality therefore varies, although it is sufficiently robust to draw some general conclusions.

The outputs from the project will be used to support the work of the Clean Cities Campaign on the upcoming proposal for the revision of the Ambient Air Quality Directive.

The remainder of this section describes the key features of LEZs and ZEZs, highlighting the variability in their make-up and application. It also describes the scope and limitations of this study and briefly identifies the common features of successful LEZs.

The following section sets out the findings from the review while the final section draws together the key messages from the study.

## 2.2 What are Low and Zero Emission Zones?

Emission control zones, in the form of low emission zones, clean air zones, low emission neighbourhoods, and, more recently, zero-emission zones have been a feature of air quality policy since the first ones were introduced in Sweden in 1996. Essentially, they are urban areas where vehicles of a specified type (heavy

[1] https://www.toi.no/getfile.php?mmfileid=49204

goods vehicles (HGVs), delivery vehicles, buses, taxis, private cars, etc) have to achieve a specified emission standard in order to gain entry, or to avoid payment of a charge for entry. They can take many different forms based on the size of the area, the vehicles they apply to, the restricted emission standards and the form of enforcement. Typically, they are linked to "Euro standard" emissions classes, with vehicles that do not meet those standards either not being allowed to operate within a designated concerned area or required to pay a charge or fine if they enter the designated area during its hours of operation. Enforcement varies from sophisticated Automatic Number Plate Recognition (ANPR) cameras to simple windscreen stickers, with enforcement through traffic or parking control officers. The actual level of enforcement applied can vary greatly between zones, however. Most European countries where LEZs have been introduced have standardised their rules, although there can still be significant variation across zones in the same country. By way of example, Boxes 1 and 2 below show the standardised approaches for the Netherlands and the UK.

**Box 1: Environmental Zones in The Netherlands**

- Low emission, or "Environmental" Zones have been in place in some form in The Netherlands since 2008. However, a 2019 decree under the Road Traffic Act has provided a standardised approach to Environmental Zones currently and in the future:
- From 2022, zones for HGVs and buses can be set up (either or both), allowing only those vehicles equipped with engines that meet the Euro IV (green zones) or Euro VI (purple zones) emission standards.
- Between 2020 and 2025, zones for cars and vans (up to 3.5 tonnes) can be set up, allowing only those vehicles that meet the Euro 3 (yellow zones) or Euro 4 (green zones) emission standards.
- From 2025, zone for cars and vans can be either green (i.e. Euro 4 or higher) or blue (Euro 5 or higher).
- Also from 2025, zero emission zones can be set up for vans and HGVs.

Note that, by 2025, Euro 4 vehicles will be at least 20 years old.

**Box 2: Clean Air Zones in the UK**

Under the *UK Plan for Tackling Roadside Nitrogen Dioxide Concentrations* (2017)[1], local authorities, where exceedances of the $NO_2$ limit value are located, must consider setting up a Clean Air Zone. These zones are based on four classes, A-D, shown below. The expectation is that the type of zone used will depend on the severity and predicted longevity of the exceedances. In all cases, the relevant emission standards are Euro VI for HGVs and buses, Euro 6 for diesel cars and vans, and Euro 4 for petrol cars and vans. Enforcement of the CAZ is generally through the use of ANPR cameras, with charge notices issued by a centralised authority. CAZs are in addition to the London LEZ and Ultra-Low Emission Zone (ULEZ), and to the schemes operating or in development in other cities (such as the ZEZ in Oxford).

**Table 2-1: Defra Clean Air Zone Classification**

| Class | Vehicle type |
|---|---|
| A | Buses, coaches, taxis, private hire vehicles |
| B | Buses, coaches, taxis, private hire vehicles, heavy goods vehicles |
| C | Buses, coaches, taxis, private hire vehicles, heavy goods vehicles, vans, minibuses |
| D | Buses, coaches, taxis, private hire vehicles, heavy goods vehicles, vans, minibuses, cars; the local authority has the option to include motorcycles |

## 2.3 Data sources

This evidence review is based on a number of sources of data which include:

- Work undertaken by Transport & Environment (T&E) and other NGOs on the effectiveness of LEZs and ZEZs, in particular the 2019 report by T&E which looked at the effectiveness of LEZs[2] was used as a starting point for the evidence review for work undertaken up until that date. These sources of information were cross referenced against other information sources such as peer reviewed papers
- As part of the 2018 UK plan for meeting the $NO_2$ Limit Values, UK cities where exceedances occur were required to consider and, if necessary, implement Clean Air Zones. To support this framework, Ipsos and the University of Leeds were commissioned to undertake a post evaluation of local $NO_2$ plans. Publicly available outcomes of this work, which is ongoing, have been reviewed
- The European Environment Agency (EEA) database of NAPCP policies and measures is part of the process for submitting National Air Pollution Control Programmes (NAPCPs) to the European Commission. Member States are required to provide information on policies and measures (PaMs) being implemented. Although NAPCPs do not contain detailed information on impacts, data within the EEA database has been reviewed as a starting point to follow up information on specific zones
- In 2019, the Greater London Authority implemented an Ultra-Low Emission Zone (ULEZ) in central London, which has, in 2021, been expanded to the North and South Circular (inner Ring Road), an area 18 times the size of the original zone. The ULEZ is in addition to a Low Emission Zone which has been in place since 2008 placing restrictions on HGVs and large vans. Post implementation evaluation of the ULEZ, based on both calculated emissions reductions and monitoring, has been reviewed. Consultation is currently underway for a potential expansion of the ULEZ to the M25 (outer Ring Road)
- A review of the recent (post 2016) scientific literature on the impacts of Low Emission Zones using keyword searches. This has included papers spanning a number of European Countries including Spain, Germany, Portugal and France
- A review of city-led evaluations of the impacts of LEZs across Europe
- A review of information relating to ZEZs, for example the feasibility work for the Oxford ZEZ; and
- A review of LEZs across Europe from the https://urbanaccessregulations.eu/ website to ensure that any zones, in particular incorporating Euro 6 restrictions, have been captured above.

