TØI report 1666/2018

Astrid H Amundsen
Ingrid Sundvor

Institute of Transport Economics
Norwegian Centre for Transport Research

Low Emission Zones in Europe

Requirements, enforcement and air quality

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Sammendrag:

Målet med lavutslippssoner (LEZ) er å redusere utslippet av partikler og NO_2 i sonen, ved å forhindre eller begrense tilgangen til bruk av de mest forurensende kjøretøyene. I utgangspunktet ble tiltaket mest brukt for å redusere utslippet av partikler, hovedsakelig fra tunge kjøretøy. Nå er fokuset vel så mye på å redusere NO_2-utslippet. Kravene er generelt sett strengere for dieselkjøretøy enn for bensinkjøretøy. LEZ ble tidligere hovedsakelig brukt for å redusere bruken av eldre tunge kjøretøy, men flere land har nå også innført krav til andre kjøretøykategorier. En overvekt av landene som har LEZ har innført tiltaket fordi de ikke overholder EUs grenseverdiforskrift for lokal luftkvalitet.

Effekt av lavutslippssoner på luftkvaliteten er vanskelig å vurdere pga. flere metodiske utfordringer. Med bedre kunnskap om reelle utslipp fra biler vil fremtidens lavutslippssoner kunne være bedre tilpasset byenes behov.

Summary:

The objective of low emission zones (LEZs) is to reduce particulate and NO_2 emissions, by preventing or limiting access for the most polluting vehicles. Initially, the measure was implemented to reduce particulate matter, mainly from heavy duty vehicles. Now the focus is also on reducing NO_2 emissions. The requirements are generally more stringent for diesel vehicles than for petrol vehicles. LEZs was previously used primarily to reduce the use of older heavy duty vehicles, but several countries have now also introduced requirements for other categories of vehicles. An overweight of countries that have LEZs, have implemented the measure because they did not comply with the EU Limit Values for local air quality.

Effect of LEZs on air quality is difficult to evaluate because of several methodical challenges. With improved knowledge on real emissions from road traffic the future LEZs can be better adapted to the needs of the cities'.

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Transportøkonomisk Institutt
Gaustadalleen 21, 0349 Oslo
Telefon 22 57 38 00 - www.toi.no

Institute of Transport Economics
Gaustadalleen 21, 0349 Oslo, Norway
Telefon 22 57 38 00 - www.toi.no

Preface

The aim of this report is to investigate regulations for and enforcement of European Low Emission Zones (LEZs), and to evaluate the effect of LEZs on local air quality. In Europe there are now around 260 LEZs in operation in different cities. The LEZs have been implemented to reduce the vehicular emissions of Particles and nitrogen dioxides. Many countries in Europe are struggling to comply with the air quality limits set by EU, and LEZs is one of the measures implemented to reduce the air quality problems. The cities who have implemented LEZs hope that this measure will reduce the number of old (and more polluting) vehicles, and encourage people to use zero (or low) emission vehicles, or find other means of travel. The effect of these measures will depend on several factors, e.g. the severity of the regulations, the number of vehicles affected and the level of enforcement.

The Swedish Transport Agency has given TØI the task to perform this study. Sweden was the first country in Europe to implement a LEZ, and is now considering extending their current LEZ regulations to also include other types of vehicles than Heavy Goods Vehicles.

This report is written by Astrid H. Amundsen and Ingrid Sundvor. Ingrid Sundvor has written the parts about air quality, and the effect of LEZ on air quality. Astrid H. Amundsen has been the project manager and has written the other parts of the report, while Erik Figenbaum has been responsible for quality assurance. Contact person at the Swedish Transport Agency has been Kristofer Elo. TØIs Secretary Trude Rømming has been responsible for the final preparation of the report for publication.

Oslo, October 2018
Institute of Transport Economics

Gunnar Lindberg	*Erik Figenbaum*
Managing Director	*Research Director*

Content

Summary

Low Emission Zones in Europe

Requirement, enforcement and air quality

TØI Report 1666/2018
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Many countries are struggling with high levels of particles (PM_{10} and $PM_{2.5}$) and nitrogen dioxide (NO_2), and road traffic is often an important contributor to excess emissions in city areas. Low Emission Zones (LEZ) is a defined area where access for the most polluting vehicles are regulated, either by forbidding the most polluting vehicles to enter the zone, or by demanding a fee for the polluting vehicles to enter or drive in the zone. It is challenging to evaluate the effects of LEZs on air quality, but the measure is used in many cities in Europe. Initially the focus of the LEZs were to reduce particle pollution, and in particular to reduce the emissions from heavy duty vehicles. Today, local vehicle exhaust has a more limited contribution to PM levels in many European cities, and increased focus is given to NO_2 emissions when defining the criteria for the LEZs. Especially diesel vehicles are now targeted and all vehicle types, both light and heavy, are more often included in the regulations.

Sweden recently extended their current LEZ regulations

A Low Emission Zone (LEZ) is a defined area where access for the most polluting vehicles is regulated, either by a total ban or a fee. There are now more than 260 LEZs in Europe. Most of the cities who have implemented a LEZ were exceeding the EUs limit values for Particle (PM) and/or Nitrogen Oxide (NO_2). The first European LEZs were mainly focused on PM, but as many cities also are struggling to meet the NO_2 requirements, this compound is now also targeted in LEZs. Especially the high "real world" NO_2 emissions from diesel vehicle have been in focus. Many cities in Europe are considering to strengthen their existing regulations, while new cities are considering to implement a LEZ.

Sweden was the first European country to implement LEZs. Stockholm, Gothenburg and Malmö implemented their LEZs in 1996. The LEZ regulations in Sweden limited the access of heavy duty vehicles, but the Swedish government has recently made it possible to also include other vehicles in LEZs.

The purpose of this study is to investigate the LEZ regulations in other European cities, and how these regulations are enforced. In addition we are looking into the air quality in Swedish and other LEZ cities, and examining the possible effect on air quality of the LEZ regulations.

LEZ regulations

If more than one city in a country wants to implement a LEZ, some form of national framework should be in place. This will both ease the implementation process for the city/municipality and make it easier for the vehicle owners to follow the regulations.

Even if there is a national framework for LEZ, it is up to the individual city if they consider LEZ as a good measure to reduce their air pollution problems, and where they want the zone to be.

At the moment not all European countries have a national framework, and the framework which do exist differs from country to country. In a study financed by the European commission (2017), the following recommendations concerning national framework were proposed:

- Developing a system for vehicle requirements. For example developing the sticker-system as used in Germany and France.
- Common list of exemptions, with possibility for some local adaptations.
- Ban versus the possibility for paying a charge.
- If an Automatic Number Plate Recognition (ANPR) will be used, prepare the necessary national databases.
- If retrofitting is allowed, have national standards of how to class different retrofitting technologies.
- National road signs for LEZs.
- Define the day charges to enter the zone and the fines for non-compliance.

Even with a national framework in place some local adaptation, for example concerning possible exemptions should be possible. But it is important that the number of exemptions are held at a minimum, to increase the effectiveness of the regulation.

If possible, increased cooperation between neighbouring countries concerning both information and regulations would be optimal.

Camera versus manual control

The countries studied in this study use either camera surveillance (with ANPR -Automatic Number Plate Recognition) or manual control to enforce the LEZs. Some cities use a combination of the two.

One of the main advantages with camera control, is the possibility to more or less control all vehicles. But, a near 100 per cent detection rate depends on the number of cameras and the positioning of the cameras. London, with a huge LEZ, uses a camera based surveillance system with both fixed and mobile camera units. The fixed cameras are in general situated at the outer border of the LEZ, while the mobile units are used at roads with high traffic volumes within the zone. One disadvantage with the use of camera surveillance with ANPR, is the need to develop several databases and also the different privacy issues.

Manual control will only check a limited sample of the vehicles with access restrictions in the zones. Several cities with manual control of the LEZ regulations had severe problems with both compliance and the amount of (lack of) control activity in the beginning. With increased focus on this, the enforcement has improved. In most cases the police alone will not have the capacity (or will) to prioritize this type of control activity. To improve the compliance, cities with manual control often combine manual control by police with manual control by other regulatory agents. For example, both in Berlin and in Paris the traffic wardens issue a majority of the fines. The police is only responsible for a small percentage of the total amount of fines.

Germany and France both use stickers to make the manual control within the zone easier. This approach is especially advantageous if more than one vehicle type have restrictions.

Table S.1: Some pros and cons with camera versus manual enforcement of LEZ regulations

	Camera surveillance (with ANPR)	Manual control
Pros	• Able to control more or less all the vehicles • Good solution especially when a high percentage of the vehicles are included	• Easier to implement • Less privacy issues • Stickers ease the control
Cons	• Can be more expensive and time-consuming to implement, especially if starting from scratch • Need to build up several databases • Privacy issues • Need cameras around and within the zone for maximum detection rate of the internal traffic • Need more cross-border agreement	• Can be difficult to get the police to prioritize • Just a percentage of the vehicles will be checked • Can have high labour costs

In the LEZs studied in this report, the compliance with regulations is relatively high, and in several cities in the range of 95-98 per cent. The compliance rate will depend on several factors, including: How strict the regulations are, which vehicle types that are included, the number of exemptions, ban versus possibility for period-access, price of period-access passes, the fines, and the perceived and actual risk of detection and the capability to collect fines.

Effect of LEZ regulations on air quality

What impact a LEZ will have on air quality depends directly on the traffic's contribution to the pollution levels and how efficient the LEZ will change the vehicle fleet composition towards cleaner vehicles, and potentially reduce the total traffic volume. This will then further rely on several factors like the size of the zone and how strict the limitations are.

There are several studies, both modelling and measurements with statistical analysis, which have been performed for LEZs, but the conclusions of the effects varies. The challenges in these evaluations are many, and for instance the use of wrong emission factors for diesel vehicles has been one important challenge for the modelling studies. For air quality measurement studies it is difficult to separate the effect of the LEZ from other measures introduced. This, however does not mean the LEZs did not or will not have an effect. Increased diesel shares in the vehicle fleet and a general increase in number of vehicles and traffic volumes have contributed to more emissions, and hence counterbalanced the emission reduction effect of the LEZs.

There are, however data showing that the zones do alter the vehicle fleet and hence reduce emissions from the targeted vehicle groups. For this to have significant effect on air quality the targeted group needs to be a significant source of the pollution. The non-exhaust contributions from traffic to PM_{10} is large, and PM also have several other sources. LEZs is today therefore not expected to have significant effects for this compound except if it so strict that it significantly limits the total traffic volume. LEZs are, however considered to be efficient for NO_2, CO_2 and other exhaust compounds if targeting a large enough part of the fleet and/or are stringent enough. Several measures are needed to reduce air pollution and LEZs is one of the useful tools at hand for municipalities.

1 Introduction

1.1 Background

Many countries are struggling with high concentrations of particles (PM_{10} and $PM_{2.5}$) and nitrogen dioxide (NO_2) in the air, and road traffic is often an important contributor in city areas. The pollution levels in cities reduce people's health, and can lead to premature deaths. According to the European Environmental Agency (2017), about 430 000 people die prematurely in Europe due to exposure to $PM_{2,5}$, and approximately 78 000 died prematurely due to NO_2 exposure. The Air Quality Directive (2008/50/EC, see chapter 1.3) demands that cities that exceed the allowed limits for air pollution, develop *Action Plans* and implement necessary measures to reach the limit values.

A Low Emission Zone (LEZ) is one measure many cities implement to reduce the number of highly polluting vehicles. LEZ is a defined area where access for the most polluting vehicles are regulated, either by forbidding the most polluting vehicles to enter the zone, or by demanding a fee for the polluting vehicles to enter or drive in the zone.

In the early years the regulations in the LEZs were usually only directed at heavy goods vehicles (HGVs). The HGVs contributed to a high proportion of the air pollution compared to their numbers, especially the older vehicles. The regulations were connected to the age of the vehicle, and HGVs older than a certain age were forbidden to enter the zone. The goal was to encourage a faster upgrade of the vehicle fleet to less polluting vehicles. Retrofitting the vehicles to comply with newer emission standards was permitted.

In the beginning LEZs were mainly used as a measure to reduce the level of particles in city air, and the regulations for the zones were adapted accordingly. In Europe LEZs are usually connected to the vehicles Euro standard (exhaust emission regulation level). Since 2010, many cities found themselves struggling to comply with EUs NO_2 regulations. With the implementation of the Euro 5/V vehicle exhaust regulation it became clear that the NO_2 emissions in real traffic did not correspond to the expected emission reductions based on the new Euro standard levels for NO_X emission of the vehicles. Emissions from the vehicles in real traffic were much higher than what was expected from the results in the type-approval test. This situation was especially noticeable for diesel vehicles (see also tables of emission factors in Appendix 2).

The NO_X emissions from petrol cars have decreased with increasing Euro standard levels, but the same is not true for diesel cars. For diesel cars (and heavy duty diesel vehicle) the NO_X emission in real-traffic conditions increased significantly from Euro 4/IV to Euro 5/V. EU is now adjusting their testing regime, so that the test situation is more realistic for the actual use of the vehicles. With the disclosure of also extensive manipulation during type approval testing by the car industry, the development of new improved emission regulations and test procedures have become crucial.

Sweden was the first European country to implement LEZs. Stockholm, Gothenburg and Malmö implemented their LEZs in 1996. The previous LEZ regulations in Sweden regulated the access of heavy duty vehicles, but the Swedish government recently made it possible to also include other vehicle types in the LEZs. With the motivation to be able to comply with EUs current limit values (see chapter 1.3), several cities have also regulated the access of other vehicle types than just the HGVs. According to the EU website Urban Access Regulations, there were more than 260 LEZs in Europe by the end of 2017.

1.2 Purpose and limitations

The purpose of this study is to investigate the LEZ regulations in European cities, and how these regulations are enforced. In addition we are looking into the air quality in Sweden and other LEZ cities, and examining the possible effect of the LEZ regulations.

The Swedish Transport Agency (Transportstyrelsen) wanted to focus on the following countries: Sweden, Germany, France, Belgium, UK, The Netherlands and to some degree Norway. These are all countries who have or plan to extend the regulations in their LEZs to also include other vehicle types.

Some of these countries have several LEZs, we have therefore limited the number of cities included in the analysis somewhat, based on the following criteria:

- Several vehicle types are included in the LEZ, not only HGVs
- Cities which were of special interest for the Swedish Transport Agency
- City size and zone size somewhat similar to Stockholm/Gothenburg.

1.3 EUs air quality regulations

Historically, there have been several European Commission trans-national directives related to air quality, see Table 1.1. These directives set thresholds for the air quality level to protect human health, and the environment, see Table 1.2. They also contain criteria for the assessment of the air quality. There are limit values set for several compounds, which are legally binding, as well as requirements on measurements and reporting. Rules are defined for measurement site location and classification, data validation and instruments, ensuring compatibility across countries. A member state which is not compliant need to adopt an action plan with appropriate measures so that the exceedance period will be as short as possible.

Table 1.1: Some important EU Directive regulating air quality. Source: EC 2018a

EC Directive	Regulated by the Directive
1996/62/EC	Ambient air quality assessment and management
1999/30/EC	Give limit values for NO, NO_2, PM, SO_2 and lead (First daughter directive)
2004/107/EC	Changes related to Cadmium, nickel, arsenic, and PAHs
2008/50/EC	Merges other directives into one. New limit values for $PM_{2.5}$. Possibility of time extension to reach limit values (up to three years for PM_{10}, and up to five years for NO_2). Air Quality Action Plans to describe how the member states will meet the limit values
2015/1480/EC	Location of measurements sites, reference methods and data validation

If a member state fails to adopt measures that are sufficient to reach the limit values in reasonable time, the EU court can start an infringement procedures. In May 2018 (EC

2018b), there were 16 infringement cases pending against Member states (Belgium, Bulgaria, the Czech Republic, Germany, Greece, Spain, France, Hungary, Italy, Latvia, Portugal, Poland, Romania, Sweden, Slovakia, and Slovenia).

There is a limit value for $PM_{2.5}$ to be met at all locations. However, for $PM_{2.5}$ an Exposure Concentration Obligation (ECO) and a National Exposure Reduction Target (NERT) is also established. These targets are set by use of an Average Exposure Indicator. The ECO of 20 µg/m³ is to be met by 2015 and the NERT by 2020. The level of NERT reduction is based on concentration levels over a three year period including 2010, and depending on the initial levels a reduction in percentage for $PM_{2,5}$ is set. These two exposure based regulations are only applied for background stations and considered per nation as a whole.

Table 1.2: EU limit values for particulate matters and nitrogen dioxides. Source: EC 2018c

Pollutant	Concentration (averaging period)	Legal nature*	Permitted exceedances each year
$PM_{2.5}$	25 µg/m³ (1 year)	Target value from 1.1.2010 Limit value from 1.1.2015	-
PM_{10}	50 µg/m³ (24 hours) 40 µg/m³ (1 year)	Limit value from 1.1.2005 Limit value from 1.1.2005	35 -
NO_2	200 µg/m³ (1 hour) 40 µg/m³ (1 year)	Limit value from 1.1.2010 Limit value from 1.1.2010	18 -

*It was possible for member states to apply for extensions for up to five years depending on the pollutant.

1.4 Air quality measures and sources

The air quality is defined according to the concentration level for a component with unit of mass per volume of air. The origin of the pollution is several emission sources both natural and anthropogenic, local sources as well as sources from other regions or even continents. Chemical processes occur in the atmosphere and will change both the pollution levels and chemical composition of the air over time.

The source contribution to the air quality concentration levels in a specific city will therefore set the stage of what effects one can expect from a measure. Contributions varies from city to city and this means that the same measure might have a different effect in two cities which are otherwise similar. Source contributions also varies among the pollutants. A good knowledge of city sources is hence important to find appropriate measures (Thunis et al. 2017). There is also a risk that a measure could move the problem to a different location or component. Such perspectives should therefore also be assessed when evaluating measures.

Another important factor on what effect a measure will have, is the air dispersion conditions. Due to dispersion the effect of the same emission reductions from two different sources might not give the same concentration reductions because location (e.g. at ground level or through a chimney) and time (e.g. rush hour or at night) of the emissions affects the concentration levels. Dispersion is driven by meteorological conditions. The general variation in concentrations due to variation in meteorological conditions might be larger than the change due to a measure. There are also many other variables that one need to account for in the attempt to single out the effect of the measure (see section 4.5 for more on evaluation of LEZs).

The principal source of exceedances of NO_2 annual limit values in Europe is reported to be road traffic (Jimmink et al. 2010). PM has more sources and the contribution of local traffic to the annual mean is in general much lower than for NO_2. In the Nordic countries biomass burning for house heating and dust produced by use of studded tires are considered the main local sources of PM pollution, but the overall yearly mean value has a large contribution from long-range transported air pollution and regional background levels (Arnio et al. 2016, Høiskar et al. 2014, Furusjö et al. 2007, Querol et al. 2004). The situation for $PM_{2.5}$ in urban areas have been studies by Thunis et al. (2017) using the SHERPA tool and indicating the variation of source sector contributions across European cities. They conclude that for this component many cities will have positive effects of local actions at a city scale, even if the targeted sectors vary and the contribution from regional background is relatively large. They also emphasise that cities contribute significantly to country and overall concentrations. Therefore, reducing air pollution needs a multilevel approach.

1.5 Method

1.5.1 Literature review

This study is based on a literature review. Literature has been searched for in databases of peer reviewed articles as well as open web articles which TØI has access to. References in the found literature are further investigated when relevant. Much of the relevant information is however not to be found in research articles. Hence, literature for this review has been taken from a wide range of sources. We have investigated reports, articles in international journals, newspaper articles, and information on different web-pages (EU, national and city level). The documentation used have been written in several languages (French, German, Swedish, Dutch, Norwegian and English). We have also been in direct contact with representatives of LEZs, mainly at the city level.

1.5.2 Air Quality Data Collection

The Air quality data used in the report is mainly collected from official sites either from local authorities in the individual country or from European Environment Agency (EEA). Data sources is in each case referenced. Classifications of measurement sites should follow the guidelines of EU, and also the quality control should be validated accordingly. However, we do not have detailed information about all circumstances around the stations, and the data is taken as is. The statistics are also not calculated by us and we have used the means and percentiles given. We therefore are not responsible for possible errors in the data or classifications of the sites etc. The data downloaded from EEA might not be the full list of existing measurements, but ensure the best use of available data which should follow common quality standards.

The components which are the main motivation for introducing a LEZ are PM and NO_2, and hence also the components we discuss and focus on when looking at air quality data. Priority has been given to traffic measurement stations. When several stations are available for a city, at least the station with the highest yearly mean value in 2016 for NO_2 has been selected. A further criteria has been that the data at this station has a long enough time series. PM_{10} values are, if measured, shown for the same station location. If PM is not measured at the selected NO_2 station, the station with the highest PM_{10} yearly mean is selected. If stations in the city investigated are showing exceedance of the daily mean limit value for PM_{10}, this is mentioned but data is not shown. Time series are tempted to be plotted from years both before and after the LEZ was introduced, if data are available.

1.6 Abbreviations

Table 1.3 shows a list of abbreviations used in the report.

Table 1.3: List of abbreviations used in the report

ANPR	Automatic Number Plate Recognition
CC	Congestion Charging
HDV	Heavy Duty Vehicle
HGV	Heavy Goods Vehicle
LCV	Light Commercial Vehicles
LDV	Light Duty Vehicle
LEZ	Low Emission Zone
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides (NO_2 and/or NO)
PM	Particulate Matter
RDE	Real-life Driving Emissions
T-Charge	Toxicity-Charge
ULEZ	Ultra-Low Emission Zone
ZCR	Zones à Circulation Restrainte (*French LEZ*)

2 LEZ regulations and effects

2.1 Cities in Sweden

2.1.1 Requirements

Sweden was the first country to implement Low Emission Zones (LEZs), as a measure to reduce pollution from vehicles. Swedish cities could from 1992 legally ban heavy duty vehicles from entering "*environmental sensitive areas*". These are areas struggling with pollution and noise, and at the same time areas with a lot of dwellings and pedestrians/cyclists. After this change in the regulations the cities of Stockholm, Gothenburg and Malmö worked together constructing a framework for how to implement a LEZ (Stockholm Stad 2008). The Swedish LEZs are now regulated by Trafikförordning (1998:1276).

The main goals of the LEZs were to:

- Reduce the emission contribution from HDVs in central parts of the cities
- Improve air quality in the areas, and reduce noise
- Speed up the replacement (or retrofitting) of older vehicles
- Stimulate a technological innovation towards less polluting vehicles
- Contribute to air pollution improvement also outside of the LEZ boundaries.

Stockholm, Gothenburg and Malmö implemented their LEZs in 1996. The current LEZs regulate buses and trucks (gross weight >3.5 ton). In *general diesel trucks and buses, older than six years are not allowed to enter the Swedish LEZs*. There is currently no time limits on Euro VI vehicles. Sweden has LEZs in: Stockholm, Gothenburg, Malmö, Lund, Helsingborg, Umeå, Uppsala and Mölndalen. All the Swedish LEZs have to follow the regulations stated in Trafikförordning (1998:1276), but it is up to the municipality to decide if they want to implement a LEZ or not, and the size.

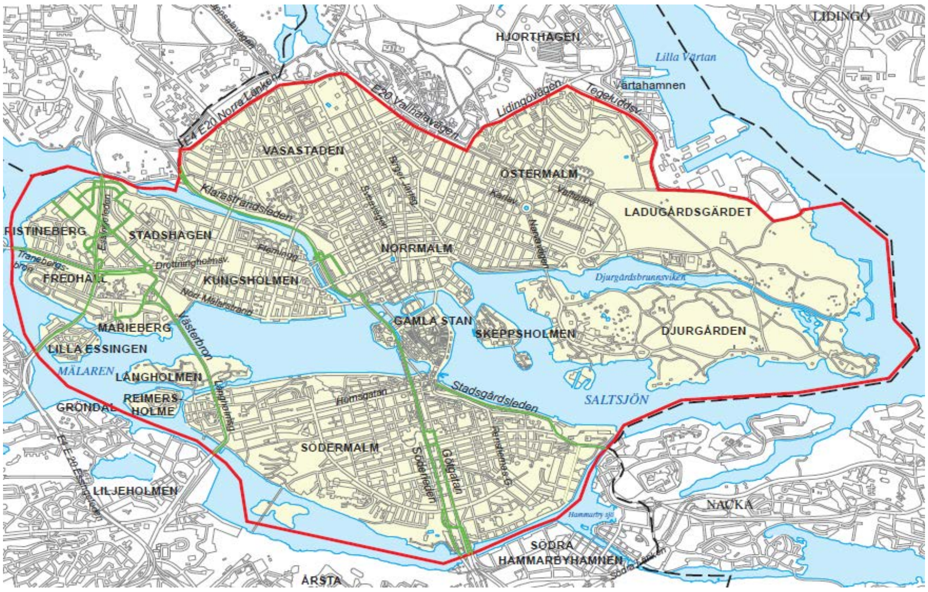

Figure 2.1: The Stockholm LEZ boundaries. Source: Stockholm Stad

Stockholm implemented a congestion charging zone in 2007. This zone has almost the same borders as the LEZ.

The LEZs were implemented to reduce the level of PM and NO_x in the cities, and it was possible to retrofit older vehicles with exhaust gas purification systems (e.g. particle filters), and thereby increase the number of years the vehicles can enter the zone. Other measures to reduce the pollution in Swedish cities at present are for example: A ban on use of studded tires on some streets, dust binding processes using CMA (Calcium Magnesium Acetate), promoting zero- and low-emission vehicles, increased focus on walking/cycling and the use of public transport.

Vehicles exempted from the LEZ regulations are (Stockholm stad 2018):

- Vehicles used for transport of disabled/sick persons
- Emergency vehicles
- Military vehicles
- Veteran vehicles
- Vehicles on gas/ethanol.

The 30th of August 2018, the Swedish regulation, Trafikförordningen (1998:1276), was amended. The regulation now open for the possibility to also include other types of vehicles in a LEZ. The government is allowing the counties that want to have a LEZ to choose between the following three zone regulations from 2020 (Svensk författningssamling 2018):

- LEZ 1: Regulating heavy duty vehicles as today.
- LEZ 2: Also regulations for cars, vans and minibuses. Euro 5 or Euro 6 requirement for petrol/diesel vehicles in these categories.
- LEZ 3: Only allow low emission vehicles to enter the zone (electric/fuel cell, Euro 6/VI gas vehicles and Euro VI plug-in hybrid).

The reasons for the extension of the vehicles included by the LEZ regulations, are that several Swedish cities still struggle with poor air quality, and have together with other countries received warnings from the EU court (see chapter 1.3). In Stockholm 94 per cent of the traffic is performed by light duty vehicles (LDVs- passenger cars and light commercial vehicles). LDVs are responsible for 62 per cent of the traffic related PM emission and 46 per cent of the NO_x emission (Stockholm stad 2017), which is a motivation to also include the LDVs when implementing measures to reduce air pollution.

Table 2.1: Overview of requirements and enforcement of some of the LEZs (Miljözon) in Sweden

Year of installation	Vehicle	Requirement (January 2018)	Enforcement
Stockholm 1996	Trucks, buses	Euro V vehicles can enter the zone until 2020 (or 8 years after first registration). Euro I-IV can no longer enter the zone.	Manual control
Gothenburg 1996	Trucks, buses	Euro V vehicles can enter the zone until 2020 (or 8 years after first registration).	Manual control
Malmö 1996	Trucks, buses	Euro V vehicles can enter the zone until 2020 (or 8 years after first registration).	Manual control
Lund 1999	Trucks, buses	Euro V vehicles can enter the zone until 2020 (or 8 years after first registration).	Manual control

2.1.2 Enforcement

The LEZs in Sweden are enforced by random inspection from the traffic police (checking the registration number of the vehicle). The fine for non-compliance is 1000 SEK (≈ 107 Euro).

The compliance with the regulations in Stockholm was approximately 95 per cent in 1997, while this had decreased to 90 per cent in 2007 (Stockholm stad 2008), see Figure 2.2. In Malmö the compliance was about 89 per cent in 2009 (Trafikverket 2010), and 94 per cent in 2012 (see Figure 2.3). Göteborg last checked the compliance in 2011, and a compliance rate of 96 per cent were observed (Nilsson 2018). According to Trafikverket (2010) the compliance with the Swedish LEZ regulations have generally been between 90 and 95 per cent.

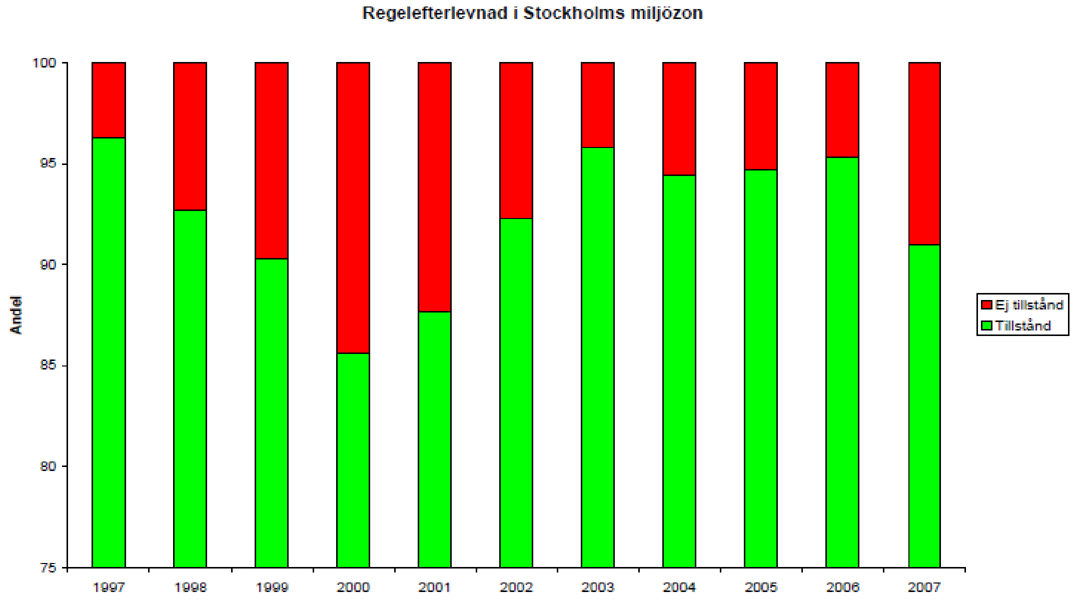

Figure 2.2: Compliance with LEZ regulations in Stockholm, 1997-2007 (red- non-compliance). Source: Stockholm Stad 2008

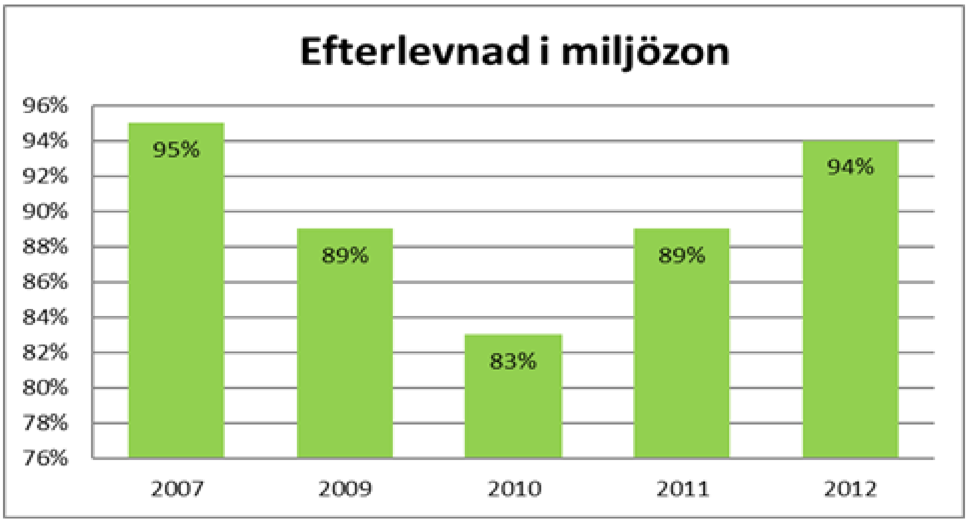

Figure 2.3: Compliance with LEZ regulations in Malmö, 2007-2012. Source: C. Gyarmati, Malmö stad

The compliance with the existing regulations varies somewhat from year to year. The level of control is one factor influencing the compliance. In Stockholm the police has reduced their control activity in the LEZ, which may have influenced the level of compliance (Stockholm stad 2017).

2.1.3 Air Quality

The EU Directive limit values are implemented in the Swedish regulation called the environmental quality norm (Miljökvalitetsnormer). The Swedish regulation also includes a daily limit value and an extra hourly limit value for NO_2. Beside the limit values in the norm there are national environmental quality objectives and local targets ("Frisk Luft"). These objectives are set to no more than 15 $\mu g/m^3$ for the annual mean and 30 $\mu g/m^3$ for the daily mean, which is much lower than the EU directive limits. The NO_2 limit in the environmental quality objective is also lower, with an annual mean of 20 $\mu g/m^3$ and an hourly limit of 60 $\mu g/m^3$. Gothenburg has for instance defined local intermediate targets for air quality to be reached by 2020. For NO_2 the target is 20 $\mu g/m^3$ for the annual mean in a large part of residential areas and at most schools (at 95 per cent of schools and at the residence of 95 per cent of the population). For PM the daily average should not be over 30 $\mu g/m^3$ for more than 37 days per year (Göteborg stad 2017).

For the last years in Stockholm and Gothenburg the PM_{10} levels have decreased, but NO_2 levels have been close to, and also over, the annual limit value at some locations (see Figure 2.4 and Figure 2.5). A NO_2 concentration map for the emission year 2015 is shown for Stockholm in Figure 2.6. One can see that high values are mainly found in street canyons and along larger access roads. In 2017 it was observed lower levels of NO_2 than previous years, but the reduction varies among the stations. Local conditions like increase in traffic volume and the HDV share can explain part of this variation (SLB 2018). The limit values were not met at two stations, which means that further emission reductions are needed.

Stockholm is in compliance with the limit values for PM_{10}. The decreasing levels, especially in the city centre, are explained by the reduction in the use of studded tires and intensive dust binding activities. If the limits are to be complied without dust binding, the studded tyre share in the fleet needs to be further reduced (SLB 2018). For both PM_{10} and NO_2 the objective values are not met. For $PM_{2.5}$ both the limit values and the objectives were met in 2017.

In Gothenburg, NO_2 levels have been decreasing compared to the 1970s. Concentrations have also been reduced in the urban background over the latest years, but throughout the 2000s the levels at traffic stations have been more stable (Västsvenska paketet 2014). In 2016 the limit values were exceeded for NO_2. At the station Haga the observed NO_2 annual mean in 2016 was higher than the observed value in 2007 (see Figure 2.4). The Swedish hourly and daily limit values were not met neither at Haga nor Gårda. As the limit values were not kept the objectives were also not met for this component. The relatively high values in 2016 can be explained by somewhat unfavourable weather conditions this year for NO_2 (Göteborg stad 2017), but limit values are of course to be met independent of weather.

For PM the levels have been steadily decreasing and the limit values were kept at all stations (see Figure 2.5), but the objectives and targets for PM_{10} were not reached. At Gårda both the annual mean and the daily means were too high (Göteborg stad 2017).

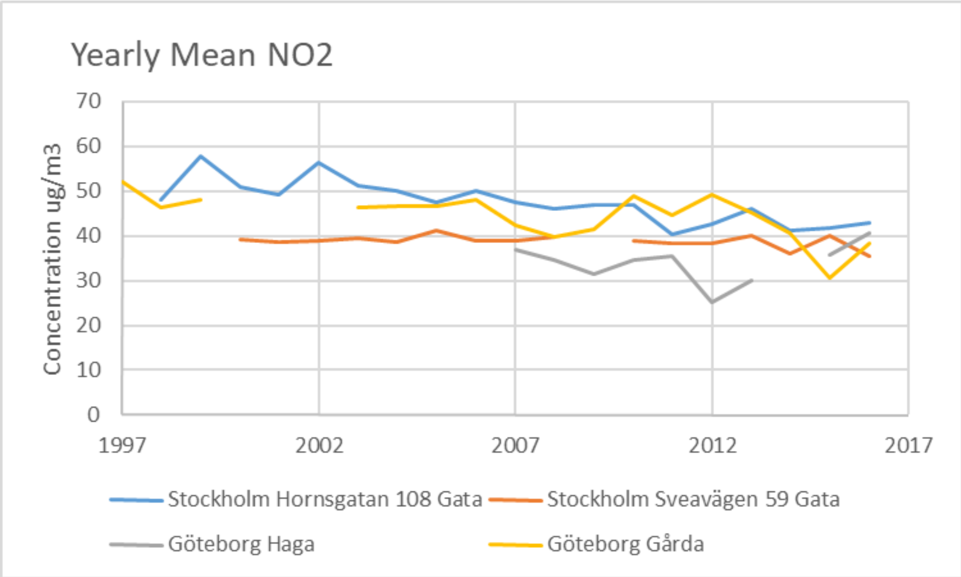

Figure 2.4: NO_2 concentrations at selected traffic locations in Stockholm and Gothenburg. Source: EEA

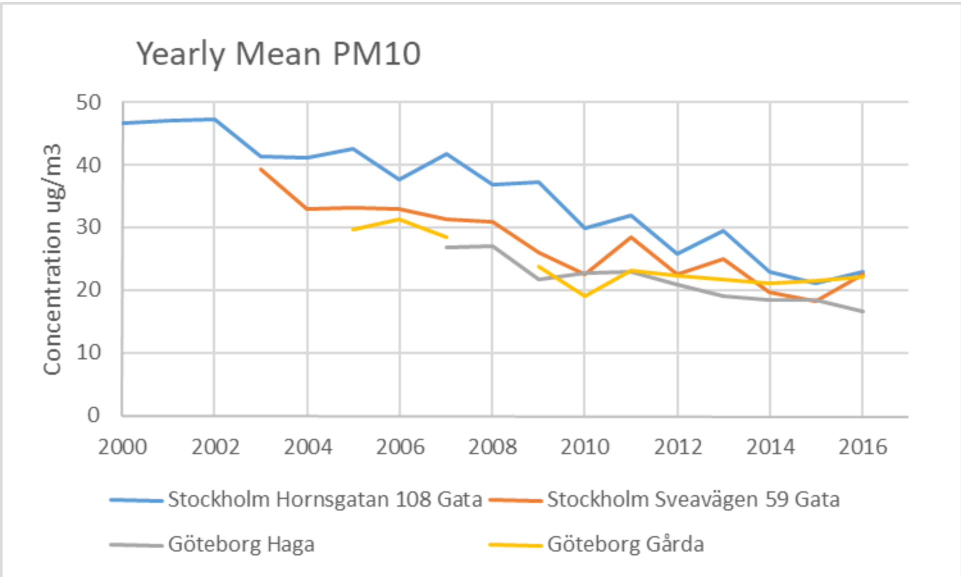

Figure 2.5: PM_{10} concentrations at selected traffic locations in Stockholm and Gothenburg. Source: EEA

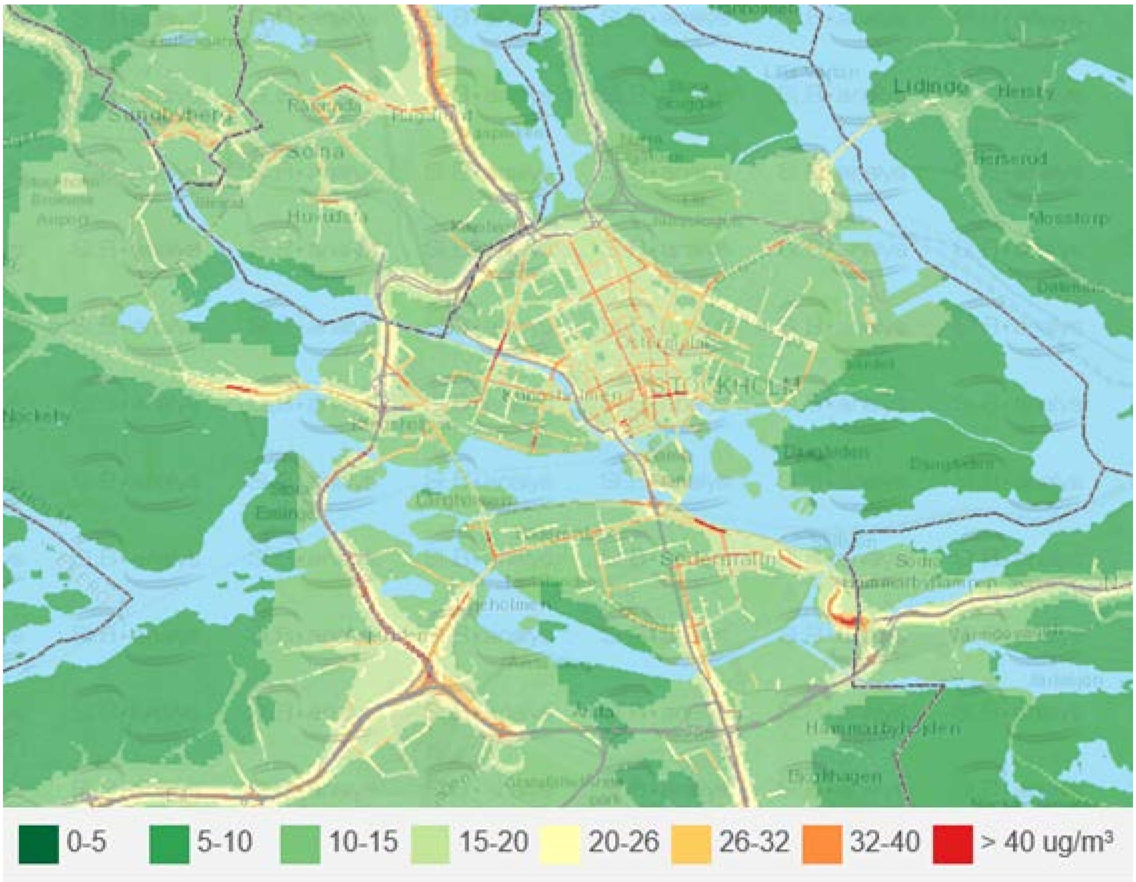

Figure 2.6: Concentration map for NO_2 of Stockholm. Source: SLB-analys on assignement for Östra Sveriges Luftvårdsförbund

2.1.4 Effect studies of LEZs

The Stockholm LEZ has been evaluated for the year 2000 (Johansson and Burman 2001). The average age of both busses and trucks have been reduced as a consequence of the LEZ. Emission modelling give an emission reduction for the heavy duty fleet of 40 per cent of the PM emissions and 10 per cent reduction of the NO_X emission. The lower reductions for NO_X is partly explained by the possibility to retrofit the vehicle with particle filters which would not reduce NO_X emissions. The effect on concentrations are much lower than the emission reduction as HDVs are only one of many sources. Dispersion modelling gave a NO_X reduction of 1.5 per cent at street level at Hornsgatan. In comparison the evaluation of the congestion charging (Johansson et al. 2014) gave a NO_X reduction of 8 per cent at the same location.

The LEZ in Umeå was evaluated in 2012 by modelling concentrations of NO_2 at some streets for two future scenarios (2014 and 2020) with and without the LEZ. The study gave largest effects in 2020 with up to 18 per cent expected reduction for the annual mean at Västra Esplanaden.

2.2 London, UK

2.2.1 Requirements

In the early 2000s, the air quality in London was among the worst in Europe, and failing both EUs and national requirements for PM and NO_x (Transport for London 2008, Ellison et al. 2013). In 2008, about 4 300 deaths in London was attributed to long-term exposure to $PM_{2.5}$ (Miller 2010). In 2005, about 47 per cent of PM_{10} and NO_x emissions in London were attributed to road traffic (Transport for London 2006). The LEZ in London was implemented to help the city work towards achieving the European limit values for air quality and the UKs national air quality objectives (Transport for London 2008). Other measures was also implemented, for example pilot projects testing out zero emission busses.

The LEZ in London was implemented in January 2008, and covers 1 580 km^2. The requirements within the zone have been altered several times since then. London also has congestion charging (CC) which was implemented in 2003. The LEZ and the CC-zone do not have the same boundaries (see Figure 2.7 for boundaries).

Development of LEZ requirements (Ellison et al. 2013, Wang et al. 2017):

- February 2008: Minimum of Euro III for trucks over 12 tons.
- July 2008: Minimum of Euro III/3 also for freight vehicles of more than 3.5 tons and buses/coaches over 5 tons.
- January 2012: Minimum of Euro IV for HDV (trucks over 12 tons, lorries 3.5-12 tons and bus/coaches over 5 tons), and minimum of Euro III/3 for vans (1.2-3.5 tons), minibuses (below 5 tons) and caravans/ambulances (between 2.3-3.5 tons).

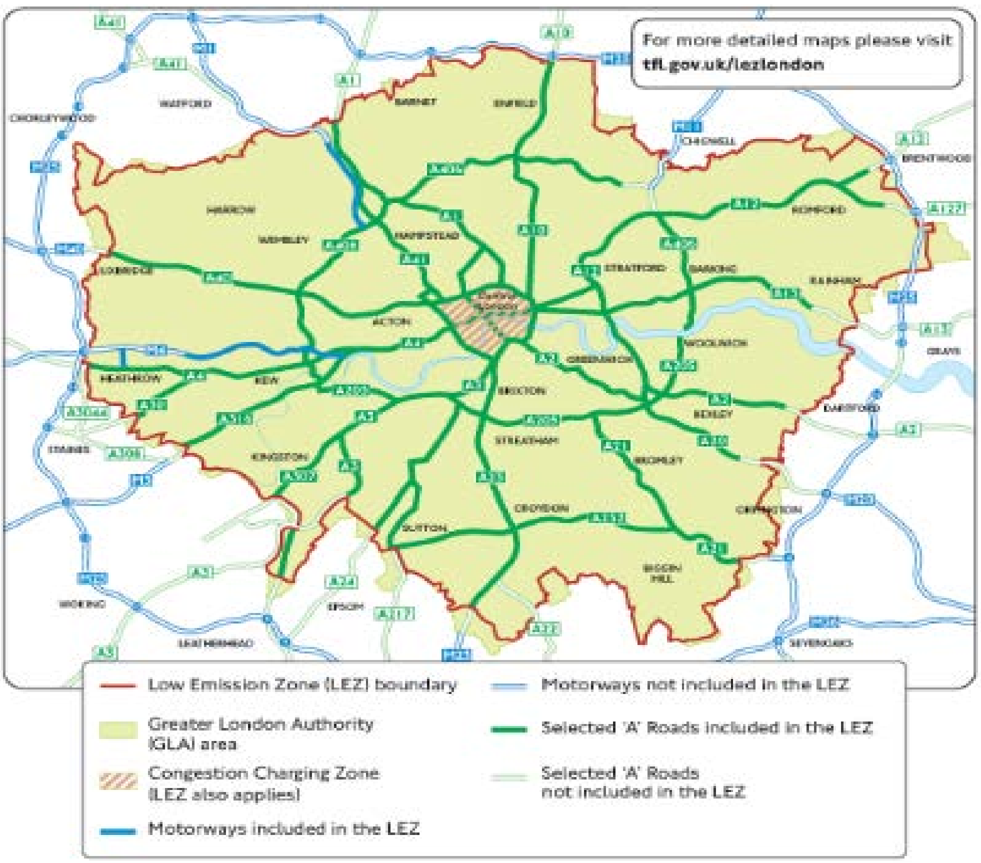

Figure 2.7: Boundaries for London's LEZ and CC-zone. Source: Transport for London

London plan to implement an Ultra-Low Emission Zone (ULEZ) in the central part of the city in April 2019 (Government of London 2017). This zone will cover the same area as the CC zone (see Figure 2.7). The ULEZ will replace the current T-Charge (Toxicity-Charge/emission surcharge) zone. The T-Charge was implemented in 2017 (October) as a first step to implement the ULEZ. There is a plan to expand the area of the ULEZ in 2021.

The T-Charge zone *includes private cars*, but not motorcycles and mopeds (see Table 2.2 for more information). The ULEZ will include motorbikes. The revenue will be used by Transport for London to maintain a greener transport fleet and reduce pollution (Government of London 2018).

Both the T-Charge and the ULEZ was/is implemented to deal with the air pollution level in the inner city, and especially NO_x and PM. Due to the implementation of ULEZ, the following emission reductions are expected (Government of London 2017):

- 50 per cent reduction of NO_X from HGV
- 30 per cent emission reduction from busses and coaches
- 8-12 per cent emission reduction from cars and vans
- 100 000 people in London will no longer live in areas exceeding the NO_2 limits.