It should be noted that a fully exhaustive literature search has not been undertaken. However, it is judged that by reviewing the above sources, and speaking to contacts about other zones and potential data sources, it is unlikely that a study reporting greater improvements than those reported will have been missed. Appendix A1 lists the data sources used.

## 2.4 Study Limitations

LEZs and ZEZs accelerate and/or enforce changes to the vehicle fleet which are already happening. There are two principal evidence streams upon which the air quality improvements from LEZs and ZEZs can be gauged:

- measurement studies, which necessarily look backward in time and so can only consider the effects of existing zones; and

[2] https://www.transportenvironment.org/wp-content/uploads/2021/07/2019_09_Briefing_LEZ-ZEZ_final-1.pdf

- modelling studies, which might look backward in time but are often carried out as part of designing the zone and so entail future predictions.

While the measurement-based approach should, in principle, provide the most robust evidence of a zone's effect on air quality, in practice the effect of an LEZ is challenging to determine. This is because air quality is likely to have changed over time even without the zone in place, making it impossible to have simple and straightforward 'counterfactual' measurements against which to compare those collected after implementing the zone. A variety of approaches have been used in the literature, from simple comparisons of measurements in two time periods, to more complex statistical analyses which are, themselves, small models.

With the modelling approach, reliability is limited by the myriad of underpinning assumptions. Crucial for LEZ/ZEZ studies are the road transport emissions factors and transport activity data (including assumed fleet changes in response to the restrictions). Notwithstanding this uncertainty, modelling studies have a fundamental advantage of being able to focus solely on the effects of the intervention without the confounding effects of 'the real world'. These studies are also able to consider the effects of future, or relatively recent, interventions for which there is only very limited measurement evidence.

Evidence has been collected from a wide variety of published sources, spanning a wide range of analytical quality. It has not been possible to revert to the original measurements and/or model assumptions and this review has exclusively considered material within published reports. Where the literature sources have quantified the effect of an LEZ or ZEZ, a high-level review has been carried out of the likely robustness of these conclusions. This has considered the overall suitability of the methodology but not the detail of the calculations relied upon.

An important point to note is that the status of a study within peer-reviewed vs 'grey' literature was not assumed to denote its analytical quality. In practice, several studies were found in peer-reviewed literature which are considered to be fundamentally flawed with respect to confidently assigning a LEZ as the cause of observed concentration changes. It was considered that significantly more effort would be required to determine a robust counterfactual position before those changes could be reliably linked to the LEZ. Conversely the 'grey' literature was found to contain some extremely helpful analyses.

Appropriately quantifying small changes often requires greater accuracy than do large ones. For example, a reduction of 2 $\mu g/m^3$ with error bars of +- 4 $\mu g/m^3$ might be either a reduction or an increase, but a reduction of 30 $\mu g/m^3$ +- 4 $\mu g/m^3$ is a clear benefit. It is well established that average reductions in NOx emissions from Euro 3/III through to Euro 5/V diesel vehicles were disappointing, which is in large part due to the well documented mismatch between the tested emissions for such vehicles and their real-world performance[3]. Thus, studies focusing on zones which mandate Euro 5/V or older vehicles have failed to robustly show appreciable reductions in $NO_2$ concentrations. It is similarly well established that average NOx emissions from Euro 6/VI diesel vehicles are lower than from earlier models, thus these zones provide more opportunity to robustly demonstrate an effect.

## 2.5 Factors affecting the impact of zones

From the data sources accessed for this review, a number of factors have been identified which significantly change the likely effectiveness of LEZs and ZEZs. While it is not the intention to discuss them exhaustively, Table 2-2 summarises the key factors.

[3] https://www.transportenvironment.org/discover/dieselgate-who-what-how/

**Table 2-2: Factors increasing the impact of zones**

| Factor | Ways impact is affected |
| --- | --- |
| **Emissions specification** | The level of emission performance required by the zone will clearly impact the traffic emissions within the zone. However, the scale of reduction will be dependent on the stringency of the emission standard *relative* to the fleet average for that urban area. Thus, a zone which mandates Euro 4/IV when the majority of vehicles in the fleet already meet that standard will not have as large an impact as one which mandates Euro 6/VI. |
| **Vehicle type and exemptions** | As noted above, zones vary in terms of the vehicle classes they seek to control. The impact of the zone will therefore depend on the proportion of local emissions the given vehicle class makes up. For example, if HGVs account for 15% of the local emissions of $NO_X$, even the most stringent ZEZ can only reduce traffic emissions in the area by 15% if it only addresses HGVs, and an LEZ by much less than that. In addition, LEZs generally have some form of exemption for local residents, businesses or specific groups. These can range from additional time to achieve compliance to an outright exclusion from control. Exemptions help make the zone more acceptable to local people and ease the additional burden on the people the zone seeks to protect. However, too many exemptions both reduce the effectiveness of the zone and make it confusing, reducing compliance rates generally. |
| **Size** | The size of the zone in relation to the urban area can have different effects. If the zone is very small, it can simply result in the displacement of vehicles rather than their replacement by newer, cleaner alternatives. As a result, the total emissions reduction is small. However, a well targeted but small zone can have a significant wider impact. For example, the Oxford Zero Emission Zone was initially very small, covering only a few streets in the city centre, and only included buses. However, the ZEZ included one of the main hubs for bus routes, and thus buses accessing that hub carried the benefit of low and zero emission capability across their entire routes. Thus, a small zone at a strategic point in the transport network can have a far wider impact. In addition, local authorities may find it more difficult to justify very large zones as they cover more local residents and businesses (on which they will impose a financial burden), and so larger zones may be less stringent. |
| **Timing** | Newer vehicles are generally lower emission than older vehicles as they are both required to meet stricter emission standards, and there is increasing penetration of electric vehicles; in addition, emissions performance tends to degrade with age. Thus, the fleet will become cleaner over time as older vehicles are replaced in the normal course of events. Therefore, the impact of an LEZ will reduce over time, as the normal turnover of the fleet 'catches up' with the emission requirements of the zone. The zone may still have a purpose, in helping to remove the oldest and most polluting vehicles rather than shifting the fleet average, but the impact will become smaller over time (unless the emissions targets are revised). |

| | |
|---|---|
| **Enforcement** | The level and stringency of enforcement will, alongside the severity of the penalties for non-compliance, have an influence over the level of compliance and thus the impact of the zone. Modelling for the Bath CAZ tested the impact of different levels of charge, although this was focussed on achieving the current $NO_2$ Limit Values and not the maximum possible impact[4]. |
| **Penalties and support** | The main objective of LEZ and ZEZs is to accelerate the cleaning of the vehicle fleet. As such, they provide the "stick" for people and businesses operating in the zone to either upgrade their vehicles or find alternatives (e.g. walking or cycling). However, the effectiveness of the zone is enhanced through the provision of support for local businesses to upgrade their vehicles, through subsidised loans or grants. This both improves the acceptability of the zone (allowing potentially for more stringent standards) and increases "pre-compliance" with the zone. |
| **Lead-in and outreach** | Zones which carry the support of the majority of residents and businesses are more likely to be successful and more likely to be able to impose higher emission standards. Obtaining such majority support requires extensive, active, and carefully targeted engagement and outreach. |

[4] https://beta.bathnes.gov.uk/policy-and-documents-library/baths-clean-air-zone

# 3 Evidence Review Findings

## 3.1 Data sources

The data sources, which include those listed in section 2.3, are included in more detail in Table A1-1 in Appendix 1.

## 3.2 Main findings

During this project, three key issues have become apparent:

- Older zones, especially those based on the Euro 4 and 5 emission standards for diesel vehicles, have tended to be less beneficial. This is in large part due to the well documented mismatch between the tested emissions for such vehicles and their real-world performance.
- Relatively few reports are available which assess the impact, through change in measured pollutant concentrations, for LEZs based around Euro 6/VI. Measurement studies of zones based on Euro 4 and earlier have tended to show smaller impacts, especially for $NO_2$ concentrations, potentially for the reason set out above.
- The key aims and drivers for zones vary. Some zones are targeted directly at $NO_2$ (such as the UK CAZs) and some, like the Berlin Umweltzone, are targeting PM, while a key driver for ZEZs is the reduction of GHG emissions. In addition, for some zones, the removal of older, more polluting vehicles is a higher priority than driving the uptake of newer vehicles. Thus, what constitutes success will vary between zones and may not equate to maximum concentration reduction for either $NO_2$ or PM.

It should be noted that the results highlighted below represent a minority of available information on LEZs. Most tend to show little or no measurable impact as a result of the LEZ, especially for older zones, often for the reasons set out above, e.g. a low level of ambition with the "clean" vehicles being mandated having a similar (or even worse) real-world performance to those being replaced. Nevertheless, the results below show that LEZs can have a significant impact on urban air quality under certain conditions.

### 3.2.1 Maximum improvements from measurements (contemporary conditions)

From the reports reviewed as part of this project, the highest measured reductions in concentrations were:

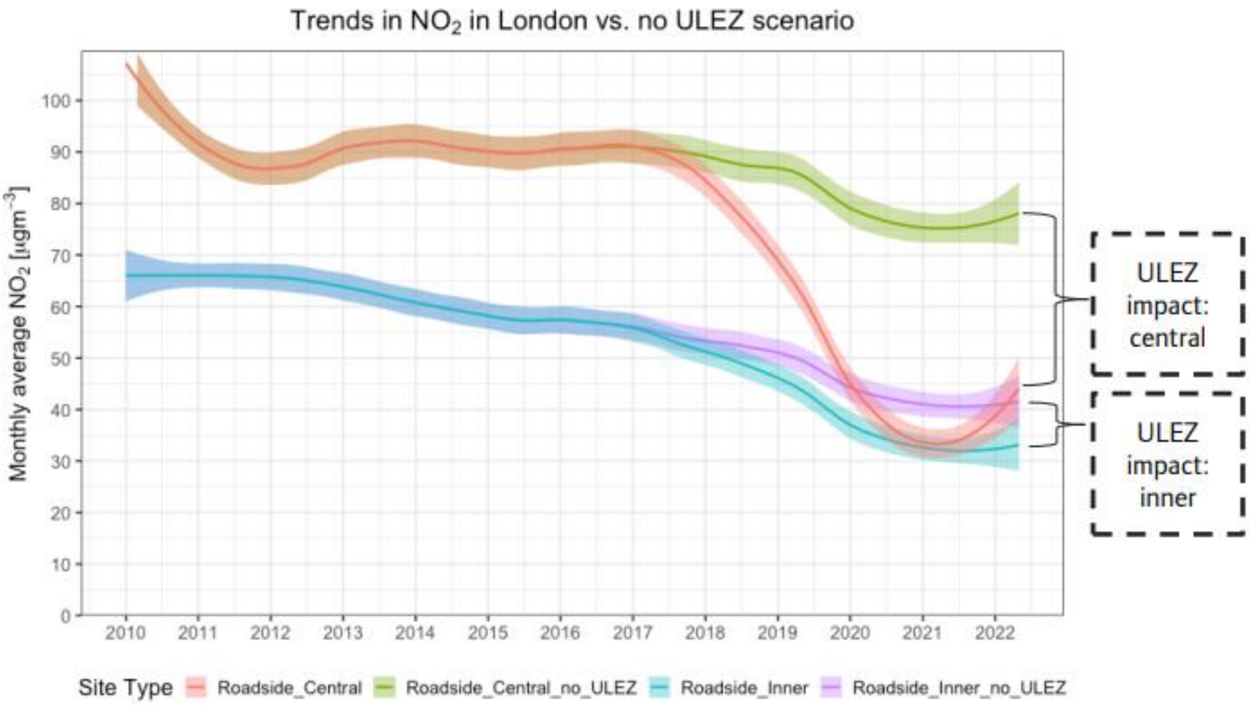
- 44% reduction in $NO_2$ concentrations in central London, compared to a calculated baseline, following the introduction of the expanded ULEZ in 2019[5]. This equated to a 35µg/m$^3$ reduction in concentrations and is based on a CAZ type D (see Box 2, above).
- 15µg/m$^3$ reduction $NO_2$ concentrations in Madrid Centre before and after the implementation of an LEZ based on Euro 3 petrol and Euro 4 diesel vehicles[6].
- 15% reduction in $PM_{10}$ concentrations in Munich and 10% in Berlin[7], based on a ban of pre-Euro 4 diesel and Euro 1 petrol vehicles.