Table 2.2: Overview of requirements and enforcement method of the LEZ in London. Source: urbanaccessregulations.eu and local LEZ homepages

Year of installation	Vehicle	Requirements (January 2018)*	Enforcement
2008	HDV	**LEZ**. Meet Euro IV standards for PM, or pay daily charge of £200.	ANPR
	Van, minibus	**LEZ**. Meet Euro 3 standards for PM, or pay daily charge of £100.	ANPR
2017	HDV	**T-Charge**. Meet Euro IV requirements, or pay.	ANPR
	LDV	**T-Charge.** Meet Euro 4 requirements, or pay. MC/Moped not included.	ANPR
2019	HDV	**ULEZ**. Meet Euro VI standards for PM and NO_x or pay daily charge.	ANPR
	LDV	**ULEZ**. *Diesel*: Meet Euro 6 standards for PM and NO_x. *Petrol*: Meet Euro 4 standards for NO_x. *MC/Mopeds ec.*: Euro 3 standards for NO_x. Meet standards or pay daily charge.	ANPR

*Proposed requirement for ULEZ in 2019.

UK also has LEZs in four other cities. But these cities only have regulations for local busses (under local agreement):

- Norwich, Euro III for NO_x
- Nottingham (2010), Euro III
- Oxford (2014), Euro V
- Brighton (2015), Euro V. LEZ consists of only one road.

Scotland is planning to implement LEZs in four of their biggest cities before 2020 (Transport Scotland 2017). Glasgow will be the first city, and will in 2019 have a city centre zone with restriction for buses, in 2022/23 the restrictions will include all vehicles entering the zone (The National 2018).

2.2.2 Enforcement

London use a system with cameras and Automatic Number Plate Recognition (ANPR) to monitor the LEZ. The picture and vehicles registration numbers are anonymized immediately for data protection purposes. Data from the individual cameras are sent to a central hub, using mobile phone technology (Transport for London 2008). The encrypted registration details received from the cameras are matched with encrypted versions of other databases. The database contains a set of "business rules", which establishes the Euro standards and the compliance status of each vehicle observed (Transport for London 2008). The system will check the vehicles against vehicles registered in the national vehicle database and additional databases (Transport for London 2018a). The system automatically tell if the vehicle meet the LEZ requirement, if the vehicle is retrofitted to meet the standard, if the vehicle is exempted, if you are registered for discounts and if you already has paid the daily charge. Foreign vehicles will have to register before entering the zone.

According to Wang et al. (2017) there is about 350 cameras installed in the LEZ. Due to the vast area of the LEZ, every access road into the zone is not covered by cameras. The cameras are located mainly in areas with high traffic volumes. These cameras are supplemented by a number of mobile camera units to randomly sample other routes (Siemens 2016). In addition, there are about 650 cameras covering the congesting charging zone (which share borders with the T-Charge zone and the upcoming ULEZ).

In London the system is based on either pre-pay or payment by midnight the following day. If the payment is delayed, the amount owed will increase (Wang et al. 2017). The payment for entering the LEZ with vehicles not meeting the requirement is £100 for vans, minibuses and other specialist vehicles. For HDVs (lorries, busses, specialist HDVs) not in compliance with the requirements the daily charge for entering is £200 (Transport for London 2018b). Registering your vehicle and paying the charge is managed via Transport for London's home page for LEZ.

If the required LEZ charges are not paid by midnight the following day, the penalty charges is (Transport for London 2018c):

- Vans and minibuses: £250 if payed within 14 days, 15-28 days £500, if not £750.
- HDVs: £500 if payed within 14 days, 15-28 days £1000, if not £1500.

The cost for entering the T-Charge zone if your vehicle do not comply with the requirements is £10 (residents get a 90 per cent reduction). An automatic payment system is available in the CC and T-Charging zone. If the daily charge is not payed, the penalty is £80 (if payed within 14 days) or £160 (Transport for London 2018d). If not payed within 28 days, the charge will increase to £240. If the penalty charge is still not payed, an enforcement agent will be employed to recover the outstanding dept (e.g. come to your home and collect outstanding debt), the same process is also used when enforcing the LEZ and the CC-zone.

The ULEZ charge level will be £12.50 for cars, vans and motorbikes, and £100 for lorries, busses and coaches (Government of London 2018).

In a feasibility study performed before the implementation of the London LEZ, a manual control scheme using 20 units (police and or traffic wardens) were expected to have an detection rate of about 5-6 per cent, while a camera based scheme (with 125 fixed and 10 mobile units) was expected to have a detection rate of about 70 per cent (Deloitte 2005).

After the first week of the LEZ operation in 2008, 50 000 HGVs had entered the zone, of which 91.5 per cent were in compliance with the regulations (Transport for London 2008). By the end of April 2008, the compliance-rate had reached 95 per cent. This was considered a great result, considering a compliance of 75 per cent January 2007, one year prior to the implementation of the LEZ (Transport for London 2008).

According to Transport for London (2017) more than 98 per cent of the vehicles, which entered the LEZ in 2017, met the specified environmental requirements. In 2017, 35 500[1] penalty charging notices were issued for entering the LEZ without complying with the regulations. The compliance rate for the T-Charge Zone was about 95 per cent, and about 278 penalty charges was issued in a three month period (Oct-Dec 2017).

2.2.3 Air Quality – regulations and levels

The UK is required to meet the requirements of the EU Directive on local air quality, but by 2018 they are still not in compliance. Air quality observations at selected stations are shown in Figure 2.8 and Figure 2.9. The trend of NO_2 at Marylebone road in London for the almost 20 year period indicates an increase before a decrease back to the year 2000 level. The average for all sites are naturally lower, but they are also showing a clearer decreasing trend over the period. Most stations in the UK had from 2005 to 2016 a significant decreasing trend or no significant trend while only a few stations had a significant increasing trend for NO_2 and NO_x (Laxen et al. 2018). Even with decreasing trends, there are several measurement sites with NO_2 levels above the limit value. Marylebone road in London has NO_2 levels well above 80 μg/m^3 which is more than twice the limit of 40 μg/m^3.

Also other cities in UK have too high concentration levels. In Oxford the road site measurement station has shown decreasing levels, and the measurements were in 2017 for the first time below the limit value for NO_2. In the city of Nottingham there is only reported data for one urban background site and no traffic station (EEA statistics 2018). However, measurements with diffusion tubes and model calculations show that several streets are exceeding or are likely exceeding the limit value. Projections indicate that this will also be the case in 2020 if no further measure towards NO_2 is implemented (Nottingham City Council 2018).

For PM the levels have been decreasing and have been below the limit value the last years, see Figure 2.9. (DEFRA 2018). In May 2018 the UK launched a new Clean Air Strategy (UK Gov 2018) which defines a goal for annual $PM_{2.5}$ to reach the WHO guideline value of 10 μg/m^3 by 2025. This would mean that further PM reductions and measures targeting particles will be required.

[1] Information from Transport for London (e-mail correspondence).

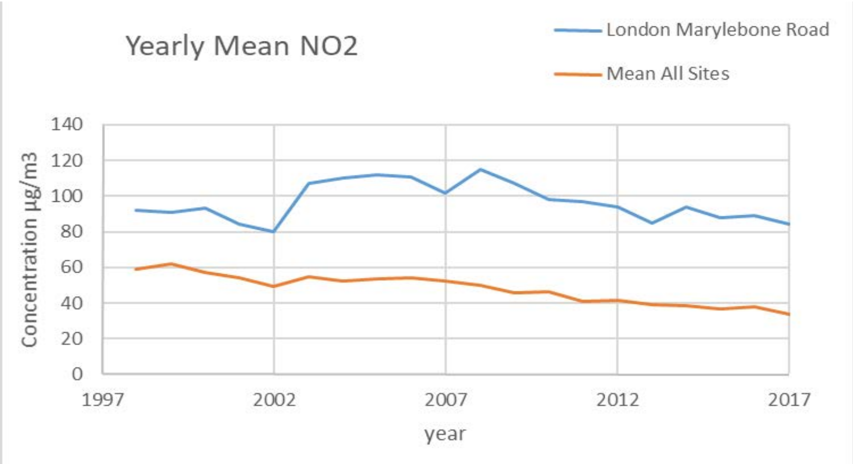

Figure 2.8: Annual mean concentration of NO_2 at road site measurement stations in the UK. Source: DEFRA

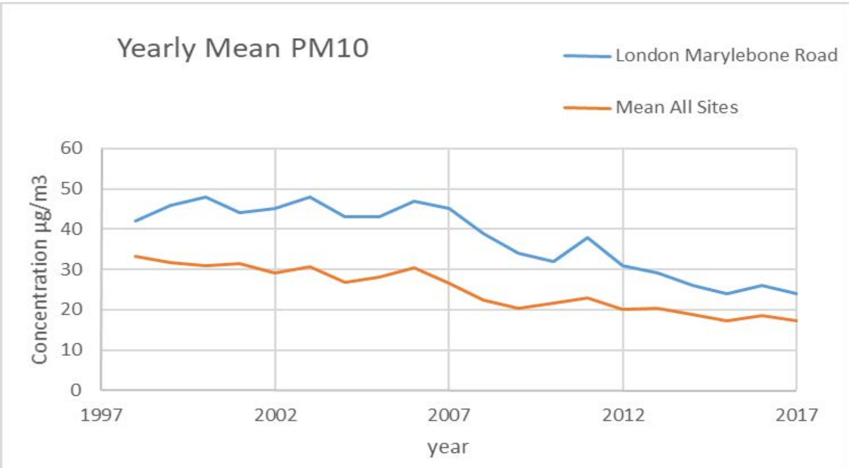

Figure 2.9: Trend of annual mean concentration for PM_{10} at road side measurement stations in the UK. Source: DEFRA

2.2.4 Effect studies of the LEZs

Ellison et al. (2013) studied the effect of the London LEZ in the period 2001 to 2011 and found that the zone increased the rate of fleet turnover in the first years after the introduction. They also report on an overall increase in freight vehicles in London and more HDVs inside the zone. At the same time some of the freight increase resulted in change of vehicle types with more use of LCVs. Their analysis of the effect on air quality gave a 2.46 – 3.07 per cent reduction for PM compared to 1 per cent just outside the zone. However, no such difference was observed for NO_x. They also found indications of larger improvement of the air quality in streets with a larger fraction of HDVs.

Jones et al. (2012) studied in detail the particle number concentration compared to the NO_x concentrations. They found that a sharp decrease observed around 2008 mainly was due to the introduction of "Sulphur free" fuel in 2007. The LEZ might have also contributed to some reduction as there were observed differences between measurements inside the zone in London and Birmingham without a LEZ.

2.3 Cities in Germany

2.3.1 Requirements

Germany has almost 60 LEZs (Umweltzone) in operation (Umwelt Bundesamt 2018), and other cities are considering implementing a LEZ.

In 2005, 81 German cities violated the regulation of maximum number of days in exceedance of the PM_{10} daily limit (Wolff 2014). In 2014 approximately 66 000 Germans died prematurely due to exposure to $PM_{2.5}$ and approximately 13 000 died prematurely due to NO_2 (European Environmental Agency 2017). Germany is one of many European countries with a pending case in the EU court (see chapter 1.3).

The introduction of LEZs in Germany is based on the two EU directives (Umwelt-Plakette 2018a):

- Directive 1996/62/EC
- Directive 1999/30/EC (set legal limit values for NO_2, NO, SO_2, PM)

These two directive were the basis for the national law about LEZs (35. BImSchV), and later on Directive 2008/50/EC was implemented (39. BImSchV). These laws regulate the national framework for the German LEZs.

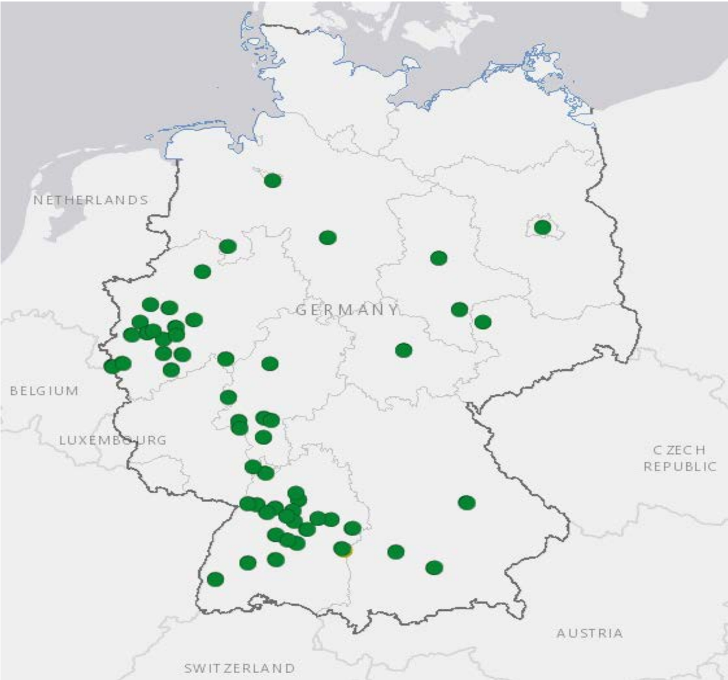

Figure 2.10: Overview of the different LEZs in Germany. Source: Open Street Map, Garmin and Umwelt Bundesamt

The German government has a common framework for LEZs. Vehicles are categorised into four emission classes, see Table 2.3. All cars, buses and trucks in Germany are required to have a windshield sticker indicating their vehicles emission level (Wolff 2014). The same stickers are used in all German LEZs. The requirements can vary between the cities, and they have become stricter since the first implementation of LEZs. In the beginning, only vehicles without stickers were banned from entering the zone. Now most LEZ cities in Germany only allow vehicles with the green stickers (Table 2.3) to enter the zone. All vehicles (including electric, gas and foreign) entering the LEZ need to have a visible sticker.

Table 2.3: Requirements behind the different LEZ "stickers" in Germany. Source: Green-Zones GmbH (©)

Eco badge Class	First registration date or Euro standard						
	Two-, three- and light motorized four-wheelers	Cars, Campers < 2,8 t		Light Utility Vehicles < 3,5 t		Trucks, Busses Campers > 2,8 t	
		Diesel	Petrol	Diesel	Petrol	Diesel	Petrol
4 GR UN 2004	no badge necessary and possible	Euro 6 starting 01.09.2015	Euro 6 starting 01.09.2015	Euro 6 starting 01.09.2015	Euro 6 starting 01.09.2015	EURO 6 starting 01.01.2014	EURO 6 starting 01.01.2014
4 GR UN 2004	no badge necessary and possible	EURO 5 from 01.01.2011 until 31.08.2015	EURO 5 from 01.01.2011 until 31.08.2015	EURO 5 from 01.09.2010 until 31.08.2015	EURO 5 from 01.09.2010 until 31.08.2015	EURO 5 from 01.10.2009 until 31.12.2013	EURO 5 from 01.10.2009 until 31.12.2013
4 GR UN 2004	no badge necessary and possible	EURO 4 from 01.01.2006 until 31.12.2010	EURO 1-4 from 01.01.1993 until 31.12.2010	EURO 4 from 01.01.2006 until 31.08.2010	EURO 1-4 from 01.10.1993 until 31.08.2010	EURO 4 from 01.10.2006 until 30.09.2009	EURO 1-4 from 01.10.1993 until 30.09.2009
3 GE LB 2003	no badge necessary and possible	EURO 3 from 01.01.2001 until 31.12.2005	-	EURO 3 from 01.01.2001 until 31.12.2005	-	EURO 3 from 01.10.2001 until 30.09.2006	-
2 RO T 2002	no badge necessary and possible	EURO 2 from 01.01.1997 until 31.12.2000	-	EURO 2 from 01.10.1997 until 31.12.2000	-	EURO 2 from 01.10.1997 until 30.09.2001	-
No Eco badge	no badge necessary and possible	EURO 0-1 until 31.12.1996	without catalyst	EURO 0-1 until 30.09.1996	without catalyst	EURO 0-1 until 30.09.1996	without catalyst

The following types of vehicles are in general exempted from the German LEZ regulations (urbanaccessregulations.eu):

- Veteran cars older than 30 years
- Military and NATO vehicles
- 2 and 3-wheel motorcycles
- Vehicles driven by/or carrying disabled persons
- Ambulances and other emergency response vehicles
- Work machines/tractors e.g.

All vehicles in the major cities with LEZs in Germany, are required to meet the requirement of a green sticker. In Berlin more than 90 per cent of the vehicle fleet already have a green sticker (Umwelt Bundesamt 2018). When the LEZs first were implemented in Germany the focus was on the PM level. The level of PM is still a problem in many cities, but recently the main focus is on the high NO_2 levels. According to Umwelt Bundesamt (2018) the existing regulations in the LEZs is not enough to comply with the EU NO_2 regulations. Therefor is it necessary to consider implementing other measures to comply with the regulations. Examples of possible measures can be (Umwelt Bundesamt 2018):

- Strengthening of the LEZ regulations, with a possible implementation of a blue sticker (taking into account NO_x emission, and real driving emissions (RDE)).

- Considering implementing stricter emission standards for professional use vehicles (e.g garbage trucks, construction vehicles, snow plough e.g).
- Reducing the number of vehicles entering the zone. Focusing on facilitating public transport, walking and cycling. New Park and Ride facilities outside the cities.
- Implementing specific measures directed at reducing diesel vehicles in the cities.

Figure 2.11 show estimated NO_2 reduction for different measures that can be implemented in German cities. Bans or further restrictions on diesel vehicles are the measures with the most promising effects.

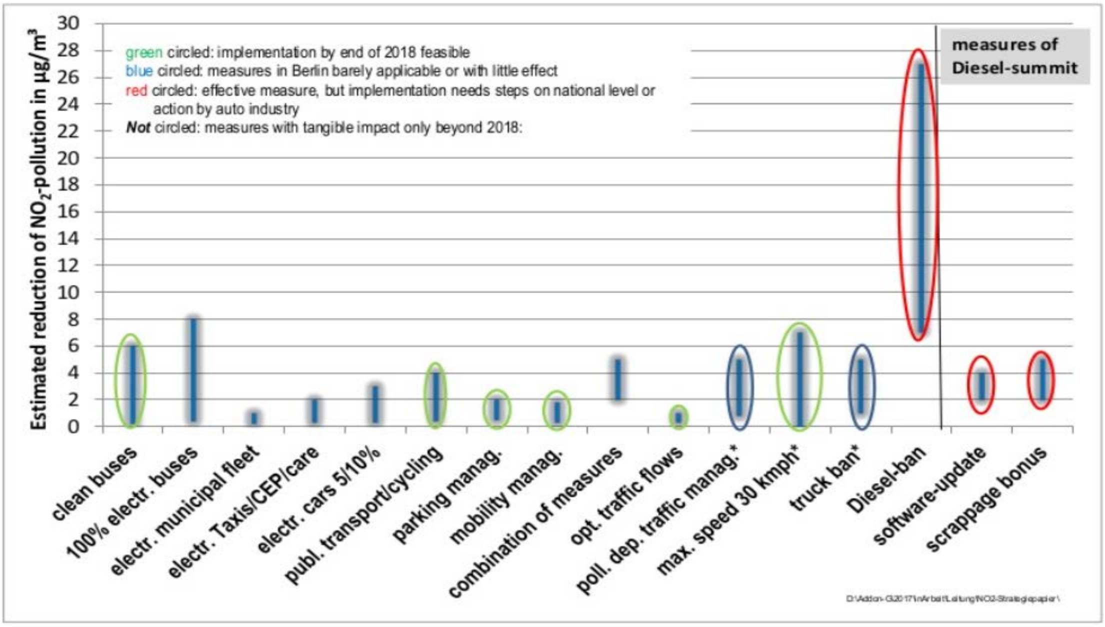

Figure 2.11: Estimated reduction of NO_2 for different measures mentioned in action plans for Hamburg, Stuttgart and Berlin. Source: Lutz 2017

A Federal court decision of 27.02.2018, allows cities and municipalities in Germany to implement driving bans for diesel vehicles. This is a measure the cities can use if struggling to meet the EUs limit values for NO_2. The city of Hamburg banned diesel vehicle not complying with Euro 6/VI standard from entering two streets sections (Max-Brauer-Allee (50 m) and Stresemannstraβe (1600 m) in June 2018 (Hamburg Blaue-Plakette 2018). One of the streets will ban HGVs complying with Euro V standard or older, while the other street will have a ban on diesel passenger vehicles and HGV complying with Euro 5/V standards or older (Reuters 2018, Wahler 2018). Some exemptions are available: e.g. residents of the two streets, trash collectors and taxis.

The Federal Environmental Agency are considering introducing a "blue" badge, in addition to the existing three colours already in use (green, yellow, red). See Table 2.4 for the vehicles proposed to receive the light and dark blue badges. This is a proposal, and not jet legally binding.

Table 2.4: Proposed vehicle classes covered by the blue badges. Source: Blaue-Plakette 2018a

Badge	Vehicles
Light blue	• Petrol vehicles with Euro 3-6 standards (with direct injection, but without particulate filters) • Diesel vehicles with Euro 5 standards (and SCR retrofitting) • Diesel vehicles with Euro 6b and 6c standards
Dark blue	• Petrol vehicles with Euro 3-6 standards (without direct injection) • Petrol vehicles with Euro 6c and 6d standards (and direct injection) • Petrol vehicles with Euro 3-6 standards (direct injection and particulate filters) • Diesel vehicles with Euro 6d standards • Electric vehicles without combustion engines • CNG/LPG vehicles with Euro 3-6 standards

The blue badges are planned to be used in cities with diesel vehicle restrictions or "the blue zones". The city of Stuttgart has approved a traffic ban for diesel vehicles. From January 2019, diesel vehicles not complying with the Euro 5 standard will be banned from the city (Stuttgart Blaue-Plakette 2018). Other cities in Germany are also considering to implement Blue-zones.

Figure 2.12: Proposed blue badges for Germany

Table 2.5: Overview of requirements and enforcement method for some of the German LEZs (Umweltzone). Source: urbanaccessregulations.eu and local LEZ homepages

Year of installation	Vehicle	Requirement (January 2018)	Enforcement
Berlin 2008	Trucks, buses, vans and cars	*Diesel vehicles* -Euro 4/IV, *Petrol*- Euro I/1 Green stickers.	Stickers/ Manual control by police
Munich 2008 (Oct.)	Trucks, buses, vans and cars	*Diesel vehicles* -Euro 4/IV, *Petrol*- Euro I/1 Green stickers.	Stickers/ Manual control by police
Cologne 2008	Trucks, buses, vans and cars	*Diesel vehicles* -Euro 4/IV, *Petrol*- Euro I/1 Green stickers.	Stickers/ Manual control by police
Frankfurt 2008 (Oct.)	Trucks, buses, vans and cars	*Diesel vehicles* -Euro 4/IV, *Petrol*- Euro I/1 Green stickers.	Stickers/ Manual control by police
Stuttgart 2008 (Mar.)	Trucks, buses, vans and cars	*Diesel vehicles* -Euro 4/IV, *Petrol*- Euro I/1, Green stickers. **2018 (Jan.)**: *Diesel vehicles* -Euro 5/IV **2022**: *Diesel vehicles* -Euro 6/VI	Stickers/ Manual control by police

2.3.2 Enforcement

In Germany the compliance of the LEZ regulations is controlled manually, by the police and traffic wardens.

All vehicles entering the LEZs are required to have a sticker. Even if the vehicle meet the emission requirement, it will be regarded as non-compliant if it do not carry the sticker, and the fines will have to be paid. The penalty for entering a LEZ without a sticker, or with the wrong sticker is €80. An administrative fee of at least €25 will be added to the fine (Umwelt-Plakette 2018).

In general the police is responsible for controlling moving vehicles, while the regulatory agency (traffic wardens) is responsible for controlling parked cars. In a LEZ a combination of both is therefore not unusual.

In 2012 the level of control activity was investigated in 47 LEZs. Only four of the 47 LEZs had an effective control scheme in place, more than half had practically no control at all (Deutsche Umwelthilfe 2012). For the LEZ to have the intended effect, just putting up the necessary signs and issue stickers is not enough, it is necessary to have an effective control scheme in place (Deutsche Umwelthilfe 2012). When a similar study of 76 LEZs was performed in 2015, 38 of the LEZs had effective controls of both parked and vehicles in motion (Deutsche Umwelthilfe 2015). But 27 of the LEZs still had a level of control which were not adequate.

More than 90 per cent of the vehicles in the Berlin LEZ are satisfy the exhaust requirements for the Green stickers (Umwelt Bundesamt 2018). Studies in Berlin, Stuttgart and six cities in the Ruhr area, showed that the compliance to the LEZ regulation was about 95-99 per cent for private cars and approximately 85-93 per cent for trucks and vans (Ademe 2018).