[5] https://www.london.gov.uk/WHAT-WE-DO/environment/environment-publications/expanded-ultra-low-emission-zone-six-month-report
[6] Using Smart City Tools to Evaluate the Effectiveness of a Low Emissions Zone in Spain: Madrid Central; Lebrusan and Toutouh; *Smart* Cities (https://www.mdpi.com/journal/smartcities); 2020
[7] Low emission zones reduced $PM_{10}$ but not $NO_2$ concentrations in Berlin and Munich, Germany; Jianwei, *et al*; *Journal of Environmental Management* (https://www.sciencedirect.com/journal/journal-of-environmental-management); 2022

- An analysis of the LEZ in Lisbon reported a 22% reduction in $NO_2$ concentrations and 29% in $PM_{10}$[8]. However, a similar reduction was seen at monitoring stations outside the LEZ and so the effect may have been independent of the LEZ itself.

The impact of the ULEZ in London, shown in Figure 3-1, illustrates some of the potential additional effects on air quality. The ULEZ was implemented in central London in 2019, prior to lockdowns resulting from the Covid-19 pandemic, the easing of which can be seen in the uplift in the red line in the graph. However, this also shows that the $NO_2$ trend was decreasing sharply in the 12 to 18 months prior to the zone being initiated, indicating pre-compliance as a result of the publicity and support provided in the lead-in period. A benefit was also identified in inner London, i.e. outside the area covered by the zone, indicating "wash-over" as the fleet using the wider area reflects the accelerated uptake of cleaner vehicles. Therefore, comparing concentrations immediately prior to the zone going live, and against locations just outside the zone, would have significantly under-estimated its effect. At the very least, this underlines the need to carefully design evaluation methodologies before a zone is introduced.

**Figure 3-1: Impact of the ULEZ in London**




Source: Greater London Authority[9]

### 3.2.2 Maximum improvements from projections (future conditions)

From the reports reviewed as part of this project (which included a number of cross-Europe summaries of current LEZs), the highest projected or modelled air quality benefits were:

[8] Impact of the implementation of Lisbon low emission zone on air quality; Santos *et al*; *Journal of Hazardous Materials* (https://www.journals.elsevier.com/journal-of-hazardous-materials); 2019

[9] https://www.london.gov.uk/sites/default/files/expanded_ultra_low_emission_zone_six_month_report.pdf

- 42.7% (26.4 μg/$m^3$) reduction in $NO_2$ concentrations in the city of Bath in the UK[10], as a result of implementing a CAZ type D (see Box 2, above).
- 24% reduction in $NO_2$ concentrations in Paris[11], based on a hypothetical mix of Euro 6 diesel/VI based controls.
- 16-33% reduction in $NO_2$ concentrations in Brussels[12], although the control level is not specified.
- 17% (8.2 μg/$m^3$) reduction in $NO_2$ concentrations in Manchester, UK[13], based on implementing a CAZ type C (see Box 2, above).
- 10% reduction in concentrations of $PM_{10}$ in central Madrid[14], based on a mixture of restrictions on pre-Euro 6 diesel/VI vehicles.

The range in benefits described above reflects the variability in both the zones themselves and the methods used to estimate their impacts. Even where zones and fleets are very similar, differences in assessment methodology, such as the models used and the assumptions included in the models, can produce significant differences in outcome. For example, modelling for Bath in the UK for a type D CAZ predicted a 42.7% reduction in $NO_2$ concentrations (which is not unreasonable given the results in London, see Fig 3-1 above), whereas modelling for a, very similar, type C CAZ in Manchester predicted a 5-8% reduction, and an 8% reduction in Birmingham for a type D CAZ. Figure 3-2, below, shows the predicted concentration changes in Bradford, UK, as a result of implementing a CAZ (the CAZ in Bradford went live in October 2022). It demonstrates the variation in concentrations which could result from the CAZ, ranging from 30-35% to 21-25% reduction within the zone, although all areas of the Council's area will benefit from air quality improvements.