In 2016 (Jan.-Nov.) 23 299 vehicles in Stuttgart were registered either with a wrong-coloured badge or without a badge (Stuttgarter Nachrichten 2017). About 5 500 fines were issued, while the other cases still were pending.

Table 2.6 show the number of fines issued in the Berlin LEZ. Most of the fines are issued by the "Ordnungsämter" (e.g. traffic wardens) and not by the police. The majority of the fines are issued to vehicles that did not have a Berlin number-plate on their vehicle. Only a small percentage of the fines were issued to "moving" vehicles.

Table 2.6: Number of fines issued in the Berlin LEZ in 2016 and 2017. Source. Lutz 2018

	2016	2017
Ordnungsämter		
-Vehicles from Berlin	8 106	7 935
- Other vehicles	53 435	53 880
Police		
- Vehicles from Berlin	2 448	1 227
- Other vehicles	1 198	2 554
Total	65 187	65 596

In the beginning of 2018 only 116 000 of the 330 000 vehicles traveling in Hamburg in an average day, are of the Euro VI/6 standards. With ban of vehicles older than Euro V/5, the new regulation of June 2018 will affect a high number of vehicles. The police has found

36 infringements of the diesel-ban in Hamburg between August 1st 2018 and September 15th (Whaler 2018).

2.3.3 Air Quality

According to Umweltbundesamt (UBA), the PM_{10} daily mean limit value was in 2017 only exceeded at one location in Germany, Am Neckartor in Stuttgart (Minkos et al. 2018). However, only a couple of years earlier several stations were above or close to the limit. In Figure 2.15 one can observe that this parameter can change drastically from one year to another, often related to variation in winter conditions, as most days above 50 μg/m^3 occur during the winter.

The yearly mean values have been decreasing and for the stations shown in Figure 2.14 the PM_{10} levels have been below the limit the last years. This is contrary to the NO_2 observations which were all above the limit value even if some stations show decreasing levels, see Figure 2.13. For Germany as a whole UBA estimates that about 46per cent of the urban traffic stations were above the NO_2 limit value in 2017 (but based on preliminary data for 2017) (Minkos et al. 2018).

For $PM_{2.5}$ the UBA estimate that German's reduction target of about 15 per cent reduction is likely to be met based on the levels the last three years.

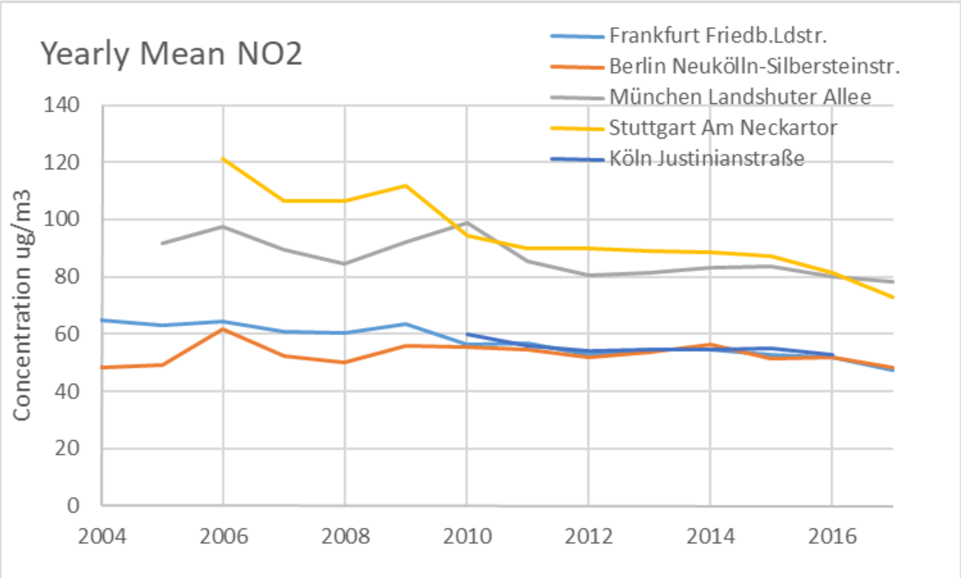

Figure 2.13: Annual mean concentration of NO_2 at some selected traffic sites in cities with LEZ. Source: EEA

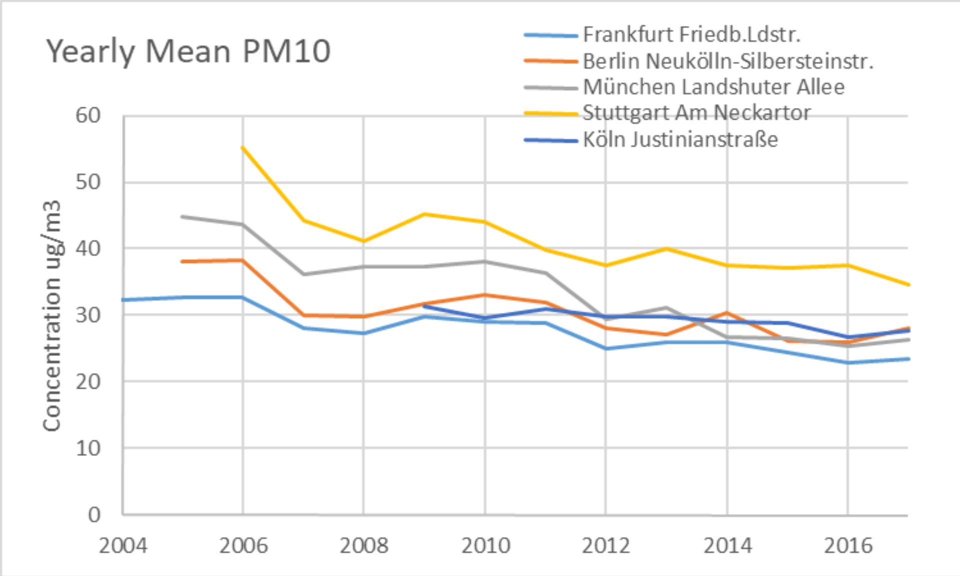

Figure 2.14: Annual mean concentration of PM$_{10}$ *at some selected traffic sites in cities with LEZ. Source: EEA*

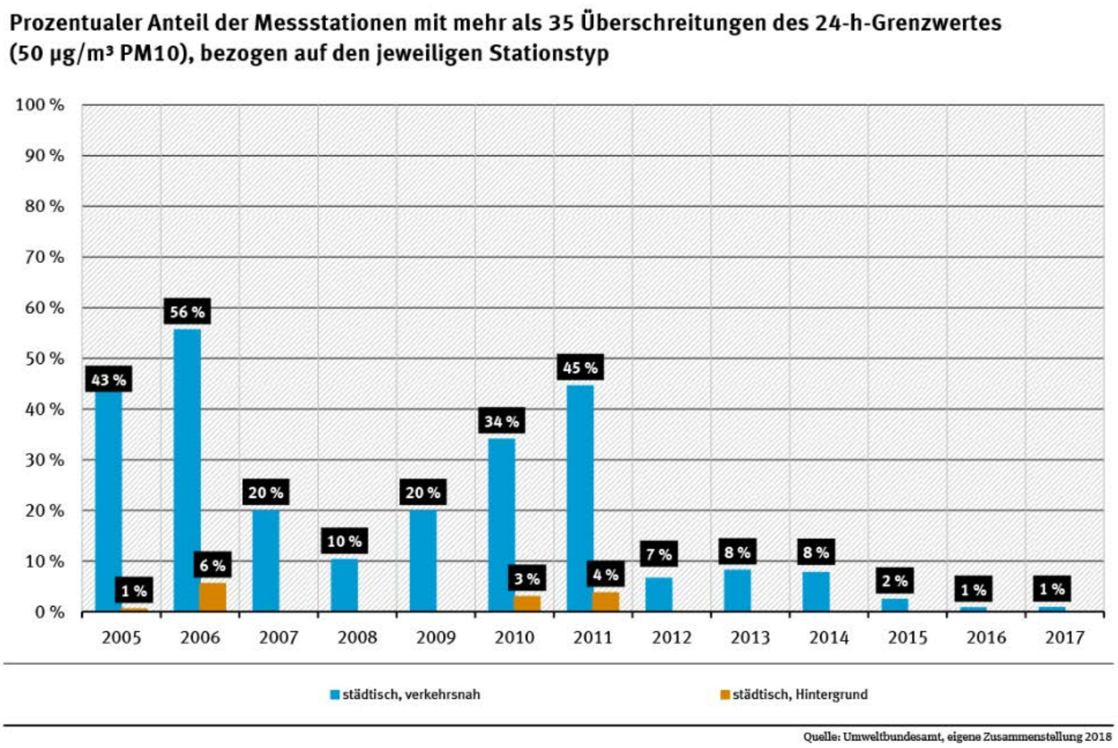

Figure 2.15: Percentage share of measurement stations in breach of the daily limit value for PM$_{10}$*. Blue bars indicate traffic stations and orange the urban background stations. Source: UBA*

2.3.4 Air quality effect studies

Several studies on the possible effects on air quality of the LEZs in Germany have been undertaken. The studies analysed the effect nationwide, for several cities or for a single city. A rather extensive overview of German studies can be found in Cyrys et al. (2018). For PM_{10} the studies they refer to, indicate an effect from 15 per cent reduction of the urban background to no effect at all. Among the 11 studies nine were performed for only the first stage introduction. The study finding the largest effect is also the most recent (Jiang et al.

2017) including all stages of the LEZ introduction going from red to only green stickers being allowed.

As Holman et al. (2015) and Ademe (2018) discuss, the debate on effect studies has been ongoing for some time. Difficulties in finding effects and variation on results based on the same data reflect for instance the challenge of methods, see section 4.5 for a further discussion.

Initially the German zones had the focus of reducing PM. Fewer studies have looked at NO_2 , but the effects are reported to be small. With the current knowledge on NO_x emissions from diesel vehicles one would not expect large differences either. The largest effects in German studies of the LEZs are found for Black Carbon (BC) and almost all studies report rather high reductions.

Emission reduction can be due to newer vehicles with lower emissions, but also the total volume of vehicles can be changed as observed in Berlin. In Berlin they found a decrease in number of vehicle ownerships just after the introduction of the LEZ in 2008. Then the vehicle number continued to increase but in 2016 the number of passenger cars is still not back to the pre 2008 level. However, there are now more motorcycles and trucks in Berlin (Berlin 2018).

2.4 Cities in Belgium

2.4.1 Requirements

A LEZ was implemented in the city of Antwerpen the 1st of February 2017, and in January 2018 an additional LEZ was implemented in Brussels. Belgium also plan to implement LEZs in the cities of Gent and Mechelen in 2020.

The legal framework for implementing LEZs is based on Decree 27/11/15 and Governmental decisions of 26/2/2016 and 31/3/2017 (Lenders and De Gelder 2007). The regional framework give categories of permitted vehicles, indicate conditions where local authorities can be less strict and provides a database with permitted vehicles (Lenders and De Gelder 2007). It is however up to the local governments to decide if they want to implement a LEZ or not. Local governments can make adjustments to the regulations, and for instance give admission to certain categories of vehicles against payment.

The regional Government in Brussels decided to implement a LEZ in 2016, as part of a long term plan on air quality, climate and energy (Traject et al. 2017). One of the main reasons for implementing the LEZ was the fact that the city did not comply with the EU air quality standard. The NO_2 requirement was especially problematic. Belgium is one of several countries the Commission has launched legal action against (Euractiv 2017). According to the European Environmental Agency (2017), more than 8 000 Belgian citizens died prematurely due to exposure to $PM_{2.5}$ in 2014, while approximately 1 900 died prematurely due to NO_2 exposure.

The city of Antwerp is considering extending the size of their LEZ (Lenders and De Gelder 2017). The existing LEZ borders are shown in Figure 2.16. In Antwerp several park-and-ride facility are established just outside the LEZ to ease the everyday transport of the citizens.

Figure 2.16: LEZ in Antwerp (Orange bubbles – automates for day-passes). Source: City of Antwerpe

The LEZ in Antwerp has restrictions for all motorized vehicles with four-wheels, while Brussels has restrictions for cars, vans and buses, see Table 2.7.

In Brussels the following vehicles are automatically exempted from the LEZ regulations (City of Brussels 2018a):

- 2-wheel vehicles
- HGV (category N2 and N3, and some N1)[2]
- Electric and hydrogen vehicles
- Emergency vehicles
- Veteran vehicles (older than 30 years)
- Agricultural and forestry tractors.

It is both in Antwerp and Brussels possible to apply for exemption from the requirements. In Brussels these exemptions are limited to (City of Brussels 2018a):

- Vehicles for transport of disabled persons
- Vehicles adapted for markets, fairgrounds etc.
- Motorhomes.

In Antwerp, those with a parking card for persons with disabilities and a low income, can apply for exemption. Foreign vehicles have to register before entering the LEZs in Belgium. You can register up to 24 hours after entering the zone, but it is recommended that you do so before entering.

The entire capital region of Brussels (161 km^2) is covered by the LEZ, see Figure 2.17. The only exemptions is the ring road, and some street allowing access to parking lots.

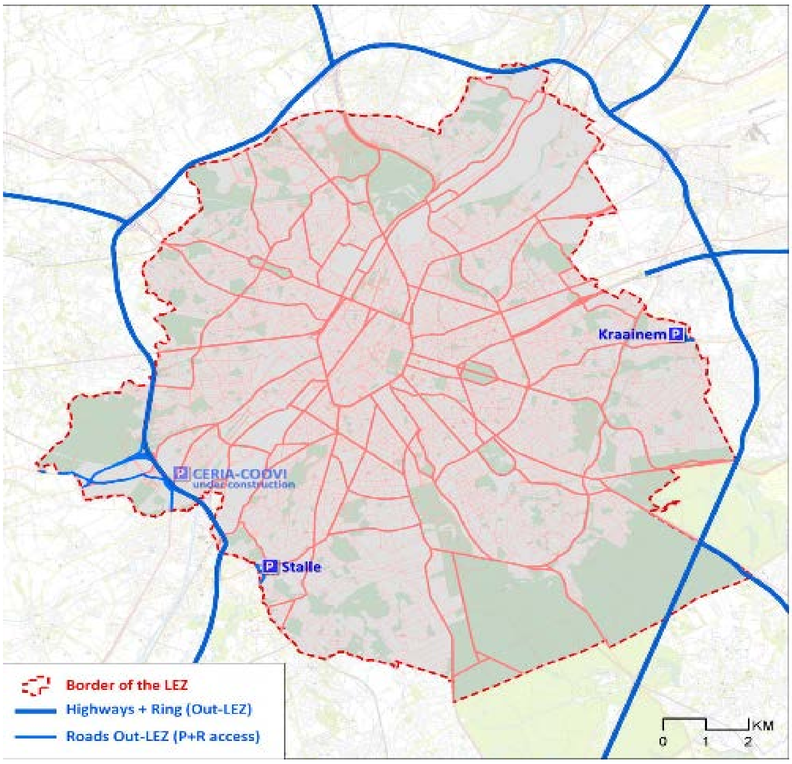

Figure 2.17: LEZ in Brussels. Source: LEZ.Brussels

[2] N1, N2 and N3 describe the different weight-classes of the vehicles. N1 – up to 3 500 kg, N2 – between 3 501 and 12 000 kg, N3- more than 12 001 kg.

Table 2.7: Overview of requirements and enforcement method of LEZ (Lage-emissiezone) in Belgian cities. Source: urbanaccessregulations.eu and local LEZ homepages

Year of installation	Vehicle	Requirement (January 2018)	Enforcement
Antwerp 2017	All 4-wheelers	Euro I/1 for petrol vehicles, and Euro III/3 with particle filters for diesel vehicles. **2020**: Euro II/2 for petrol, and Euro V/5 for diesel. **2025**: Euro III/3 for petrol, Euro VI/6 for diesel **2027 (Sep):** Euro III/3 for petrol, Euro VId/6d for diesel. **2028:** Euro IV/4 for petrol, Euro VI/6d for diesel.	ANPR
Brussels 2018	Cars/ vans (N1)/ buses	Euro II/2 for diesel vehicles. **2019**: Euro III/3 for diesel, Euro II/2 for petrol **2020**: Euro IV/4 for diesel, Euro II/2 for petrol **2022**: Euro V/5 for diesel, Euro II/2 for petrol **2025**: Euro VI/6 for diesel Euro, III/3 for petrol	ANPR

2.4.2 Enforcement

In both the operating LEZs, cameras are installed along the boundaries of the LEZ and in the city centre (Smart ways to Antwerp 2018b, Low emission Zone Brussels 2018b). The cameras in both Antwerp and Brussels are connected to an ANPR system. The cameras take an overview picture of the vehicle, and one picture zoom in on the number plate. The digital photo of the number plate is then "translated" into numbers and letters.

In addition to camera surveillance, the police perform random controls of vehicles, with a special focus on foreign vehicles.

Different databases are connected to the system. These have access to vehicle types and Euro standards, owners name and home address, registered retrofitting and exemptions. Foreign vehicles have to register to enter the zone. Retrofitted vehicles and vehicles entitled to exemption also have to register. Unlike in the Antwerp LEZ, Brussels does not allow retrofitting of vehicles to meet the requirements. To allow time for last minute registered vehicles, the number-plates are checked against the databases 10 days after having entered the zone.

Antwerp is hoping to gain access to Dutch and French databases to ease the identification of offenders, and possible also to other countries vehicle information's, to ease the surveillance of foreign vehicles (Lenders and De Gelder 2017).

In a transition period lasting until 2020, *some vehicles* are allowed to enter the LEZ in Antwerp, if they register (Smart ways to Antwerp 2018c), and pay for it (reduced prices for people living within the zone) and meet these specific criteria:

- Diesel Euro III/3 diesel vehicles without particle filters
- Vehicles older than 40 years
- Diesel Euro II/2 and III/3 vehicles used for maintenance and utility work

- Diesel Euro II/2 and III/3 vehicles used for emergency interventions
- Diesel Euro II/2 and III/3 vehicles used by traders attending markets and fairs.

Other vehicles can buy day-passes up to eight times each year, these day-passes costs €35 (Antwerp and Brussels). The day-passes can be brought on-line or in one of the payment terminals located within the zone.

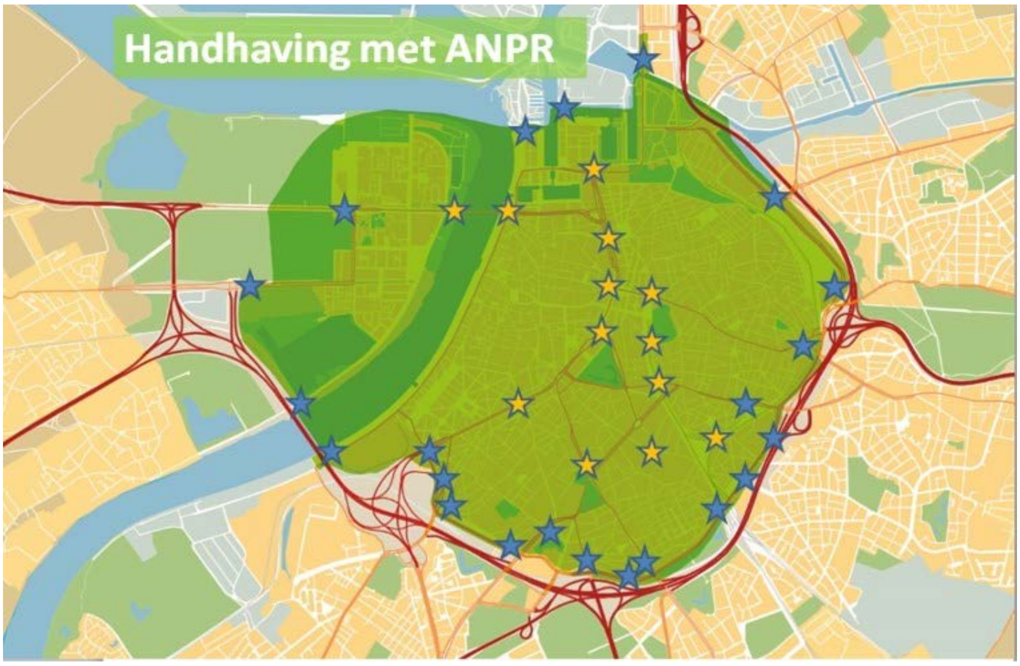

Figure 2.18: Location of ANPR- cameras in Antwerp (blue stars- cameras operating January 2017, yellow stars- planned new cameras). Source: Gazet van Antwerpen 2017

The penalty for unlawful entry in Antwerp is €150, and €250 for the second offence, while further offences within a 12 month period is fined with €350.

Brussels has a transition period until October 2018, in which no fines will be issued. From October 2018 the penalty for unlawful entry will be €350 (Low emission Zone Brussels 2018c). No new fines will be issued in a three-month period after this. It is hoped that the owner in this period manage to find a way to comply with the regulations. Brussels will also have a three month transition period in 2019 and 2020. This transition period is only valid for new vehicles included by the restrictions (Low emission Zone Brussels 2018b). If your vehicle is in compliance with the regulations, but you have forgotten to register (i.e. owners of foreign vehicles), the fine is €150.

The cameras in the Antwerp LEZ on average checks 725 000 vehicle a month (Lenders and De Gelder 2017). In February 2017 (when the LEZ was implemented) the compliance of the vehicle entering the zone was almost 95 per cent, and in October the same year this had increased to almost 99 per cent. For the Belgian car fleet in general, about 90 per cent of vehicles are in compliance with the current requirements in the zone (Lenders and De Gelder 2017).

In Antwerp 77 102 Belgian citizen have been fined for unlawful entering the LEZ (Feb-Nov) in 2017, in addition to 167 foreign vehicles (Huys 2018).

The LEZ in Brussels was implemented in January 2018, but they have decided on having a nine month long transition period after implementing the zone. In this period offenders are only given a warning if their vehicle is not in compliance with the requirements.

2.4.3 Air Quality – regulations and levels

For Belgium cities it is the levels of NO_2 that are exceeding the EU limit values. Brussels also has risk of periods in the wintertime with peak values of NO_2 and particles and peaks of ozone being an issue in the summer (Brussels 2018). In Figure 2.19 one see the NO_2 levels at two traffic sites, one in Brussels and one in Antwerp. The levels have in general decreased during the period shown (until 2016), but both stations are still above the limit of 40 µg/m^3.

For PM the observations at two stations, a traffic site in Antwerp and an urban background station in Brussels -Molenbeek, are shown in Figure 2.20. The concentration levels at these two stations decreased over the time period, and are now below the annual limit value. For the daily limit value no stations were in 2017 registered above, but one station was quite close with 33 days above 50 µg/m^3 (Irceline 2018). Since 2007 no measurement station has been above the annual limit value for PM. The trend for the whole country is also decreasing levels with typically reduction of around 1 µg/m^3 per year since 2000 (Irceline 2017), see Figure 2.21.