10 https://www.bathnes.gov.uk/sites/default/files/sitedocuments/Environment/Pollution/Breathe/appendix_dii_674726.br_.042.fbc-11_aq3_modelling_report-compressed.pdf (Note that a Type C zone was implemented in Bath, although the differences between the two are small in this location)

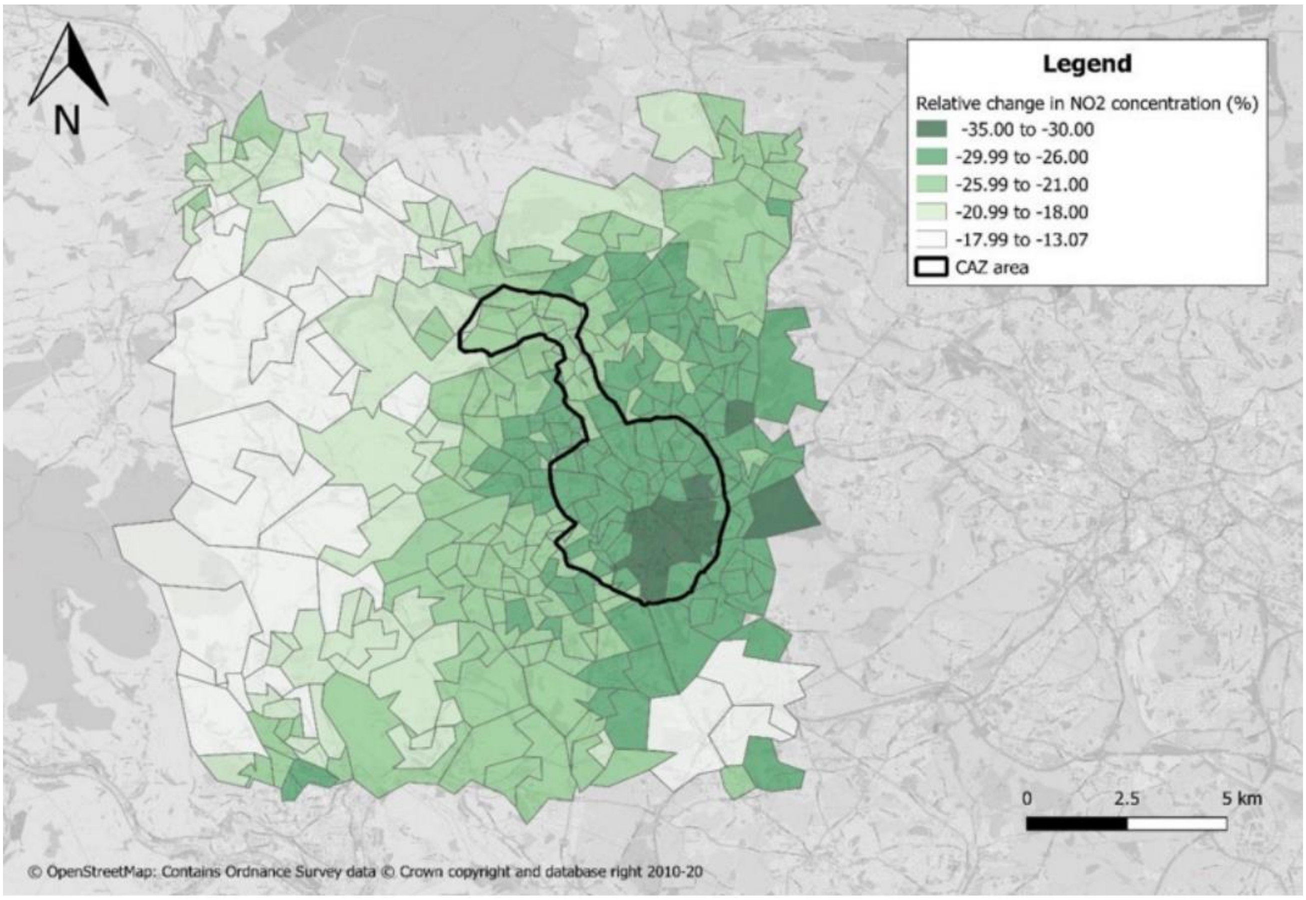
11 Implementation of various hypothetical low emission zone scenarios in Greater Paris: Assessment of fine-scale reduction in exposure and expected health benefits; Host, *et al*; *Environmental Research* (https://www.sciencedirect.com/journal/environmental-research); 2020

12 European Environment Agency NAPCP PaMs database - Low emission zone Brussels (Pam reference: 85371)

13 Greater Manchester's Outline Business Case to Tackle Nitrogen Dioxide Exceedances at the Roadside; Local Plan Air Quality Modelling Report (AQ3); 2019

14 Evaluation of emissions in traffic reduction and pedestrianization scenarios in Madrid; Sanchez, *et al*; *Transportation Research Part D* (https://www.sciencedirect.com/journal/transportation-research-part-d-transport-and-environment); 2021

**Figure 3-2: Predicted $NO_2$ concentration changes in Bradford, UK, as a result of implementing a CAZ**




Source: Bradford City Council[15]

### 3.2.3 Impact of Zero Emission Zones

Only two reports on the predicted impact of ZEZs were considered for this study: Oxford in the UK[16] and Amsterdam in The Netherlands[17]. Neither source provides a great deal of detail, and both acknowledge the uncertainty in predicting air quality in 2030. However, they are consistent in predicting a greater than 95% reduction in traffic related $NO_X$ emissions and a 50% or greater reduction in PM emissions. This is to be expected given that the only source of $NO_X$ from transport sources is fuel combustion, which is removed in a zero-emission scenario, although brake, tyre and other mechanical sources of PM are still present with electric vehicles. This results in predicted concentrations of 14.4µg/m$^3$ $NO_2$ and 9.6µg/m$^3$ $PM_{10}$ for Amsterdam in 2030. The results reported for Oxford are more mixed, with some sites showing a significant (around 50%) reduction in $NO_2$ concentrations but some (outside the zone) showing much more modest reductions. No concentration predictions are provided for $PM_{10}$.