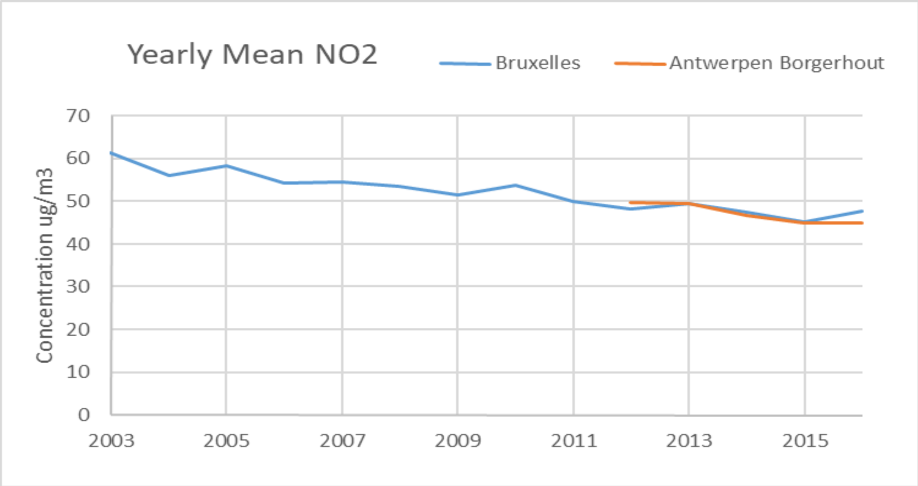

Figure 2.19: Annual mean concentrations of NO_2 at two road site stations in Belgium. Source: EEA

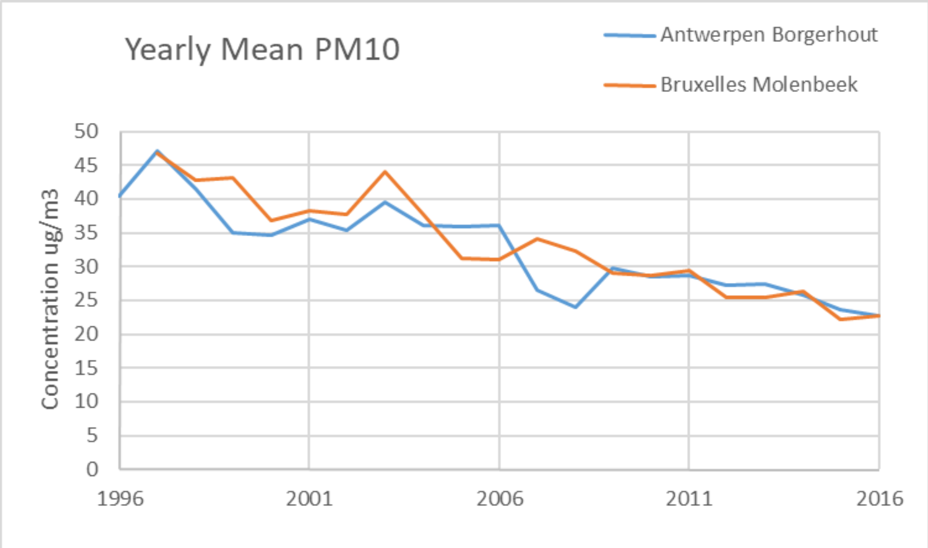

Figure 2.20: Annual mean concentrations of PM_{10} at two measurement sites in Belgium. Source: EEA

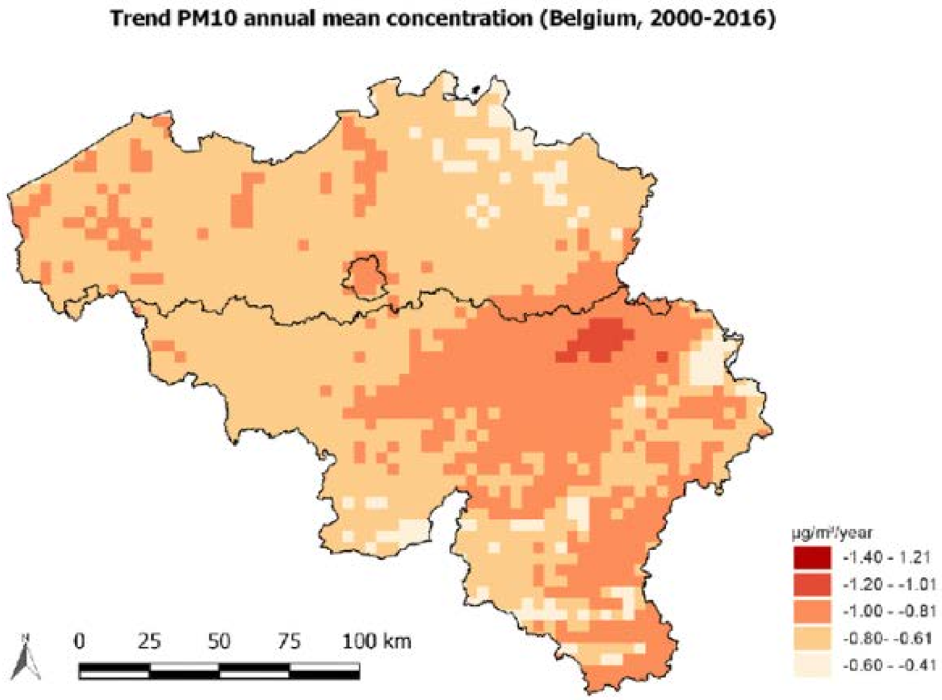

Figure 2.21: Trend in PM_{10} reduction for Belgium from 2000- 2016. Source: Irceline 2017

2.4.4 Effect studies

As the zones in Belgium are very recently implemented no study was found on effects after the restrictions came into force. Dispersion modelling, performed before the LEZ implementation for Brussels, indicates a fairly large reduction in NO_2 concentrations will occur also without the zone, but that further reductions is needed, hence the introduction of the LEZ. With the LEZ they expect to be compliant with the EU regulation for the annual NO_2 mean value sometime between 2020 and 2025 also in street canyons (ADEME 2018).

2.5 Cities in France

2.5.1 Requirements

By the end of 2017, France had 28 LEZs, which are called ZCR (Zones à Circulation Restreinte, Restricted Circulation Zones) or ZPA (Zones de protection de l`air). The ZCRs are permanent zones, while the ZPAs are weather dependent and are only in operation on days when the level of $NO_x$ and/or PM are expected to be high (Crit`air 2018a). Here we are focusing on the two existing ZCR in Paris and Grenoble. Strasburg plans to implement a ZCR in September 2018 and Lille plans to implement one in 2019. Bordeaux is also considering implementing a ZCR.

In 2012, almost 50 000 persons in France died prematurely due to exposure to air pollution (European Environmental Agency 2015). The ZCR and ZPA were introduced partly based on several governmental action plans (Crit`Air 2018b):

- The third environmental and health plan for the planning period 2015-2019
- The fine dust plan, for the planning period 2010-2015
- The emergency plan for air quality from 2012
- Plan for protection of the atmosphere from 2015
- The project "tolerable city air in 5 years" running from 2015-2020. In this project 25 local communities have committed themselves to implement measures to improve air quality (Crit'Air 2018e).

The Law No. 2015-992 (August 2015) ensures that it is possible to implement permanent restriction areas, i.e. ZCRs (Ademe 2018). The zone can cover an entire city or part of it.

The national decree (Dècret ZCR 2016-847) leaves the decision to implement a LEZ up to the local authorities. They have to follow the national framework, but can decide on the borders, which vehicles to implement, time of day for regulations, and how strict the regulations have to be to meet local environmental needs. Before implementing a LEZ, this must be justified by performing studies documenting the needs for a LEZ (Ademe 2018), i.e.:

- A description of the air quality in the area concerned
- An assessment of the number of people exposed to air quality levels that exceed the regulations
- An assessment of air pollutant emissions from road transport in the area
- An assessment of the proportion of vehicles affected by the restrictions
- An assessment of the reductions in emissions of air pollutants expected by the creation of the LEZ.

All vehicles entering the LEZs need to have a sticker indicating their Euro class or fuel type, see Figure 2.22. The same type of stickers is used in all French LEZs. The stickers show which vehicles that are allowed to enter the zone. There is also a green sticker for electric and fuel cell powered vehicles. Vehicles on gas and plug-in hybrid vehicles will receive a purple (no. 1) sticker. The sticker can be ordered online on the national web site. Vehicle owners who plan to enter a LEZ must order a sticker on the national web-page (for Crit'Air stickers). The same sticker is used in the temporary environmental zones (the ZPA).

Crit'Air-Classification

Image table©Crit'Air.fr/Green-Zones GmbH

Crit'Air-Class	Two-, three- and light motorized four-wheelers	CARS	Light Utility Vehicles < 3,5 t	Big Trucks, Lorries and Busses
	Hydrogen – and Electric Vehicles			
1	Gas powered vehicles Rechargeable Hybrid Vehicles			

Crit'Air-Classe	First registration date or Euro standard						
	Two-, three- and light motorized four-wheelers	Cars		Light Utility Vehicles < 3,5 t		Big Trucks, Lorries and Busses	
		Diesel	Petrol	Diesel	Petrol	Diesel	Petrol
1	EURO 4 starting 01.01.2017 for Motorcycles and starting 01.01.2018 for Mopeds	-	EURO 5 and 6 01.01.2011	-	EURO 5 and 6 01.01.2011	-	EURO 6 starting 01.01.2014
2	EURO 3 from 01.01.2007 until 31.12.2016 for Motorcycles and up to 31.12.2017 for Mopeds	EURO 5 and 6 starting 01.01.2011	EURO 4 from 01.01.2006 until 31.12.2010	EURO 5 and 6 starting 01.01.2011	EURO 4 from 01.01.2006 until 31.12.2010	EURO 6 starting 01.01.2014	EURO 5 from 01.10.2009 until 31.12.2013
3	EURO 2 from 01.07.2004 until 31.12.2006	EURO 4 from 01.01.2006 until 31.12.2010	EURO 2 and 3 from 01.01.1997 until 31.12.2005	EURO 4 from 01.01.2006 until 31.12.2010	EURO 2 and 3 from 01.10.1997 until 31.12.2005	EURO 5 from 01.10.2009 until 31.12.2013	EURO 3 and 4 from 01.10.2001 until 30.09.2009
4	No class for all types from 01.06.2000 until 30.06.2004	EURO 3 from 01.01.2001 until 31.12.2005	-	EURO 3 from 01.01.2001 until 31.12.2005	-	EURO 4 from 01.10.2006 until 30.09.2009	-
5	-	EURO 2 from 01.01.1997 until 31.12.2000	-	EURO 2 from 01.10.1997 until 31.12.2000	-	EURO 3 from 01.10.2001 until 30.09.2006	-
No Crit'Air	No class for all types until 31.05.2000	EURO 1 and before until 31.12.1996	EURO 1 and before until 31.12.1996	EURO 1 and before until 30.09.1997	EURO 1 and before until 30.09.1997	EURO 1, 2 and before until 30.09.2001	EURO 1, 2 and before until 30.09.2001

Figure 2.22: The different Crit`Air badges/stickers used in France. Source: Crit`air 2018f

The LEZ in Paris was implemented in September 2015, with restrictions for busses and trucks. In July 2016 other vehicle types were also included by the restrictions. The *zone is in operation on weekdays*, from 8 am to 8 pm (Crit'Air 2018c). For trucks and busses, the ban also applies on weekends and public holidays (8 am to 8 pm).

The Paris LEZ (see Figure 2.23) includes the area within the ring road (Boulevard Pèriphèrique). An extension of the boarder is planned in 2019.

Figure 2.23: ZCP in Paris. Source: Open street map

In Grenoble, the zone has restrictions for vans and trucks (Vehicle classes N1, N2 and N3), but the plan is to also include cars, busses and MCs (Crit`Air 2018d). There is also plans to extend the current zone. The driving restrictions are in operation on Mondays to Fridays, from 6 am to 7 pm. The zone have been in operation since January 2017.

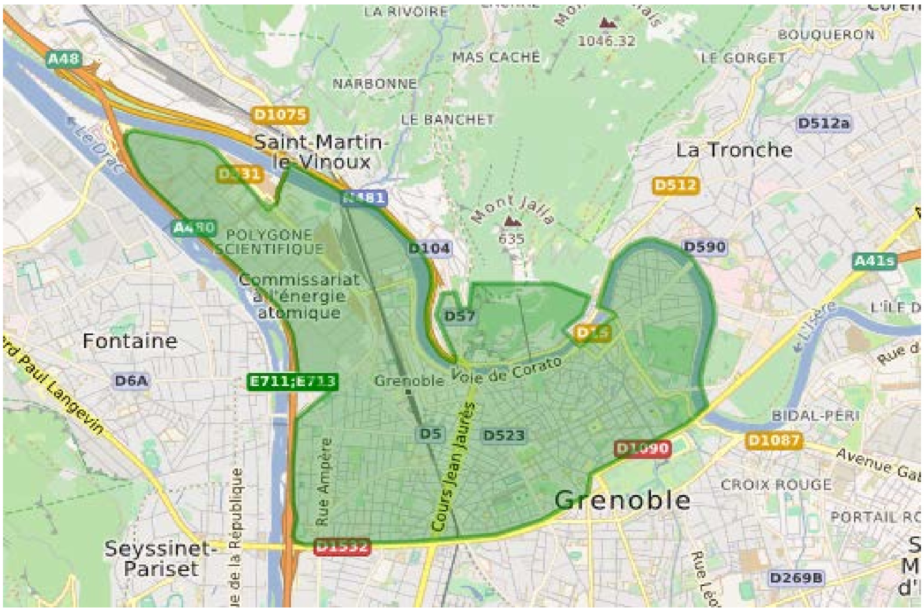

Figure 2.24: ZCP in Grenoble. Source: Open street map

The requirements can vary between the LEZ cities, and they will become stricter as years go by. There are *some exemptions* from the requirements, for example: police, fire brigade, emergency vehicles, military vehicles and vehicles for disabled persons. Other local exemptions may occur (e.g. exemption for cars older than 30 years in Paris). The vehicles with exemptions, also need to carry stickers.

Table 2.8: Overview of requirements and enforcement method of LEZ (ZCR) in three French cities. Source: urbanaccessregulations.eu and local LEZ homepages

Year of installation	Vehicle	Requirement (January 2018)	Enforcement
Paris 2015 (Sep.)	HDV LDV (2, 3 and 4 wheels)	*Diesel cars* – sticker* 4, *Petrol cars* – sticker 3, *Diesel vans* – sticker 4, *Petrol vans* – sticker 3, *MC* – Sticker 4, *Diesel HDV* – sticker 4, *Petrol HDV*- sticker 3. Sticker 5 vehicles permanently banned.	Manual police control and traffic wardens
Grenoble** 2017	HGV LCV	Vehicles without Crit`Air stickers are banned) **2020?**: Ban sticker 5 vehicles.	Manual police control
Strasburg** 2018 (Sep)	HGV LCV	N3 vehicles permanently banned. Sticker 5 vehicles banned for N1 and N2 vehicles. **2019**: Sticker 4 and 5 permanently banned. **2022** (Sep.): All N2 diesel delivery trucks will be banned.	Manual police control

*Euro requirements for different sticker, shown in Figure 2.22.

**It is expected that other types of vehicles (cars, buses, 2-, 3-, and 4- wheelers) will be included at some point in the Strasburg and Grenoble LEZs.

2.5.2 Enforcement

The Crit`Air badge cost between €3-4.4 (skipping excluded) depending on country. This price is set to cover the manufacturing of the badges, processing and distribution (Crit`Air 2018g). You will have to register on-line to apply for a badge. The registration includes a copy of the vehicle registration certificate.

Non-authorized vehicles entering the zones are fined. The fine is €68 for light vehicles (€180 if not payed by 45 days), and €135 for trucks and buses (€375 if not payed by 45 days) (Crit`Air 2018g). Non-payment of fines, may lead to prison sentences.

In Paris many of the vehicles still did not carry a sticker in 2017, so from 2018 the City Council decides to strengthen the enforcement of the regulations. In 2017, only 176 fines were issued between July and December, while 3 705 fines were issued from January to April 2018 (Le Figaro 2018). The police issued 366 of these fines, the rest was issued by traffic wardens.

2.5.3 Air Quality – regulations and levels

France follows the EU directive for limit values. They also have target values for the annual mean for $PM_{2.5}$ of 20 $\mu g/m^3$, and long term quality objectives of 30 $\mu g/m^3$ for PM_{10} annual mean value, and 10 $\mu g/m^3$ for $PM_{2.5}$.

All roadside measurements are above the annual limit value for NO_2 in Paris and surroundings suburbs. Several urban background stations are also very close to the limit value, but has been below since 2015 (AirParif 2018a).

Urban background sites have had a decreasing trend of NO_2 since the late 1990s, with the largest decrease the first years. This is explained by the introduction of catalytic converters in vehicles. The situation is a bit different for road sites, as can also been seen in Figure 2.25, which has more or less quite stable concentrations levels for a long time. In Paris, when looking at the average over several stations, there has been a decreasing trend the last years (AirParif 2018a). The reduction at urban background sites and recent decrease at traffic sites, have had large effect on the number of people exposed to NO_2 above the annual limit value, which has been reduced from 3.8 million in 2007 to 1.3 million in 2017.

The difference in the NO_2 trend at traffic sites and urban background sites also reveals an increase in the NO_2 share of the total NO_x roadside, which went from about 10 per cent to more than 24 per cent. The increase in the NO_2 share has been explained for instance by David Carslaw (2005). As particle filters have been introduced on diesel vehicles the direct NO_2 emissions have increased relative to NO_x, but also other aspects as an increase in the diesel fraction (see Figure 3.5) and new engine technologies have contributed.

For Grenoble and Strasbourg the situation is quite similar to the situation in Paris except that the levels are lower. They report an overall decreasing trend at most sites (AtMO Grand Est 2017, Atmo Auvergne Rhone Alpes 2017). As can be seen in Figure 2.26, Grenoble has had a fairly sharp decrease in PM_{10} levels compared with the other two cities. This decrease has been explained by a reduction in the industrial sector, because of reduced activity as well as cleaner production, and the residential sector with renewal of wood stoves. The reduction is also explained by cleaner vehicles, but the reduction for each vehicle has been somewhat counterbalanced by an increase of traffic volumes (Atmo Auvergne Rhone Alpes 2017). In Grenoble they also focus on the challenge of episodes with higher than usual levels. Such peak level episodes are highly dependent on weather conditions. In 2016 Grenoble for the first time, activated driving restrictions due to a pollution episode.

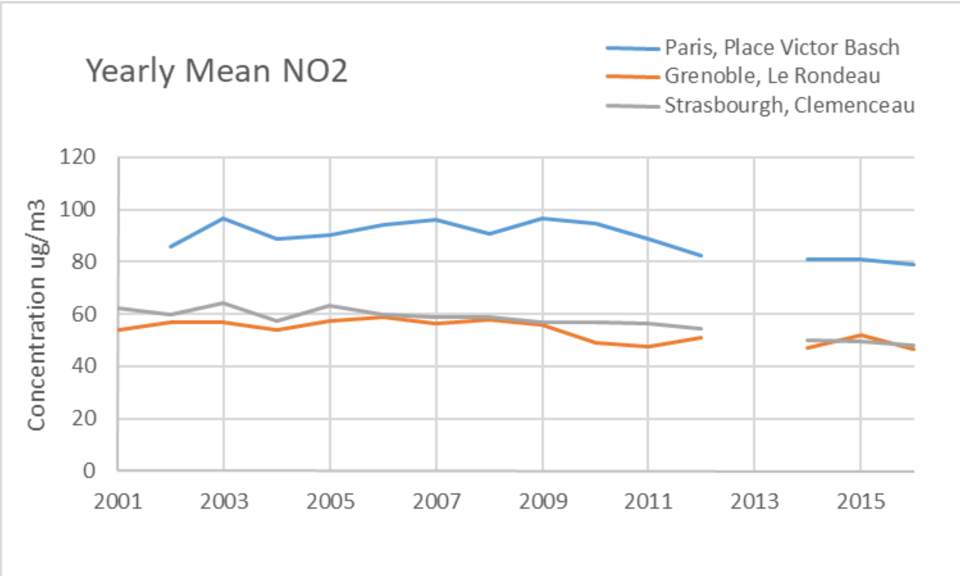

Figure 2.25: Annual mean concentration of NO_2 at three selected traffic stations in France. Source: EEA

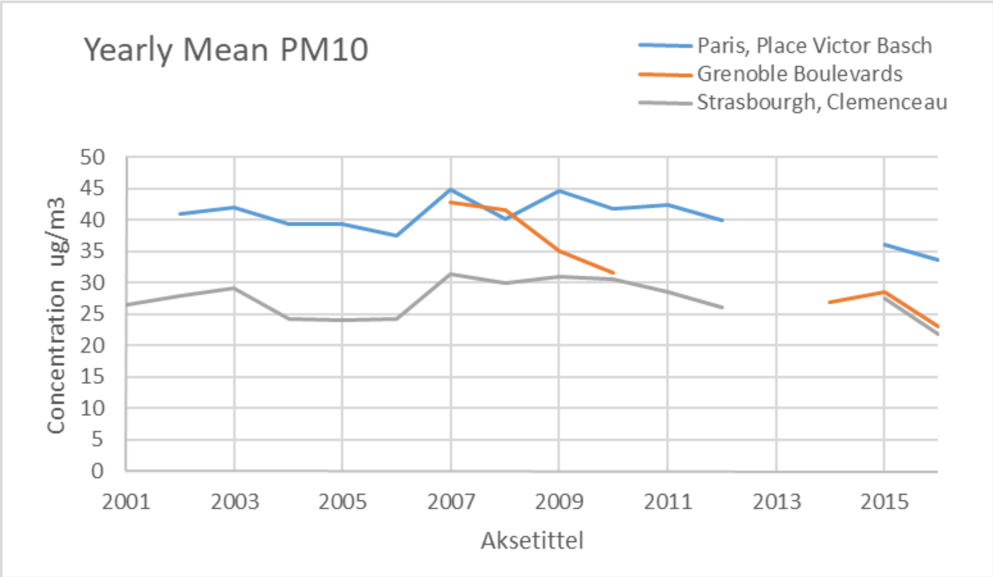

Figure 2.26: Annual mean concentration of PM_{10} at three selected traffic stations in France. Source: EEA

2.5.4 Effect studies

Air quality effect predictions of a LEZ in Paris have been reported in AirParif (2018). The evaluation was done in several steps from clearly defining source categories, expected effects on the vehicle fleet, emission reductions, concentration reductions and reduction in the number of inhabitants exposed at different concentration levels. From the base year of 2014/2015 they modelled scenarios for all years from 2016 to 2019. They also looked into other pollutants than NO_2 and PM, which emphasised for instance the important contribution of two wheelers to NMVOC emissions (Non-methane volatile organic compounds), and these results can be used to justify the inclusion of all motorized vehicles in the LEZ.

From the modelling it is expect that the LEZ will reduce concentration levels mainly for NO_2 (see example for one scenario in Figure 2.27). They estimate about 60 per cent reduction of Parisians exposed to NO_2 levels above the limit value, and up to 91 per cent reduction if a larger zone is introduced that account for the whole metropolitan population (AirParif 2018). The modelling results also indicated that even with the LEZ there will be areas above the limit value.

For PM the reduction due to the LEZ is smaller. This fact is explained by a large fraction of non-exhaust emission (about half) in the transport emissions, as well as a smaller overall contribution from road traffic to the concentrations. They conclude that more measures targeting particles are also needed if Paris is to reach the WHO guideline value for PM concentrations.

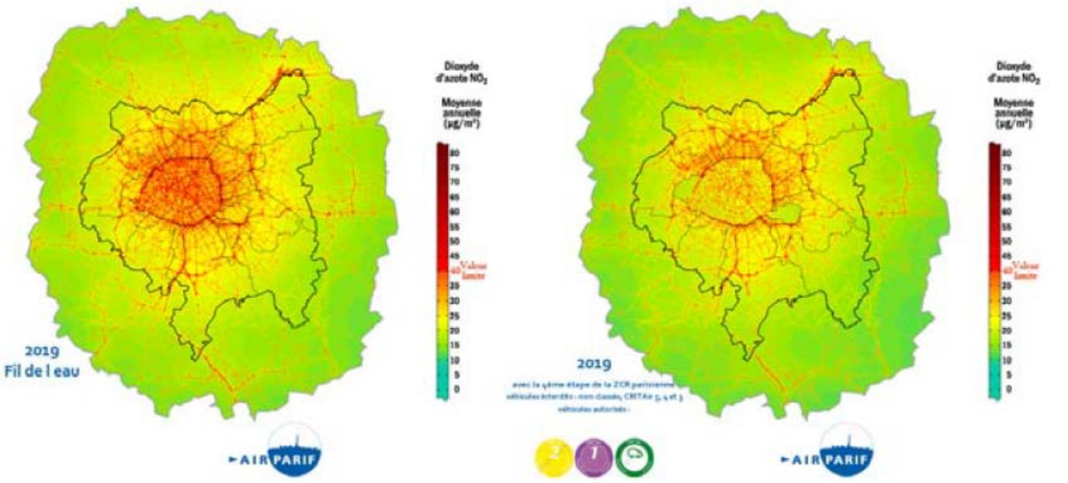

Figure 2.27: Concentration map for NO_2 in 2019 with business as usual (left) to a situation with LEZ allowing only vehicles with a yellow, purple or green stickers. For this case the LEZ is without the Boulevard periferique. Areas coloured in red are above the yearly mean limit value for NO_2. Source: AirParif 2018

2.6 Cities in the Netherlands

2.6.1 Requirements

In the Netherlands there are 13-14 LEZs that in Dutch are named Milieuzones. Some examples are: Amsterdam, Delft, the Hague, Maastricht, Rotterdam (two – one of which in the harbour area) and Utrecht. The implementation of LEZs started in 2007/2008, with restrictions on the use of older trucks.

The LEZs were implemented due to the fact that several cities in the Netherlands failed to comply with the EU directives on air quality (see chapter 1.3). Based on the national Air Quality Acts of 2001 and 2005, an action program was developed. An agreement (the *Covenant Promoting Clean Vehicles and Environmental Zoning*) between the national government, industry organisations and 10 municipalities, decided on LEZs as a measure to reduce emission (Hogenbirk 2016). In 2007 the Air Quality Act of 2005, was replaced with the Air Quality Law (Wet Luchtkwaliteit) (Hogenbirk 2016). It is up to local governments to decide if they want to use LEZ as a measure to meet the requirements or not, and if they want to use camera or manual surveillance in their LEZs. The Covenant was originally valid to 2013, but has been extended several times.