### 3.2.4 Have LEZs failed to meet expectations?

The success of a LEZ or ZEZ relies on the differential in real-world emissions between vehicle types that are excluded and those that are allowed within the zone. Many LEZs have historically sought to exclude vehicles based on Euro type approval standards which have not delivered the expected reductions in NOx emissions,

[15] https://bradford.moderngov.co.uk/documents/s32989/Exec2MarchDocDN.pdf
[16] https://www.oxford.gov.uk/download/downloads/id/4019/zero_emission_zone_feasibility_study_october_2017.pdf
[17] https://assets.amsterdam.nl/publish/pages/867636/clean_air_action_plan_1.pdf

as has been well documented (often referred to as the Dieselgate scandal[18]). Specifically, while trip-average NOx emissions from diesel vehicles were predicted to fall steadily from Euro standards 2/II thought to 5/V, reductions were much smaller than forecast[19]. This has meant that the differential in NOx emissions between the excluded vehicles and those which have replaced them has been much smaller than predicted and has severely limited the ability of many LEZs to reduce $NO_2$ concentrations.

By contrast, early type approval standards have had significant success in reducing particle mass emissions from exhausts[13] and so LEZs which encourage these earlier standards have reduced PM. For example, LEZs in Berlin and Munich have reduced PM mass concentrations by 10% and 14% respectively[20]. In practice, however, the reductions to $PM_{10}$ and $PM_{2.5}$ concentrations which current Euro standards can achieve is limited by the typically small contribution of local exhaust emissions to total concentrations (which are typically dominated by secondary components). Exhaust emissions from nearby roads often comprise only a small fraction of total $PM_{10}$ and $PM_{2.5}$ concentrations and so the effects of reducing this component are also small.

Where early type approval standards for diesel vehicles brought limited real-world benefits to NOx emissions, the same cannot be said for Euro 6/VI standards. There is now considerable evidence that trip-average NOx emissions from these vehicles, and in particular those subject to Real Driving Emissions (RDE) type approval tests, are generally significantly lower than those for earlier standards. Furthermore, the predictive emissions factors which are used to design LEZs and forecast their effects are now informed by real-world driving. This provides good reason to expect that the predicted reductions in NOx emissions from any future Euro 6/VI-based LEZ for diesel vehicles will be realised. An example of such an LEZ is the London ULEZ. Modelling carried out by Transport for London in designing the scheme estimated that NOx emissions from roads in Central London would reduce by 45% as a result of the ULEZ[21]. In practice, the latest analysis of monitoring suggests that the road increment of $NO_2$ in Central London has fallen by more than 60% as a result of the ULEZ[11], suggesting that the emissions reductions have, in practice, exceeded expectations.

Predicting the effects of ZEZs on NOx emissions and $NO_2$ concentrations (and on the exhaust component of PM) is conceptually more straightforward. There is no uncertainty to real-world exhaust emissions from EVs as replacing an ICE vehicle with an EV removes these emissions entirely. It is, though, important to note that a ZEZ which targets only a small fraction of the fleet will often have only a small effect. Introducing, for example, EV buses will not address emissions from other vehicle types.

Despite the apparent conceptual simplicity of predicting the benefits of ZEZs, no future predictions can be classed as certain. How restrictions are enforced is important, and responses to any specific charging regimes are location-specific and difficult to anticipate. Furthermore, interventions on fleet composition might also affect trip routing and mode choice. Restricting certain vehicles from certain areas can, in theory, increase the distance travelled by these vehicles (and their trip-total emissions) as they avoid the zone. Conversely, the presence of a zone might exert a positive influence on the vehicle fleet in surrounding areas since it affects vehicle purchase decisions. Emissions released outside a zone can affect concentrations inside it. In practice, most evidence points to positive effects beyond a zone's boundary[11,22].

A key consideration in predicting the effect of a zone is the composition of the vehicle fleet without the zone in place. Since fleets evolve over time, this makes the benefits of an intervention temporary. For example, it is highly unlikely that the large benefits attributed to the London ULEZ will continue indefinitely, not because emissions within the zone will increase, but because those outside the zone will 'catch up', negating the

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[18] https://www.transportenvironment.org/discover/dieselgate-who-what-how/

[19] https://uk-air.defra.gov.uk/assets/documents/reports/cat09/2112201014_1272021_Exaust_Emissions_From_Road_Transport.pdf

[20] Low emission zones reduced PM10 but not NO2 concentrations in Berlin and Munich, Germany - ScienceDirect

[21] https://www.london.gov.uk/sites/default/files/ulez_ten_month_evaluation_report_23_april_2020.pdf

[22] https://www.ipsos.com/en-uk/2021-annual-report-evaluation-local-no2-plans

benefit of the zone. All other things being equal, the later a given set of restrictions is imposed, the smaller its relative effect will be. This does not, though, mean that more stringent standards cannot be applied in the future.

Predicting the effects of LEZs and ZEZs prior to their implementation is challenging and never exact. Zones which encouraged the use of vehicles meeting early Euro standards underperformed because of known and well documented issues with these standards[23]. These issues have now been largely resolved and the relationship between forecast NOx emissions from a vehicle and those being achieved in practice is much closer than it once was. There remains uncertainty regarding how the imposition of a zone will affect fleet composition and journey types both within and around the zone, as well as the date at which the restrictions cease to have a benefit. Nevertheless, there can be a reasonably high degree of confidence that forecast effects of zones which promote Euro 6 diesel/VI, Euro 7 (yet to be defined), or EVs will achieve similar improvements to those which it is possible to predict with current models.