The Nederland is working on further *harmonisation of the national framework for LEZ* (milieuzones.nl/nieuws 2018). One of the proposed harmonisations in the July 2018 proposal, is a framework for implementing restrictions on diesel vans and passenger cars from 2020, and a strengthening of the regulations by 2025. Restrictions of petrol cars are not a part of the national harmonisation proposal. In 2022, Euro VI may be the requirement for lorries to get access to the LEZs.

In Amsterdam, monitoring stations along several roads measured values well above the limit values, and traffic was the main source of the pollution. A LEZ were therefore implemented in 2008 to reduce the traffic induced air pollution. Emission measurements in the LEZ cities for the year 2013 indicated that several of the cities still did not meet the air quality standards for PM or NO_2 (Hogenbirk 2016). This started a discussion to also include restriction on other types of vehicles in the LEZs.

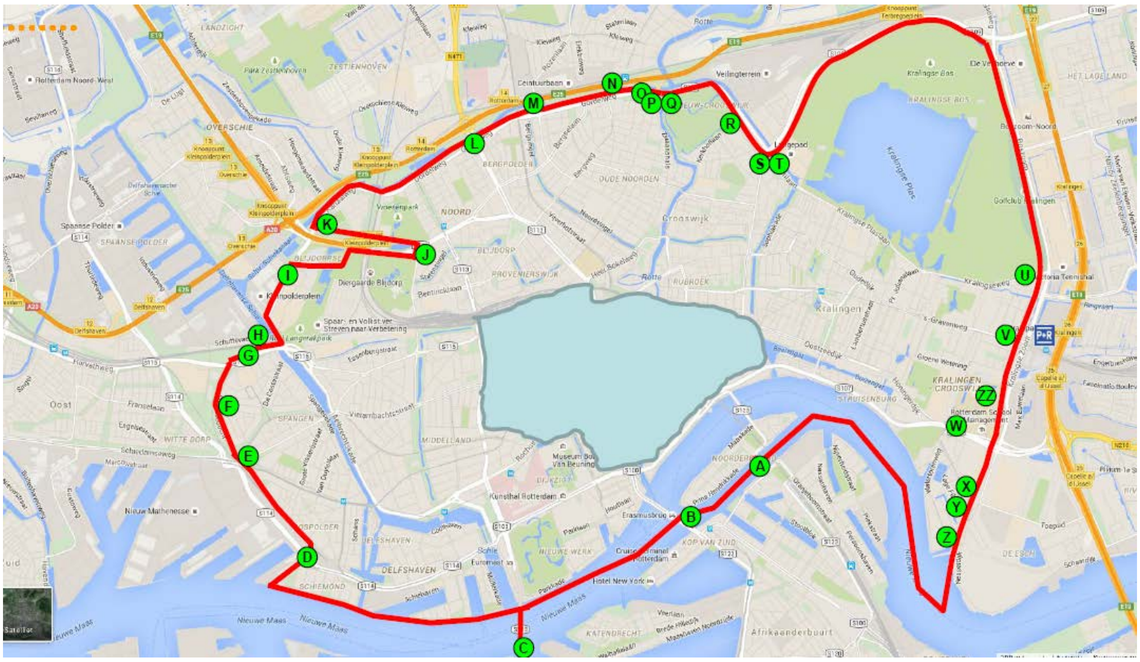

Figure 2.28: LEZ in Rotterdam 2016, and camera location. Source: van den Berg 2016

Common for all the LEZs in the Netherlands is a ban on Euro III and older diesel trucks. Some cities have also started to implement restrictions on other types of vehicles. Amsterdam included delivery vans in 2017, and in 2018 they included mopeds and taxis in their LEZ (City of Amsterdam 2018a). Utrecht included diesel cars and delivery vans in 2015, while Rotterdam included cars and vans in their LEZ in 2016.

Rotterdam expanded their LEZs in 2016, both geographically (expanded the borders) and the types of vehicles included. The reason was that the current restrictions were not enough to bring the air quality down to an acceptable limit, especially for NO_2. The traffic was responsible for a major part of the air pollution. Restricting access for the most polluting vehicles was therefore seen as a necessary measure. LEZ was considered one of the most effective measures to reduce the air pollution in Rotterdam (City of Rotterdam city 2018a).

In Rotterdam trucks are not allowed on one of the most polluted city streets, with the exception of zero-emission vehicles (van den Berg 2016). This is one of several measures in the action plan for Rotterdam, which also included extending the then existing LEZ, increase the number of charging points for electric vehicles, introduction of cleaner vehicles in the municipal vehicle-fleet, and stimulating greener travel behaviour.

Some cities have also implemented scrapping scheme's for older vehicles, or subsidies for buying cleaner vehicles. Rotterdam had a scheme for scrapping old cars and delivery vans which were operative until July 2017. Owners of older vehicles could be compensated €1000-2500, if scrapping their old vehicle (City of Rotterdam 2018b). If the vehicle was replaced with an electric vehicle or a vehicle running 100 per cent on green gas (CNG), the compensation could be even higher.

Some exemptions from the LEZ regulations:

- Vehicles older than 40 years
- Vehicles running on 100 per cent LPG
- Vehicles for transportation of disabled persons.

In Amsterdam it is also possible to apply for an exemption for a limited time period (for trucks), or if you are disabled (City of Amsterdam 2018a). It is also possible to apply for 12 one-day exemptions each year.

In Rotterdam it is possible to apply for one-day exemptions up to 12 times each year. Each one-day exemption will cost €25.30 (City of Rotterdam 2018b). Long-term exemption is possible for example for disabled persons, entrepreneur at the risk of bankruptcy, if you need repeated medical treatment at a hospital within the LEZ, or is an owner of a campervan and live within the LEZ.

The requirements in the LEZs are connected to the data of the first registration of the vehicle, see Table 2.9. This is referring to the date the vehicle first got a licence plate.

Table 2.9: Overview of requirements and enforcement method of some LEZs (Milieuzon) in the Netherlands. Source: urbanaccessregulations.eu and local LEZ homepages

Year of installation	Vehicle	Requirement (January 2018)	Enforcement
Amsterdam 2008	Trucks, diesel taxis, buses, mopeds, diesel delivery vans, camper vans	*Diesel trucks*- Euro IV, *diesel taxis* – built after 2008, *buses* – built after 2004, *mopeds* – built after 2010, diesel *delivery vans* – built after 1999. **2020**: *Diesel trucks* - Euro V/VI? **2025**: Zero-emission public transport	ANPR and manually by City wardens
Utrecht 2007 (July)	Trucks, diesel cars and delivery vans, camper vans	*Diesel trucks*- Euro IV, *diesel cars and delivery vans* – built after 2000, *camper vans* – built after 2000. **2020**: *Mopeds*: only electric?	ANPR
The Hague 2008	Trucks	*Diesel trucks*- Euro IV.	ANPR
Rotterdam 2007	Trucks, cars, delivery vans	*Diesel trucks*- Euro IV, *diesel cars and delivery vans*– built after 2000, *petrol cars and delivery vans**– built after June 1992.	ANPR and manually by City wardens
Maastricht 2012	Trucks	*Diesel trucks*- Euro IV. **2019**: cars and vans to be included	ANPR**
Delft 2010	Trucks	*Diesel trucks*- Euro IV.	ANPR

*Not enforced for petrol cars/delivery vans.
**Local government in Maastricht are considering using sticker (manual control) when including cars and delivery vans in 2019.

2.6.2 Enforcement

When the LEZs in the Netherlands were first implemented in 2007/08, Amsterdam was the only city to choose camera surveillance, the other cities used random manual surveillance. The manual control was performed by the "opsporingsambtenaren" (which for example can be parking wardens/city wardens/civil enforcement agents). Now several other cities have implemented ANPR-systems.

In 2010, only five per cent of the trucks in Amsterdam were violating the LEZ regulations, while this percentage was 20-25 per cent in Eidhoven and some other cities with manual controls (Goudappel Coffeng and Buck Consultants International 2010). In 2010, about 25 per cent of the trucks in the different LEZs did not comply with the regulations, about 1/3 of these vehicles had been exempted (either special vehicles or had applied for one-day exemptions). The other 2/3 had entered the zone without permission (Goudappel Coffeng and Buck Consultants International 2010).

Informal investigations of non-compliance have been carried out by different Non-governmental organisations. They found that on average 30 per cent of the trucks were in non-compliance with the LEZ regulations (Ademe 2018).

By 2018, ANPR systems have been implemented in most LEZ cities. But some cities combine it with manual control, especially if the camera-coverage is not optimal. Maastricht is considering implementing a sticker system in 2019, when restrictions for cars and vans are to be included in their LEZ (urbanaccessregulations.eu).

The mopeds in Amsterdam have their license-plate on the back of the vehicle, and both camera surveillance and manual control by civil enforcement agents is used for enforcing the regulation.

The penalty fine for non-compliance is €230 for trucks, €95 for vans/cars and €65 for mopeds (Amsterdam).

Rotterdam included regulations on cars and delivery vans to their LEZ in 2016. When the city did an inventory of the Rotterdam vehicle fleet in 2015, they found that only about six per cent of the cars did not already comply with the requirements, or were for some reason exempted (i.e. veteran car, vehicle used for transport of disabled) (van den Berg 2016). This meant that the expected numbers of offenders for the new regulations were low, which is also indicated in Figure 2.29.

Figure 2.29: Percentage of offenders (cars) in the Rotterdam LEZ, May to September 2016. Source: van den Berg 2016

In 2016, about 265 vehicles daily entered the LEZ in Rotterdam without being authorized (Metro news 2016). In the period from May-October 2015, 8 587 penalty fines were issued in Utrecht (NU.nl Utrecht 2015). About 10 per cent issued a complaint on their fine. Amsterdam included access regulations for delivery vans in 2017, and in March 2017, 7 380 delivery vans was observed violating the regulations (NU.nl Amsterdam 2017).

In Amsterdam, the compliance is about 98 per cent for delivery vans, and more than 99 per cent for trucks (Regterschot 2018).

2.6.3 Air Quality – regulations and levels

For the selected stations in cities in the Netherlands, decreasing trends for the pollutant concentrations in the air are visible for the measurement periods, see Figure 2.30 and Figure 2.31. These trends are visible for PM_{10} as well as for NO_2. Missing or not valid data for the Amsterdam station in the EEA data-tool do not give a basis for comparing the PM levels from this data source. Local authorities however report of PM decreasing trends at roadside stations in Amsterdam as well as at most urban background stations (van der Zee and Helmink 2018). The NO_2 levels are still above the annual limit value at some locations, and that for 2017 three out of five roadside stations were above the limit. Also measurements with diffusion tubes indicate several locations with too high concentration levels. Van der Zee and Helmink 2018 also express a worry that the levels seem to have stagnated for all components except BC. A theory for this stagnation in pollution levels is a large economic growth the last years, which likely increase polluting activity, in combination with higher NO_x emissions for newer diesel vehicles. The levels for PM is anyway well above the WHO guideline values and they emphasise the need for more measures.

The levels in Utrecht and Haag are lower for NO_2 and below the limit value. For PM_{10} the levels are close to the WHO guideline values. For Utrecht, decreasing trends are found for all measurements locations (including diffusion tubes measurements) for the period 2011-2016 (Boons 2017).

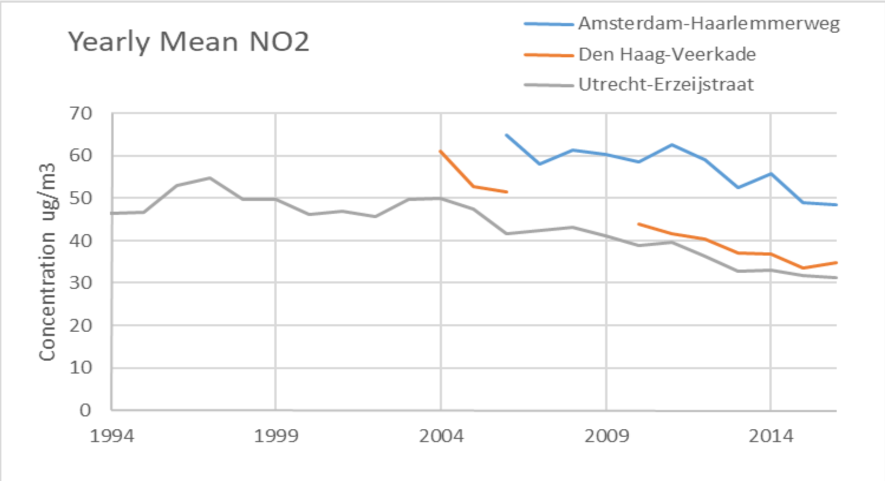

Figure 2.30: Annual mean concentration of NO_2 at three traffic stations in the Netherlands. Source: EEA

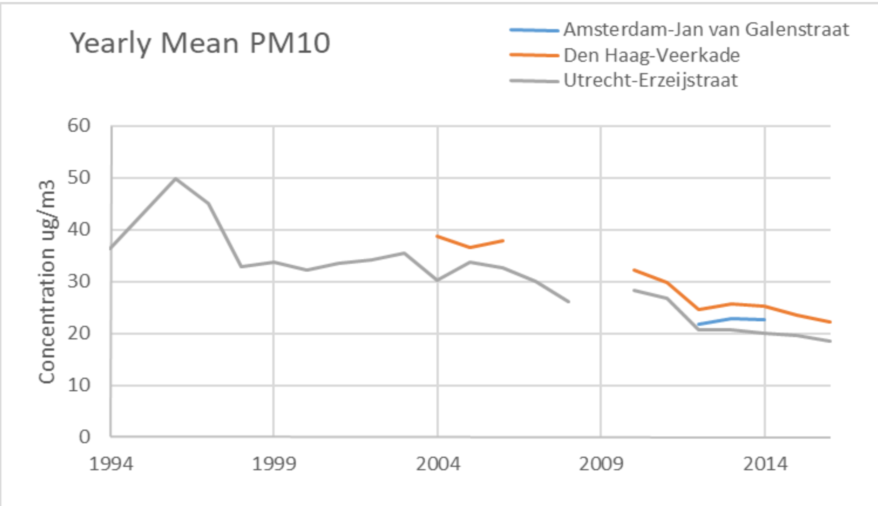

Figure 2.31: Annual mean concentration of PM_{10} at three traffic stations in the Netherlands. Source: EEA

2.6.4 Effect studies

Significant effect of the LEZ in Amsterdam was found for all compounds by Panteliadis et al. (2014). They used measurement data from two years before and to years after the introduction of the LEZ (2007-2010), and corrected for differences in meteorology and background concentrations. They found a 36 per cent reduction in the traffic contribution to PM_{10}. But, as the traffic contribution is only one of many sources, the total reduction for PM due to the zone is about 5.8 per cent. Similar effect is found for NO_2 and NO_x with 4.9 per cent and 6.4 per cent respectively.

Boogaard et al. (2012) studied effects for five cities in the Netherlands, but found no significant reduction for traffic related compounds like soot, NO_x and NO_2. They argue that the lack of an effect of the LEZ could have several plausible causes like the economic crisis in 2008, or that the zone only included heavy vehicles and that at the same time the diesel fraction increased for passenger cars.

The actual traffic volumes passing the measurement sites are lacking in both of these studies. Panteliadis et al. (2014) discuss the uncertainty related to changes in traffic volumes, and that their reported effect of the LEZ could have been biased by this. They also indicate a lack of monitoring stations outside the LEZ, that would allow for getting a better understanding of the role of background concentrations. It should also be noted that the street used in Panteliadis et al. (2014) is also not the same as in Boogaard et al. (2012) for Amsterdam.

For changes in vehicle fleets, a study from 2009 referred to in Ademe (2018) report on clear differences in fleet composition when comparing cites with and without a LEZ. Cities with LEZ have fewer old vehicles and more of the newest models.

TNO have studied effects of possibly including light commercial vehicles, taxis and coaches in the LEZ in Amsterdam (Verbeek 2015). TNO looked at the effect of banning commercial vehicles older than 2000 year models, only allowing coaches with at least Euro IV and taxis with at least Euro 5. With the proposed restrictions it was found that almost all vehicles will anyway be compliant in the planned year of implementation which was 2017, and hence the non-compliant vehicles contribute to only a small fraction of the total km driven. The extra effect of these possible new zone restrictions would be negligible.

2.7 Environmental road pricing in Oslo, Norway

2.7.1 Requirements and other measures

In October 2015, Norway was found guilty by the EFTA court for failing to comply with the concentration limits for NO_2, PM_{10} and SO_2, and for not having air quality plans that were adequate at all levels (EFTA Court 2015). Oslo, was one of the cities in Norway not in compliance with the regulations. As a result of this, a new revision of the action plan was performed and a set of additional measures were proposed. Several analysis of individual measures was initiated by the Norwegian Public Road Administration and municipalities in Norway, and several measures were considered for implementation. LEZ was one of these.

The legal situation for the possibilities to include a LEZ was at the time unclear, but in December 2016 a central act was established (Norwegian Ministry of Transport and Communication 2016). The act made it possible for municipalities to apply for a LEZ to their regional road administration. In June 2017, another change in the road legislation enabled the introduction of congestion charging and toll road differentiation according to emission classes (§ 27, Lov om vegar).

The local government in Oslo decided to add an environmental dimension to the existing toll road ring, where the toll road rates had been set after the Oslopakke 3 negotiations with the neighbouring county of Akershus. As the system of toll road collection was already well established, the added environmental dimension to the existing prices was regarded as a measure that was easier to implement.

In October 2017 the new pricing-regime was implemented, see Table 2.10. At the moment, zero-emission vehicles can pass the toll ring for free, while the prices are highest for diesel vehicles. From 2019 it is expected that zero-emission vehicles will also have to pay for passing, but the proposed fee will be significantly lower than the fee for petrol vehicles.

Table 2.10: Overview of requirements and enforcement method of environmental road pricing in Oslo. In NOK

Year of installation	Vehicle	Prices January 2018 (outside of rush hours)	Enforcement
2017	HDV*	Petrol/Hybrid: 132 (102), Diesel: 193 (163), Electric/hydrogen: 0	Electronic transponder and ANPR
	LDV**	Petrol/Hybrid: 54 (44), Diesel: 59 (49), Electric/hydrogen: 0	Electronic transponder and ANPR

Prices during rush hours and outside of rush-hours (in parenthesis). Vehicles with AutoPASS agreement get 10 per cent discount. 100 NOK≈10 €.

*Vehicles with total weight 3 501 kg and higher (excluding vehicle category M1 with valid agreement).

**Vehicle 3 500 kg and lighter (and M1 vehicles with special agreement).

Oslo planned to implement a LEZ (for heavy duty vehicle not complying with Euro VI standards) the winter of 2017/2018 (Oslo Kommune 2017a) but it was postponed (NRK Østlandssendingen 2018a). In September 2018 it was decided to further postpone the LEZ implementation (NRK Østlandssendingen 2018b). The plan was for the LEZ to cover the hole county of Oslo, and not just within the borders of the existing toll ring. The LEZ was seen as a measure for mainly limiting NO_x emissions from heavy duty diesel vehicles of

Euro V standard and older. Emergency vehicles and vehicles transporting disabled persons were to be exempted (Oslo Kommune 2017a). The plan for the LEZ was not to ban diesel vehicles from entering, but the fees for entering the zone for diesel vehicles were set high, as seen in Table 2.11.

Table 2.11: Fees for entering the proposed LEZ for HDVs in Oslo. In NOK. Source: Oslo Kommune 2018

Vehicle type	1-day	30 days	1 year
3.5-12 ton Pre Euro-Euro V	300	4 000	25 000
>12 ton Pre Euro- Euro V	600	8 000	50 000

100 NOK≈10 €

One of the main measure for particle emissions, towards individual cars, is a fee for users of studded tires. During the season when studded tires are authorized, drivers of vehicles with studded tires have to pay a fee to use their vehicle within the municipality (in Oslo, and several other Norwegian cities during the winter season). Another measure used for reducing PM is reduced speed limits on some of the major roads in Oslo to limit the production and resuspensions of particles. Intensive road cleaning, flushing and dust-binding with Magnesium chloride solution are also part of the general winter maintenance program that contribute to PM concentration reduction, and these measures are performed on a regular basis.

According to the action plan reported in 2017 (Oslo Kommune 2017b), the emission reductions needed (to be sure not to violate with the Air quality directive by 2020), can only be reached with fairly large traffic volume reductions compared to the 2015 level. In the analysis, no specific measure was given for achieving this traffic reduction, but a 20 per cent reduction target was set politically. The previously mentioned environmental charging scheme in the toll road gates gave some traffic reduction. The first three months after the introduction, the traffic was reduced by five per cent compared to the same months the year before (Statens vegvesen 2018).

Recently the local government in Oslo have also reduced the numbers of on-street parking places, and (in June 2018) made the city centre less accessible for motorized vehicles (one-way street regulations, some streets banned for private vehicles). These measures were done mainly to make the town centre more attractive for pedestrian and cyclists.

The city of Bergen also implemented environmental road prising in their congestion charging zone the 1st of June 2018. The prices are somewhat lower than in Oslo, and AutoPASS customers get a 20 per cent discount (10 per cent discount in Oslo).

2.7.2 Enforcement

The environmental road pricing is enforced by using the existing camera surveillance system. At the moment there are about 20 toll-stations with cameras in Oslo, but the plan is to install 53 new toll-stations in 2019 (NRK Østlandet 2017), se also Figure 2.32. The new toll-stations are partly added to increase the fraction of trips crossing a toll station. Today almost 50 per cent of the traffic locally in Oslo can drive without paying the toll. With the new cameras in place, this will be reduced to about 25 per cent.

The tolling-stations are operated by the company Fjellinjen AS, which is owned 60 per cent by the municipality of Oslo and 40 per cent by the neighbouring county of Akershus. To pay the fee, customers can sign an AutoPASS agreement. The AutoPASS customers receive a transponder, to be fastened on the front windshield. These transponders send signals to the receivers when the vehicle pass a toll-booth (the transponders know the type of vehicle it is issued to), so that automatic billing can be used for the tolls and fees.

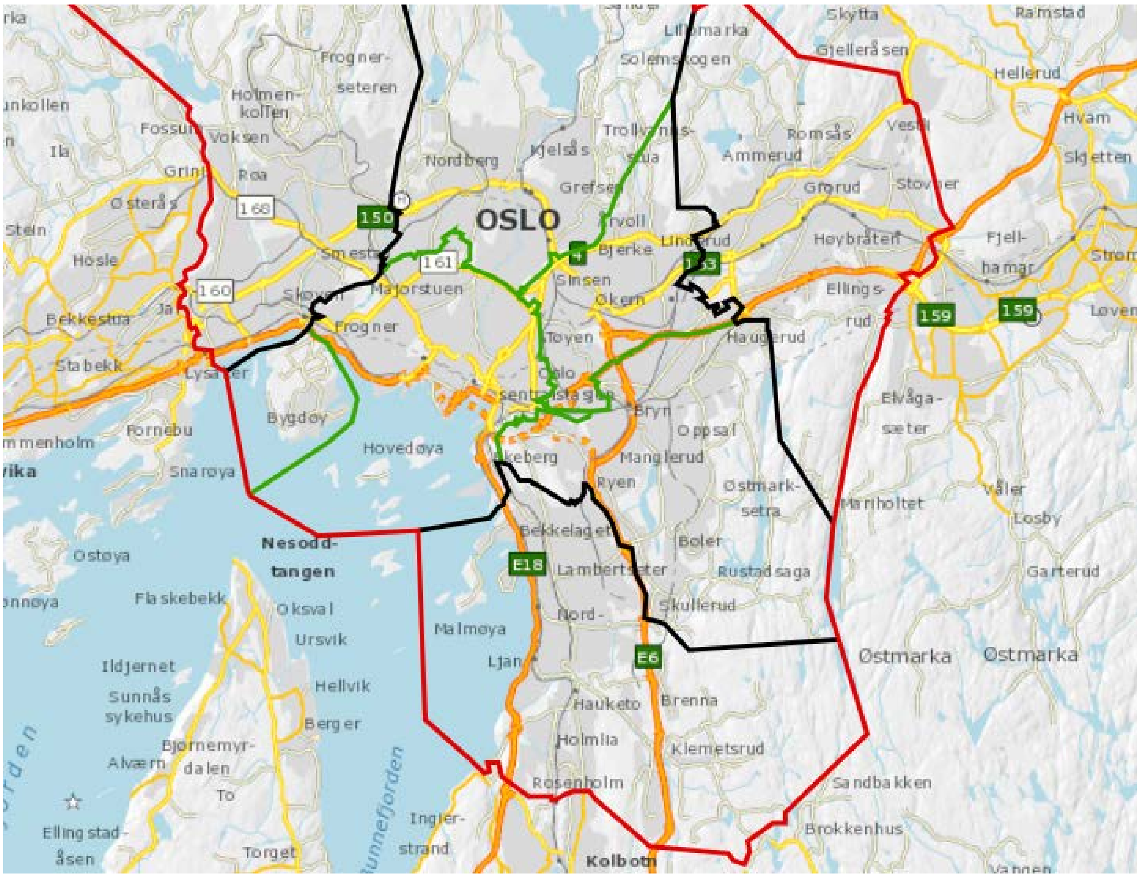

Figure 2.32: Existing and new toll-lines in Oslo (Black lines – placing of existing toll-stations, outer red lines – new city border toll-stations, green lines- new inner city toll-stations). Source: Norwegian Public Roads Administration

AutoPASS customers in Oslo get different types of advantages that other vehicles entering the zone do not receive, including:

- 10 per cent discount on all entering's
- Free passing within an hour of first entering
- Pay for maximum 60 entering's each months, the rest is free
- The AutoPASS transponder is also valid in several other toll-stations in Norway and Scandinavia.