[23] https://www.transportenvironment.org/discover/dieselgate-who-what-how/

# 4 Key messages and next steps

## 4.1 Key messages

It is clear from this research that a well-designed, carefully implemented and stringently enforced Low Emission Zone can make a significant contribution to improving air quality in urban areas. $NO_2$ concentration reductions of around 40% are not only theoretically possible but have been demonstrated in practice. Reductions of around 20% have already been achieved in a wider set of circumstances. Zero Emission Zones could have a greater effect (e.g. along the lines of the greater than 95% reduction in traffic related $NO_X$ emissions projected for Oxford and Amsterdam), but this depends on when they are introduced, and thus the relative change in the fleet, and the proportion of the fleet they cover.

In terms of particulate matter, the potential for LEZs and ZEZs is smaller. This is related to both the fact that the proportion of locally measured PM concentrations originating from vehicle exhausts is much smaller than for $NO_2$ and also that a larger proportion of the diesel fleet will already have DPFs fitted, due to earlier Euro standards. However, in some circumstances, such as in countries with older vehicle fleets (especially, e.g. municipal buses), LEZs will still have a positive impact on PM emissions. Moreover, there is an ongoing debate on the importance of reducing not only the particle mass (PM) but also particle numbers (PN), which have been found to still be emitted in large quantities by tested Euro 6 petrol and diesel vehicles.[24]

The impacts of LEZs and ZEZs on air quality are difficult to assess. This is mainly due to (1) the problems of constructing a robust counterfactual and (2) in isolating the effect of the zone from the wider changes to the vehicle fleet and driver/operator behaviours (as well as wider societal changes, such as the response to the Covid-19 pandemic, or the current energy crisis). LEZs can also positively impact on air quality in areas outside the zone and prior to their full implementation (pre-compliance). Significant preparatory work, in terms of technical design, financial support and social outreach, are needed in order for the zone to be both implemented successfully and achieve the forecast benefits.

Due to the small number of ZEZs either in operation or planned, and the even smaller number of impact assessments that have been published, this report offers relatively few insights into their future use. However, as noted above, the impact of LEZs reduces over time, as the fleet outside the area “catches up”. This offers the opportunity to tighten the standards of the LEZ so that new benefits can be accrued. However, there are currently no tighter standards than Euro 6/VI and so a ZEZ offers the only route to obtaining these additional air quality benefits. ZEZs also provide a key link point between air pollution and climate policy, and will be a crucial step towards obtaining both net zero carbon emissions and zero pollution cities. ZEZs will therefore need to become a key policy instrument for urban areas in Europe, just as LEZs are now.

[24] https://www.transportenvironment.org/discover/new-diesels-new-problems/

# 5 Appendices

# 1. Data sources

**Table A1-1: Data sources accessed for this project**

| Data Source | Country | City | Type of Report |
|---|---|---|---|
| Local $NO_2$ plans: Annual Report 2021[25] | UK | Bath | Publication by Local/ National Government |
| Bath Clean Air Zone AQ3 Air Quality Modelling report[26] | UK | Bath | Publication by Local/ National Government |
| Luchtkwaliteitseffecten van mogelijke milieuzones voor vrachtwagens en autobussen in het jaar 2022 (Air quality effects of possible environmental zones for trucks and buses in the year 2022)[27] | Netherlands | Amsterdam | Publication by Local/ National Government |
| Evaluation of emissions in traffic reduction and pedestrianization scenarios in Madrid[28] | Spain | Madrid | Peer Reviewed Literature |
| Evaluation of the Impact of Low-Emission Zone: Madrid Central as a Case Study[29] | Spain | Madrid | Peer Reviewed Literature |
| Evaluation de la Zone de Basses Emissions Rapport 2019[30] | Belgium | Brussels | Publication by Local/ National Government |
| Estimated public health benefits of a low-emission zone in Malmo, Sweden[31] | Sweden | Malmo | Peer Reviewed Literature |
| Assessment of the effect of Madrid Central on the air quality in Madrid in 2019 (as reported by T&E, 2019) | Spain | Madrid Central | Peer Reviewed Literature |
| Low emission zones reduced $PM_{10}$ but not $NO_2$ concentrations in Berlin and Munich, Germany[32] | Germany | Berlin | Peer Reviewed Literature |

25 https://www.ipsos.com/en-uk/2021-annual-report-evaluation-local-no2-plans

26 https://www.bathnes.gov.uk/sites/default/files/sitedocuments/Environment/Pollution/Breathe/appendix_dii_674726.br_.042.fbc-11_aq3_modelling_report-compressed.pdf

27 https://repository.tno.nl/islandora/object/uuid%3A8a33a12d-90af-4554-8bfe-169fdc6b5a82

28 https://www.sciencedirect.com/science/article/pii/S1361920921003618

29 https://www.researchgate.net/publication/347965886_Evaluation_of_the_Impact_of_Low-Emission_Zone_Madrid_Central_as_a_Case_Study

30 https://www.lez.brussels/medias/RAPP-2019-LEZ-FR.pdf?context=bWFzdGVyfHJvb3R8MjgyODU3M3xhcHBsaWNhdGlvbi9wZGZ8aDg3L2gwOC84ODE0NDMwNTg0ODYyLnBkZnw3NGJjNjdlZmJhMzkzMTMwODYzYTY0YzgxM2EzYjM4MTQyZWMxNWQwNjJjYTZiZmIyM2U1N2VlMmM0NjIzNDE4

31 https://pubmed.ncbi.nlm.nih.gov/35998694/#:~:text=This%20LEZ%20would%2C%20on%20average,estimated%20to%20be%20avoided%20annually.