It is voluntary to have an AutoPASS agreement. Vehicles without the AutoPASS transponders will be charged after the passing (by using the ANPR system). The registered owner of the vehicles with the specific registration number will receive an invoice one-three months after having entered the zone (the fees will be accumulating up to about 500 NOK). Invoices will also be sent to owners of foreign registered vehicles[3]. The Autopass

[3] The company Euro Parking Collection plc (EPC) is employed to identify and send invoices to owners of foreign registered vehicles.

customers will be charged once a month[4]. The AutoPASS customers usually have an agreement of automatically payment. If the invoice is not paid in time, the receiver will get a reminder (with an added charge of 70 NOK). If the invoice is still not payed, a debt-collecting agency will take over the case.

Approximately 90 per cent of the vehicles driving through the Oslo toll-stations in 2017 had an AutoPASS agreement, the rest were full-paying customers (Fjellinjen 2018).

2.7.3 Air Quality – regulations and levels

Norway's air quality regulation is stricter than the EU directive. Norway adapted in 2016 a stricter limit value for PM, lowering the annual mean from 40 $\mu g/m^3$ to 25 $\mu g/m^3$ and allowing only 30 days above 50 $\mu g/m^3$ for PM_{10}. The annual mean limit for $PM_{2.5}$ was lowered to 15 $\mu g/m^3$, but no change was done on the limit value of NO_2.

If one compare cities in Norway, see Figure 2.33, Oslo has considerably higher NO_2 levels than the other cities. Several cities have had a clear decrease of NO_2 concentrations at measurement stations to levels below the limit value. The concentration levels in Oslo are plotted for three traffic stations in Figure 2.34 and Figure 2.35. NO_2 levels seem to have decreased the last years also here, but the annual mean concentrations are anyway too high at some locations. The number of hours above 200 $\mu g/m^3$ NO_2 was too high in 2016 and 2015, but below the limit value in 2017.

For PM_{10} the trend for the annual mean is decreasing at Alnabru and Kirkeveien, while Hjortnes have more or less the same level in 2017 as in 2011. One of the large sources to PM_{10} is road dust, and the variation of the trend at these locations could be due to several factors like differences in speed and dust binding procedures. For the daily mean the levels have been below the limit value since 2013.

Modelling studies have found that for a reference years like 2014, large parts of the municipality had concentration levels above the limit value, see Figure 2.36. The city centre of Oslo, areas along the larger roads, and Groruddalen, which is a valley stretching out north-east from the city centre, had concentrations above the limit value. Therefore, the municipality have focused on measures targeting reductions of NO_x emissions.

[4] Once a month if the accumulated fees is 500 NOK or higher. A maximum of five months after the actual entering of the zone, if the accumulated fees do not reach 500 NOK in the five month time period.

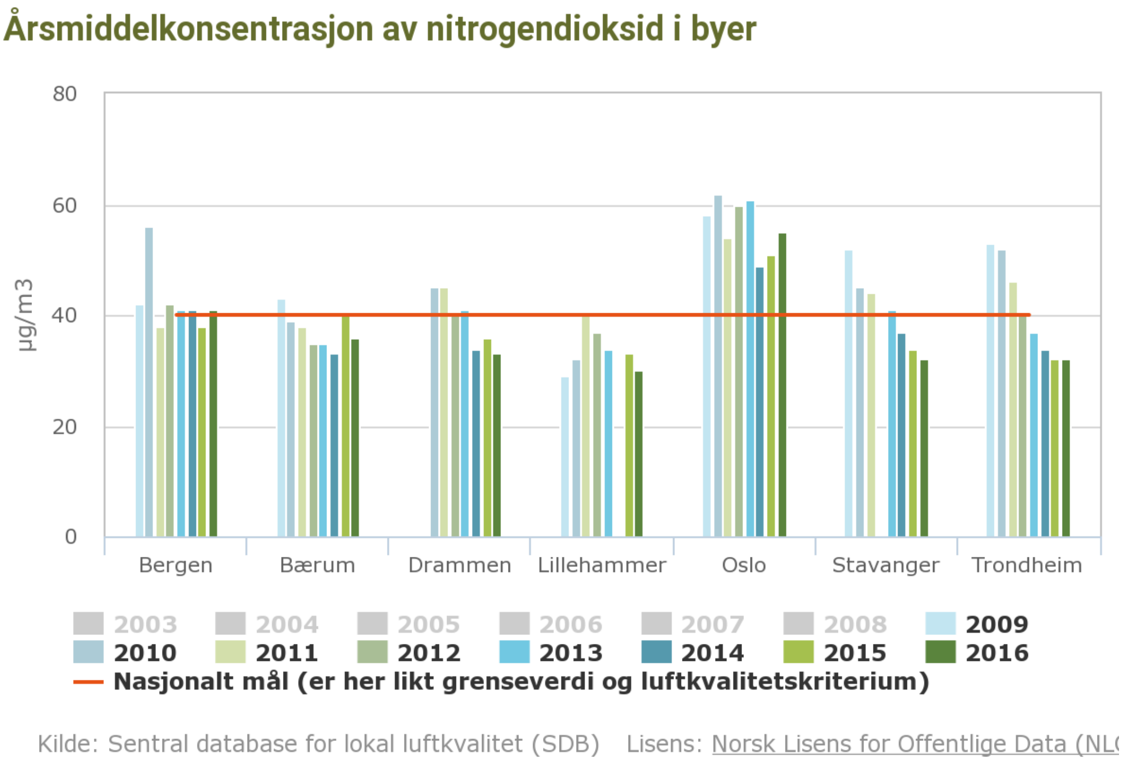

Figure 2.33: Comparison of maximum annual mean of NO_2 registered for some cities in Norway (red line – indicating national goal). Source: Miljøstatus.no

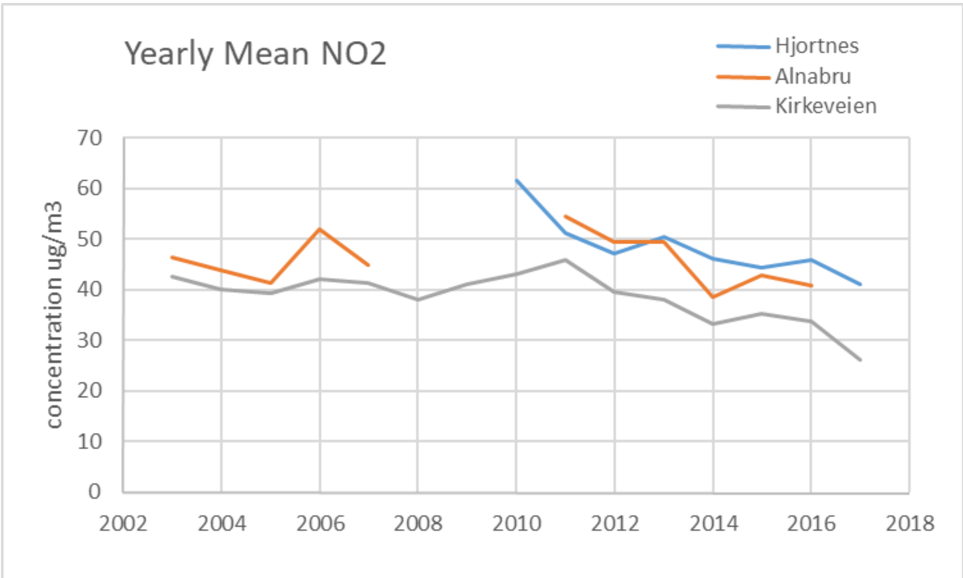

Figure 2.34: Annual mean concentration of NO_2 at three stations in Oslo. Source: EEA

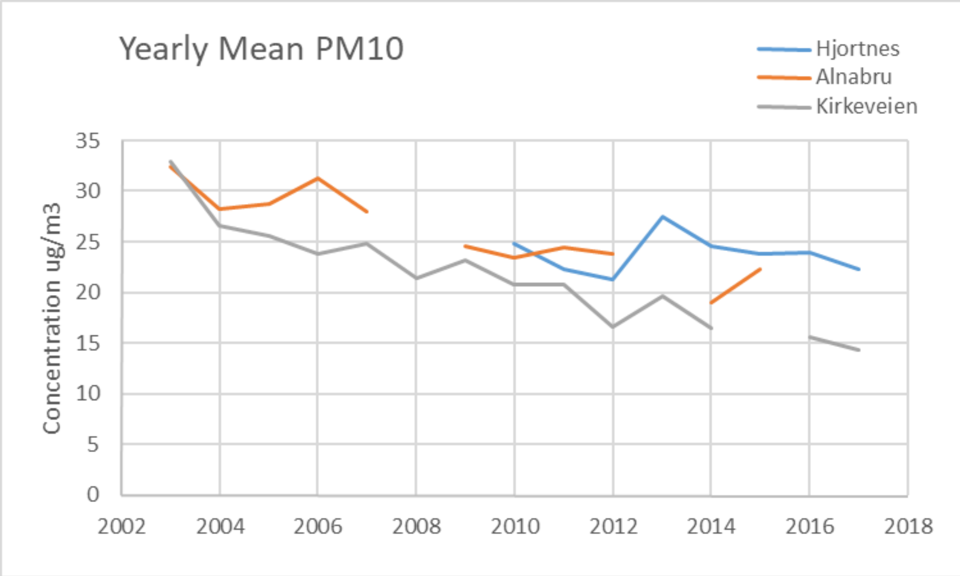

Figure 2.35: Annual mean concentration of PM_{10} at three traffic stations in Oslo. Source: EEA

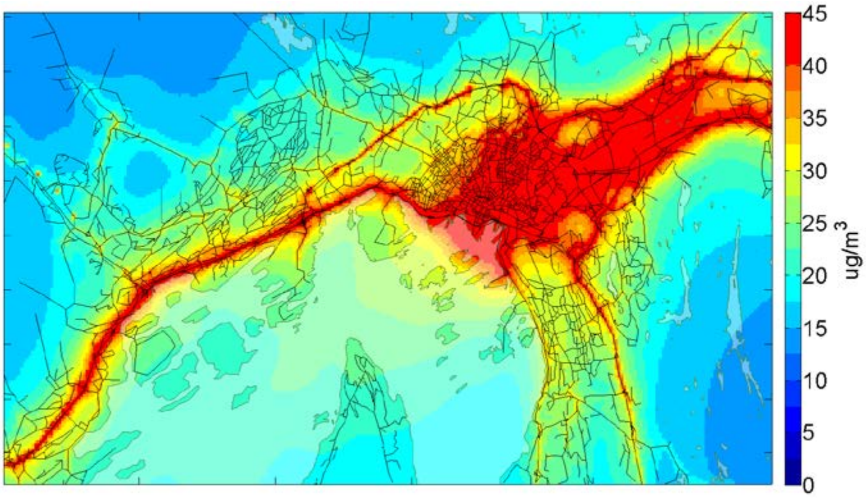

Figure 2.36: NO_2 concentration map of Oslo and some parts of the surrounding municipalities for the reference year 2013. Source: Høiskar et al. 2014

2.7.4 Effect studies

As the noncompliance in Oslo continued, several action plans were elaborated. Effects of introduction of different possible new measures were estimated with modelling studies both in 2010, 2014 and 2016. As mentioned before, one of the action scenarios included, amongst other things, a goal of 20 per cent reduction of traffic volumes (Høiskar et al. 2014). This reduction was included in the emission modelling without specifying how to obtain it, but one concluded that even with such traffic reductions and the other planned actions, there would still be areas in Oslo above the limit value. Therefore, revision of the action plan was performed again to ensure a plan which would lead to compliance (Høiskar et a. 2017). In the meantime work was also done for evaluation of possible LEZs, congestion charging with an environmental differentiation and the introduction of new toll passages.

The effect of a new toll system with congestion charging including the environmental differentiation and new toll passage locations, has been estimated using models in Cowi

(2017). The year for the estimation was 2020. It was found that it would lead to good reductions of pollution especially in the areas with the highest concentration levels. The new toll at the municipality borders explained the large effect along the access road E6 to the east and south. An important factor for the observed effect is the increased share of electric vehicles for passenger cars and Euro VI for heavy duty vehicles, that the differentiation would lead to according to the estimations. Electric vehicles have several incentives to increase their share of the Norwegian fleet. The share of electric vehicles passing the toll points is higher than the share in the total fleet. Hence, the electric vehicle share in the ADT would further increase with the new toll system.

The proposed system was estimated to also give a total traffic volume reduction of about 11 per cent in 2020 compared to the business as usual scenario (BAU) in 2020 without the new toll system. For CO_2 it was estimated a nine per cent reduction compared to BAU, and a 16 per cent reduction compared to the reference situation (2014). The total emission reduction of this measure was estimated to be 12 per cent for NO_x and four per cent for PM_{10} compared to the BAU 2020.

The effect of three possible LEZ concepts with restrictions of general use inside the defined zones were estimated by Høiskar et al. (2016). The LEZs were at the time evaluated as an extra measure on top of a possible congestion charging system. The conclusion was that introducing a LEZ for heavy duty vehicles in the whole municipality would reduce emission by a further nine per cent in 2018, and reduce the number of people exposed to levels above the limit value by 50 per cent. The other concepts including LDVs, gave larger effects and up to a 15 per cent reduction of concentrations in some of the areas with the largest concentration levels. The concentrations of NO_2 still found to be above the limit values, as can be seen in Figure 2.37.

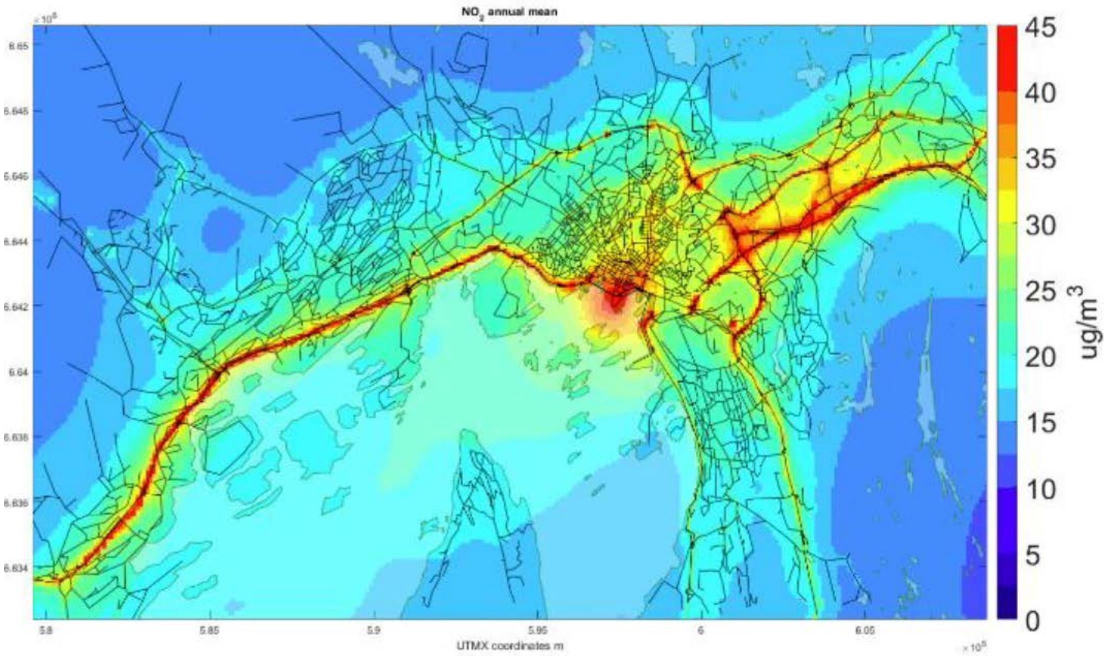

Figure 2.37: Concentration map of NO_2 for the concept of a LEZ in Oslo. Source: Høiskar et al. 2016

3 Comparisons of European cities

3.1 Air Quality

Air quality data are reported from all over Europe. Figure 3.2 to Figure 3.4. shows the pollution levels across countries for three parameters at reported measurement stations. Figure 3.2 shows stations were the daily limit value for PM_{10} of maximum 35 days above 50 $\mu g/m^3$ is exceeded. For the shown year, 2015, the larger cities and especially areas in the Po valley, Poland as well as south eastern Europe are seen to have the highest values. This is also the case when looking at the annual mean, but for the annual mean limit value more stations are in compliance. When looking at the status for NO_2 it is clear that compliance with the NO_2 annual mean limit value is a problem in more or less all larger cities across Europe, see Figure 3.4. Hence several measures need to be implemented in the cities with regard to NO_2, which explains the increase in the number of LEZs in European cities.

The overall trend is decreasing levels for most stations both for PM and NO_2 (EEA 2016). As seen in Figure 3.2 and Figure 3.3, as well as in the air quality data shown in the previous sections for individual cities, the PM_{10} limit values are not exceeded in most cities in northern, central and western Europe. The annual mean limit value is often met, while the daily limit value seem to be more challenging and more often exceeded (see Figure 3.1 and Figure 3.3). Even if the limit values are not exceeded the concentration levels still cause premature deaths, as particle pollution has health consequences at much lower levels. This has led to the introduction of target values in several cities. Norway has sharpened the limit value for PM_{10} in their national air pollution legislation to 25 $\mu g/m^3$ for the annual mean, and only allowing 30 days above 50 $\mu g/m^3$. Sweden has their National Environmental Objectives which are also targeting much lower pollution levels. The WHO guideline values, based on low negative health impact of the particle pollution, is set to an annual mean of 20 $\mu g/m^3$ for PM_{10} and 10 $\mu g/m^3$ for $PM_{2.5}$. As the WHO guideline is often used to set objective values by the national authorities, many cities in Europe continue the work for reduction of PM pollution even if the legally binding limit values have been met. The $PM_{2.5}$ national exposure reduction targets also lead to more measures being considered.

The air quality trends in Stockholm and Gothenburg are somewhat similar to what is seen at several other locations in Europe. The levels of NO_2 are decreasing at many locations, but are still often above the limit value that should have been reached by 2010. Even if the Swedish levels are not the highest in a European setting, when looking at the maximum values (see Figure 3.1), they are above the annual mean limit in 2016 at both Hornsgatan in Stockholm and Haga in Gothenburg. Actually, the observed annual mean at Haga in 2016 was the highest concentration level since 2007 at this site. Also, the environmental quality objectives are not met and further emission reductions are needed to reach the levels which are targeted.

PM levels have also decreased in Sweden, and the annual mean have been below the limit value for several years. The daily means are more often a challenge, but levels in Stockholm and Gothenburg have also been lower than the limit value the last years. As for NO_2 the environmental objectives are not met for PM_{10}.

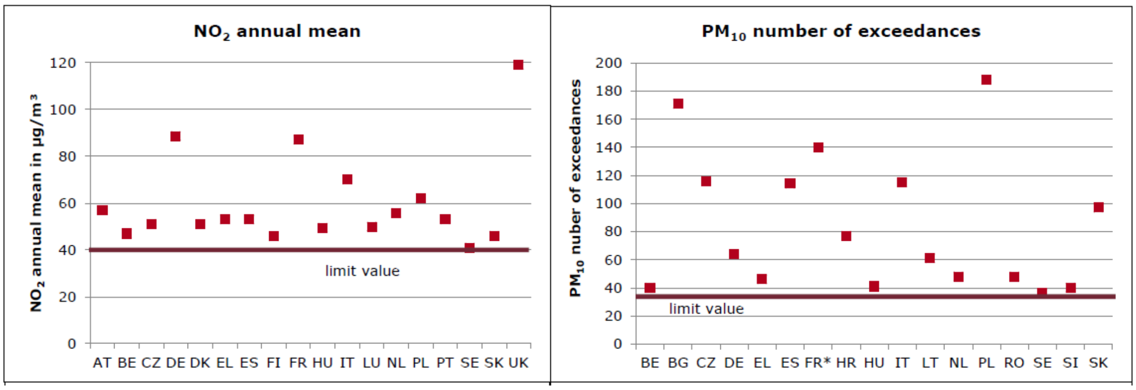

Figure 3.1: Maximum NO_2 and PM_{10} levels in EU Member States were exceedances occurred in 2014. Source: ENVI 2016

For Swedish cities the production of road dust resulting from the use of studded tyres in the winter significantly contributes to PM_{10} concentrations (Johansson et al. 2011). Even if non-exhaust also have an increasingly share of the traffic contribution to particle pollution across Europe, the Nordic use of studded tyres make the road dust issue a special Nordic challenge. Among the Nordic cities there are also large variations both in winter conditions and winter maintenance strategies as well as the share of studded tyres. Measures shown to be effective for tackling road dust are: studded tyre restrictions, dust binding, speed reductions and general traffic volume reductions (Kupiainen et al. 2016).