32 https://pubmed.ncbi.nlm.nih.gov/34872181/

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|---|---|---|---|
| Central London ULEZ 6 month report[33] | UK | London | Publication by Local/ National Government |
| Central London ULEZ 10 month report[34] | UK | London | Publication by Local/ National Government |
| Expanded Ultra Low Emission Zone 6 month report - including LEZ 1 year on[35] | UK | London | Publication by Local/ National Government |
| Our proposals to help improve air quality, tackle the climate emergency, and reduce congestion by expanding the ULEZ London-wide and other measures[36] | UK | London | Peer Reviewed Literature |
| Impact of the implementation of Lisbon low emission zone on air quality[37] | Portugal | Lisbon | Peer Reviewed Literature |
| Air Quality Improvements Following Implementation of Lisbon's Low Emission Zone[38] | Portugal | Lisbon | Peer Reviewed Literature |
| Review of the efficacy of low emission zones to improve urban air quality in European cities[39] | | | Peer Reviewed Literature |
| Effectiveness of Low Emission Zones: Large Scale Analysis of Changes in Environmental NO2, NO and NOx Concentrations in 17 German Cities[40] | Germany | 17 Cities | Peer Reviewed Literature |
| Oxford Zero Emission Zone Feasibility and Implementation Study[41] | UK | Oxford | Publication by Local/ National Government |

33 Date (london.gov.uk)

34 https://www.london.gov.uk/sites/default/files/ulez_ten_month_evaluation_report_23_april_2020.pdf

35 https://www.london.gov.uk/WHAT-WE-DO/environment/environment-publications/expanded-ultra-low-emission-zone-six-month-report

36 https://ehq-production-europe.s3.eu-west-1.amazonaws.com/39bc28e1df271326c400b28ec7622683a9582672/original/1652957227/eaa52618f8dad9eef453e6e5ea5d3be5_Our_proposals_to_help_improve_air_quality_tackle_the_climate_emergency_and_reduce_congestion_by_expanding_the_ULEZ_London-wide_and_other_measures.pdf?X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Credential=AKIA4KKNQAKICO37GBEP%2F20221006%2Feu-west-1%2Fs3%2Faws4_request&X-Amz-Date=20221006T135325Z&X-Amz-Expires=300&X-Amz-SignedHeaders=host&X-Amz-Signature=bb6b4889cf6be783b1b4081c48f7c6a4e99083e2c66bd14495939f94c31fcc95

37 https://www.researchgate.net/publication/329004554_Impact_of_the_implementation_of_Lisbon_Low_Emission_Zone_on_air_quality

38 https://www.sciencedirect.com/science/article/abs/pii/S1352231015304064?via%3Dihub

39 https://www.sciencedirect.com/science/article/abs/pii/S1352231015300145?via%3Dihub

40 https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0102999

41 https://www.oxford.gov.uk/download/downloads/id/4019/zero_emission_zone_feasibility_study_october_2017.pdf

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|---|---|---|---|
| Low Emission Zones and Population Health[42] | Germany | multiple | Peer Reviewed Literature |
| Using Smart City Tools to Evaluate the Effectiveness of a Low Emissions Zone in Spain: Madrid Central[43] | Spain | Madrid Central | Peer Reviewed Literature |
| The Paris Region low emission zone, a benefit shared with residents[44] | France | Paris | Peer Reviewed Literature |
| Implementation of various hypothetical low emission zone scenarios in Greater Paris: Assessment of fine-scale reduction in exposure and expected health benefits[45] | France | Paris | Peer Reviewed Literature |
| Birmingham Clean Air Zone Feasibility Study[46] | UK | Birmingham | Publication by Local/ National Government |
| NAPCP PaMs database - Establishment of low emission zone in Riga (Pam reference: 75886) | Latvia | Riga | |
| NAPCP PaMs database - Creation of Low Emission Zones in medium and large cities, Portugal (Pam reference: 70567) | Portugal | Not specified | |
| NAPCP PaMs database - Environmental zones up to date, Denmark (Pam reference: 59717) | Denmark | Not specified | |
| NAPCP PaMs database - Low emission zone Brussels (Pam reference: 85371) | Belgium | Brussels | |
| NAPCP PaMs database - Mise en place de zones à Basses Emission (Low Emissions Zones - LEZ) (Pam reference: 85038) | Belgium | Flanders | |
| NAPCP PaMs database - Low emission vehicles in urban areas (T4), Italy (Pam reference: 46871) | Italy | Not specified | |
| NAPCP for Belgium | Belgium | Wallonia | |
| Greater Manchester's Outline Business Case to Tackle Nitrogen Dioxide | UK | Greater Manchester | Publication by Local/ National Government |

42 https://www.sciencedirect.com/science/article/abs/pii/S0167629620310481#:~:text=By%20improving%20the%20air%20quality,decreases%20by%202%E2%80%933%25.

43 https://www.researchgate.net/publication/342057757_Using_Smart_City_Tools_to_Evaluate_the_Effectiveness_of_a_Low_Emissions_Zone_in_Spain_Madrid_Central

44 https://www.sciencedirect.com/science/article/abs/pii/S1361920921002753

45 https://www.sciencedirect.com/science/article/abs/pii/S001393512030298X

46 https://www.birmingham.gov.uk/download/downloads/id/11353/aq3_-_birmingham_caz_fbc_report-_air_quality_v3_4-12-18.pdf

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|---|---|---|---|
| Exceedances at the Roadside Local Plan Air Quality Modelling Report (AQ3)[47] | | (10 Local Authorities) | |
| What are the Impacts on Air Quality of Low Emission Zones in Denmark?[48] | Denmark | Copenhagen, Aarhus, Odense and Aalborg | Peer Reviewed Literature |

47 https://cleanairgm.com/outline-business-case/

48 https://journals.aau.dk/index.php/td/article/view/5578