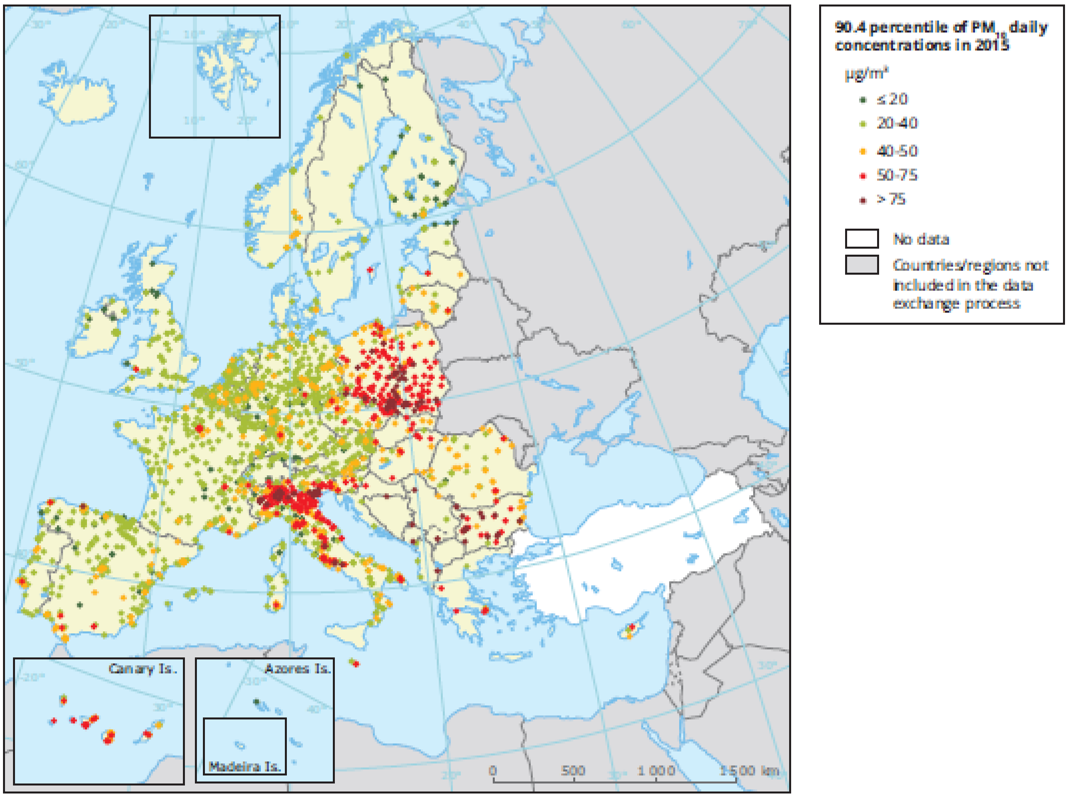

Figure 3.2: Map of the 90.4 percentile of the PM_{10} concentration, meaning the 36^{th} highest daily mean in 2015 at measurement sites. Red dots are indicating levels above the limit value

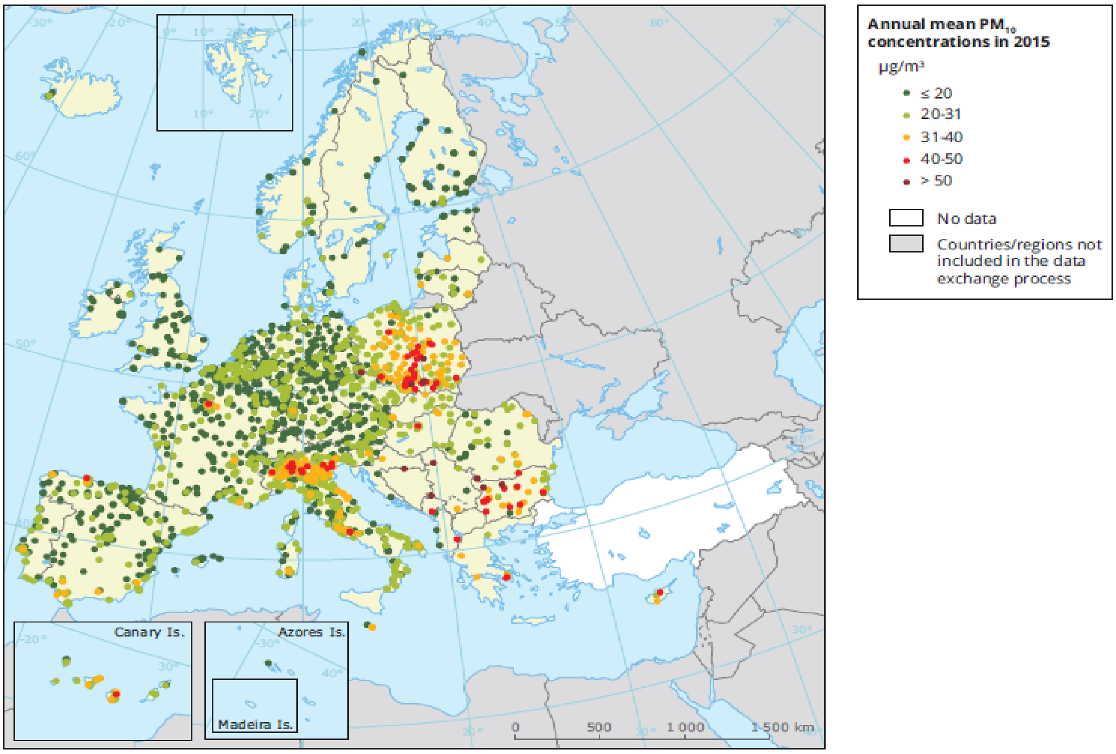

Figure 3.3: Map of annual mean concentration of PM_{10} in 2015 at measurements sites. Red dots are indicating levels above the limit value

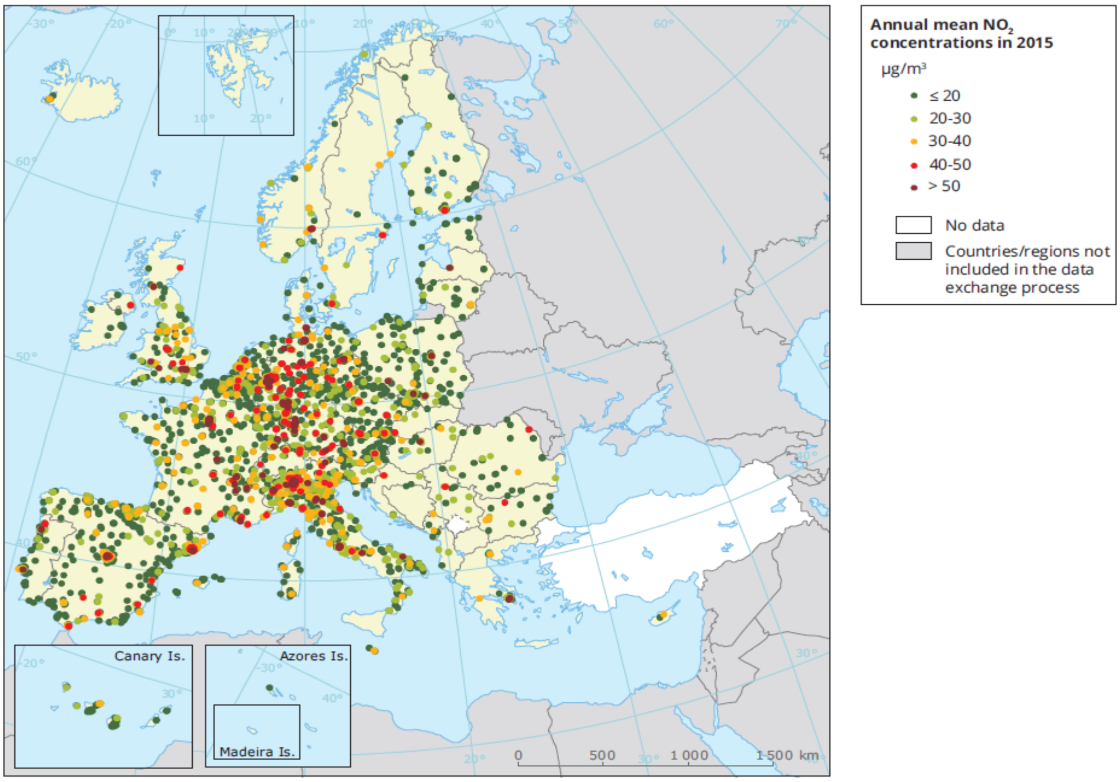

Figure 3.4: Map of observed annual mean concentrations of NO_2 in 2015 at measurement sites. Red dots mean values above the limit value

3.2 Diesel share and vehicle amounts

An important factor for the NO_x emissions is the diesel vehicle share in the fleet. In Figure 3.5 we compare the diesel fraction of passenger cars of new registered vehicles pr. year. Both Sweden and Norway had a sharp increase of the share of diesel vehicles compared to the other countries shown up to 2011-2012. All countries have had a decrease in the diesel share the last years. The Norwegian decrease has mainly been the result of a shift to electric and plug-in hybrid vehicles, and partly to petrol vehicles. Belgium and France have had a large share over a longer period, but are now at about the same level as Sweden. The Netherlands have had a fairly low diesel share between 20 to 30 per cent over the whole period (1990-2016), even if they also had an increase compared to 1990. This means that the fleet today in the Netherlands is quite different compared to for example Sweden, but also to its neighbouring country Belgium.

As NO_x emission from diesel vehicles is much higher than petrol vehicles of the same year model, this differences in diesel fraction and year of LEZ implementations is important to predict possible effects (or lack of such) on NO_2 concentrations.

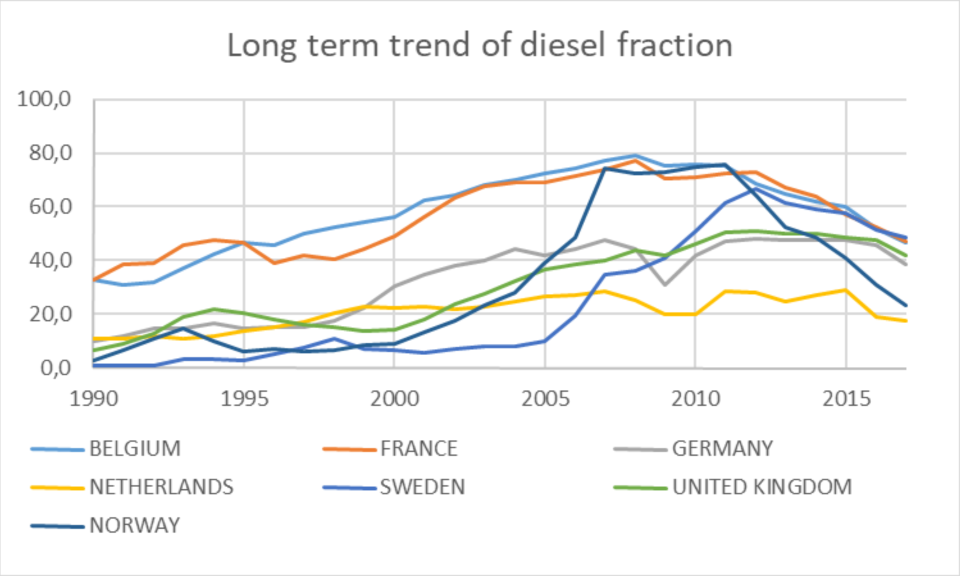

Figure 3.5: Long term trend of diesel fraction in new registered passenger cars. In per cent. Source: ACEA

For Europe as a whole the number of vehicles have also massively increased compared to the 1990s, and continue to grow (www.acea.be and www.statista.com). Car ownership is however in general lower in cites compared to the national average, whereas smaller cities usually have more vehicles pr. capita than the largest cities. Also the traffic volumes are increasing. The passenger km by car per capita increased from 1995 to 2012 in the EU with only two countries (UK and Italy) showing a decrease (UN-Habitat 2017).

4 Discussion

4.1 Why are LEZs chosen as a measure?

LEZs are mainly used as a measure to improve the air quality in cities. The cities that have implemented a LEZ usually do so because they are struggling to comply with EUs limit values for particulates (PM) and/or nitrogen dioxides (NO_2). When LEZs were first implemented the main objective was often to reduce the particle emission from older vehicles. The focus have since then shifted towards including NO_2 as more cites are not in compliance with the EU directives for this compound. This is partly due to the fact that the NO_2 emission from diesel vehicle have not decreased as much as it should, when taking into account the increasingly stringent Euro exhaust emission standard levels of the vehicles. Tests have shown that the emission from especially diesel vehicles are significantly higher in real-traffic than the limit values in the EU regulations for exhaust emissions.

Most of the European cities that have implemented a LEZ have a history of exceeding the PM and/or the NO_2 limit values at air quality measurement sites classified as traffic sites. According to a study of all the existing European LEZs in 2011, most of the cities exceeded EUs limit values for NO_2 or PM (Ecorys and MWH 2014). The cities without exceedances in 2011 might have had exceedances at an earlier time (when the LEZ were implemented), or were part of a regional LEZ connected to other cities with exceedances (Ecorys and MWH 2014).

A LEZ is often one of several measures that cities have taken on to attempt to comply with the EU air quality directives, and national environmental targets. Cities that are not in compliance, have to develop an action plan on how the city will comply with the regulations. In addition to LEZ, other measures often used to improve air quality (targeting road traffic emissions) in cities are: improved public transport, park & ride facilities, promote walking and cycling, incentives to speed up the use of "zero"-emission vehicles, speed reductions and restrictions on the use of studded tyres.

Even if LEZs are mainly used in an attempt to reduce the level of PM/NO_2, some cities also see this as a measure that can reduce the noise level as newer vehicles in general emit less noise (engine noise, aerodynamic). There are now more than 260 different LEZs in Europe, and several cities are planning to either implement a LEZ or sharpen the criteria of which types of vehicles should be affected by the regulations.

4.2 LEZ regulations

The vehicle regulations in the LEZs are based on vehicles age (year of first registration) and/or Euro class. How strict the regulation is, vary from city to city. The early LEZs mainly focused on HGVs, but also other vehicle types can be included. Passenger cars and mopeds/MC have only recently been included in some cities, but several cities are considering to include more vehicle types. Many cities have sharpened the Euro class requirements for entering the LEZ several times since the zone first was implemented.

Basing the requirement only on Euro class/age have some disadvantages. This is especially true for diesel vehicles, and some cities are implementing stricter regulations or bans especially focused on diesel vehicles.

The ability of a city to implement a vehicle access regulation is often regulated by national/regional law. The city/municipality can decide if they want to implement a LEZ or not, the LEZ boundaries, and how strict the regulations have to be to comply with local needs.

In countries having or planning to implement LEZs in more than one city, developing a national framework can make it easier for the cities as well as for the vehicle users. A national framework can for example include regulations for (European Commission 2017):

- Developing a system for vehicle requirements. For example developing the sticker-system as used in Germany and France.
- Common list of exemptions, with possibility for some local adaptations.
- Ban vs. possibility for paying a charge.
- If an ANPR-system is to be used. Prepare necessary national databases.
- If retrofitting is allowed, have national standard of how to classify different retrofitting.
- National road signs.
- Day charges to enter the zones and fines for non-compliance.

Even with a national framework it is important that there is a possibility to adapt the scheme to local conditions. Cities with a high level of non-compliance with EUs limit values for PM and NO_2, may need stricter regulations than other cities.

In Germany and France the national/regional framework include the type of enforcement to use (manual), while in the Netherlands the enforcement method can be decided by the city/municipality.

In all the LEZs, there are possibilities for exemptions for some type of vehicles. The most common exemptions are: emergency response vehicles, military vehicles, veteran vehicles, and vehicles used for transport of disabled persons or used by disabled persons. Some cities have also included exemption for low income families/business or for special vehicles used for markets and fairs. It is important that the proportion of vehicles exempted from the regulations is limited, to avoid diluting the possible effect of the LEZ. In Berlin, the rule-of-thumb was a maximum of 10 per cent exemptions (Lutz 2014). A high number of exemptions will also make control more difficult.

Before implementing a LEZ it is important to consider the options available to the persons/companies affected by the new regulations. Not everyone can afford to buy a new vehicle. Scrapping- schemes for old vehicle are one possible solution, as is the possibility for day-passes. Improving the public transport are another possibility, that can be relevant for some. People who work shift, usually do not have the same possibility to switch to public transport. Here a solution can be to do as in France, were the regulations is not enforced during the night time or in weekends. Car-sharing schemes with new or zero-emission vehicle can also be a help for some.

Most of the cities enforce the regulations also on foreign vehicles. Information to foreign drivers on how to comply with the regulations is important. In most of the LEZ cities foreigners have to register beforehand, and either get a sticker or will be added to the national databases (ANPR). In some cities it is possible to buy day-passes when visitors have arrived to the city. Availability of day-passes can make it easier for non-locals to comply with the regulations. In the case a foreign vehicle are in non-compliance with the regulations (and/or do not pay the charge), cross-border fining can be difficult. To do this, access to other countries vehicle database is necessary (both information on owner and emission class is necessary). Some countries have agreements on sharing vehicle information, but not all. It is possible to hire companies who have specialised in tracking foreign vehicles, and issue fines.

In general, the more exemptions, the less effective is the LEZ. However, local flexibility when adapting the regulations is considered important.

4.3 Automatic versus manual enforcement

In the cities we have looked at, camera surveillance with ANPR, transponders or manual control, is used to enforce the regulations. In several cities a combination of different surveillance techniques are used, see Table 4.1.

Camera surveillance with ANPR has the advantage that more or less all vehicles can be controlled. But this will depend on the number of cameras and where these are situated (and the size of the city). Cameras at the borders of the LEZ are able to control the vehicles entering or leaving the city, but in some cities much of the city traffic is caused by vehicles that do not leave the city border. London has cameras at the border of the zone, and in addition use some mobile cameras which is randomly moved between streets with high traffic volumes within the zone. In several cities in for example the Netherlands and Belgium, camera surveillance is used in combination with some manual control. The advantages with camera control increases with increased number of vehicle types included by the regulation.

Manual control were easier when HGV was the only vehicle type included by the LEZ regulations. When other types of vehicles also are included by the regulation, the number of vehicles to control can become so large that only sampling testing can be performed. In comparison, the surveillance system in the Antwerp LEZ on average check 725 000 vehicle each month (Lenders and De Gelder 2017).

Manual control is performed by the police and/or traffic wardens. In Germany, both police and traffic wardens enforce the regulations. A disadvantage with manual control is that the number of vehicles controlled is much less, which can lead to a higher non-compliance in the zones. In many countries the police is less likely to prioritizing these kind of controls compared to other violations. An option here is to make it possible for other regulatory agencies to perform the necessary controls. In Paris, as in Germany, both the police and traffic wardens are used for surveillance. Most of the control activity in these LEZs are performed by the traffic wardens. The police can stop both moving and parked vehicles, while other regulatory agents can only control parked vehicles.

Having a sticker system, as in Germany and France, will ease the control activity, and can therefore lead to a higher number of controls. The controller will have to check if the vehicle have a sticker or not, and if the sticker is the right type for the actual vehicle. The sticker should include the vehicles registration number, and some other markings to reduce the chance of forgery. When the sticker includes the registration number it is possible to control that the vehicle has the right category of sticker, and that the vehicles registration number belong to the vehicle checked.

Table 4.1: Enforcement of LEZ regulations, and environmental road pricing

Country/city	Surveillance system	Type of restriction	Fines
Germany	Manual Police & traffic wardens	Ban	80€ + 25€ admin.
France	Manual Police & traffic wardens	Ban*	64€ LDV (180€ if not paid by 45days) 135€ HDV (375€ if not paid by 45days
London Lez	ANPR Fixed and mobile cameras	Daily charge 100£ van/minibus 200£ HDV	Van/minibus: 250£, 500£ (14-28 days), 750£ (if later) HDV: 500£, 1000£ (14-28 days), 1500£ (if later)
London T-charge	ANPR	Daily charge 10£	80£, 160£ (14-28 days), 240£ (if later)
Netherland	ANPR Traffic wardens	Ban	65€ moped, 95€ cars/vans, 230 HDV
Belgium	ANPR Police	8 day-pass each year 35 €	Antwerp: 150€, 250€ (2-time), 350€ (3-time) Brussels: 350€
Sweden	Police	Ban	≈ 107€
Oslo**	Transponders ANPR	Daily charge 4.5€ LDV petrol 5€ LDV diesel 16.5€ HDV	If not paid in time, an additional 7€ charge

*In France the ban is not 24/7. The regulations in the existing LEZs do not include nights, weekends and public holidays. Some cities can have an exception to this rule for HGV.
**Not LEZ, but environmental based road pricing.

In a feasibility study performed before the implementation of the London LEZ, a manual control scheme using 20 units (police and/or traffic wardens) was expected to have a detection rate of about 5-6 per cent, while a camera based scheme with 125 fixed cameras and 10 mobile cameras, was expected to have a detection rate of about 70 per cent (Deloitte 2005). With an optimal number and placing of cameras the detection rate can be close to 100 per cent. But for some vehicles the images of the number plates will be impossible to interpret, but this source of error is decreasing as the technology improves.

According to Deloitte (2005) a manually enforced LEZ is quickest to implement, but a camera based scheme will achieve a higher detection rate and therefore deliver more air quality benefit. The most cost efficient automated enforcement regime is to use existing toll-rings/congestion charge areas, and combine this with a mix of fixed ANPR cameras and mobile units (Deloitte 2005).

Camera surveillance with ANPR allows for stricter enforcement, but rely on an extensive use of personal data, while manual enforcement is less prone to privacy issues related to privacy and data protection issues (European Commission 2017). Germany's strict privacy protection regulation, was partly a reason for choosing manual enforcement of the LEZ regulations (Lutz 2014). In Germany, the driver of the vehicle has to be present on the photo, to be able to issue a fine (European Commission 2017), while in the Netherlands and UK the photo does not have to include the driver.

Implementing camera surveillance enforcement schemes with ANPR, require the access to several types of databases. Vehicle registration databases with information of the vehicles first year of registration (combined with Euro standard), contact information for the owner, database of exemptions or retrofitted vehicles, database of registered foreign vehicles, and databases of vehicles that have paid for day-passes/period-passes, are some databases that might be needed. The vehicle registration databases usually does not include information on Euro standard, so there might be need for finding an identifier that links the vehicle type and year of registration to the implementation on the different Euro standards. All these different databases need to be able to "talk" together. Building most of these databases from scratch can be time-consuming.

Implementing a sticker system is usually easier, but it is necessary to have a system that can issue the right type of sticker to the right type of vehicle. There is also need to develop a system for foreigners to register for stickers.

Table 4.2: Some pros and cons with camera (ANPR) versus manual enforcement of LEZ regulations

	Camera surveillance (with ANPR)	Manual control
Pros	• Able to control more or less all the vehicles • Good solution especially when a high percentage of the vehicles are included	• Easier to implement • Less privacy issues • Stickers ease the control
Cons	• Can be more expensive and time-consuming to implement, especially if starting from scratch • Need to build up several databases • Privacy issues • Need cameras around and within the zone for maximal detection rate of internal traffic • Need more cross-border agreement	• Can be difficult to get the police to prioritize this • Just a percentage of the vehicles will be checked • Can have high manual costs

What the best option is for a city who want to implement a LEZ will depend on several factors, for instance: the size of the city, existing enforcement schemes, number and types of vehicles to be included, available time and budget, severity of the air quality problem, proportion of transit or internal traffic, national privacy regulations, and the size of the police force and their willingness to prioritize the enforcement of these types of regulations.

4.4 Compliance with regulations

In the LEZ studies in this report, the compliance with regulations is high, and in several cities in the region of 95-98 per cent. The rate of compliance can depend on several factors:

- How strict the regulations are
- The percentage of the vehicles within the different vehicle categories affected by the regulations
- Time since the regulation was implemented. Vehicle owners will need time to adapt to new regulations. Information to the public about new regulations should be published well in advance of any changes
- The possibility for exemptions, or to buy period access passes (and the price of the period-passes)
- The schemes detection rate
- The size of fines for non-compliance.

In several cities with a high level of compliance, only a limited share of the vehicle fleet is affected by the regulation. With stricter regulations, a higher level of non-compliance is expected, especially if there are no options for period-access-passes (or the prices for these are high).

In 2010 the compliance in the Amsterdam LEZ with camera surveillance was about 95 per cent, while cities using manual control for enforcement had an average compliance of about 80 per cent (Goudappel Coffeng and Buck Consultants International 2010). Now other LEZ cities in the Netherlands are also implementing camera surveillance. In Germany were the LEZs are enforced manually, the number of controls were very low the first years after implementation. But after the Deutsche Umwelthilfe (Environmental Action Germany) focused on controlling the enforcement level for a period, most of the LEZ cities/municipalities focused on implementing enforcement schemes. The compliance in the Berlin LEZ is high (95-98 per cent), even with manual control (European commission 2017). In Berlin most of the controls are performed by the traffic wardens, the police only performed a small portion of the actual controls.

Foreign vehicles are usually not exempted from the LEZ regulations. If the process of achieving admittance permits is too complicated or too time consuming, this can lead to high non-compliance among foreign vehicles. In cities with high numbers of foreign or non-local vehicles, it is especially important to develop good registration schemes and inform about this in the right medias. Having to collect a high number of fines from people living abroad can be expensive and time consuming.

The compliance rate will also depend on the availability of viable options for the persons not able to upgrade their vehicle in time. For low-income households and shift-workers this can be especially difficult.

4.5 Do LEZs improve air quality?

What impact a LEZ will have on air quality depends firstly on traffic's contribution to the pollution levels. Secondly, it depends on how efficient the LEZ will change the vehicle fleet composition to cleaner vehicles and possibly reduce traffic volumes. This will then further rely on several factors, for example (Stockholm stad 2017):

- How stringent the regulations are
- The size of the LEZ
- The level of enforcement of the regulations.

When a LEZ is implemented the vehicle owner has a choice to change vehicle, change travel mode, change travel destination or take the risk and or cost to violate the zone requirements. What the preferred action will be again depends on several factors. The case of modal shift will rely on for instance the public transportation availability. The adaptation will also depend on if the owner is a private user or an enterprise. Larger transport companies for instance can likely redistribute their vehicle fleet (Pasquier and Andre 2016).

A challenge is how to evaluate the possible impact of the measure. If a LEZ is to have effect over time the moment when the evaluation is undertaken will be relevant (Pasquier and Andre 2016). It is also impossible to state with certainty how the situation would have been without the zone.

A review of the effect of LEZs on air quality was published by Holman et al. (2015), shedding light especially on the challenges of evaluating LEZs. They have done a review of studies using mainly ambient air measurements to evaluate the effectiveness of LEZs in five EU countries (Denmark, Germany, the Netherlands, Italy and UK). They conclude that only the LEZs in Germany have led to significant reduction in levels, i.e. by a few per cent. Also Pasquier and Andre (2016) have reviewed the methodology of evaluating LEZs.

Measurements of ambient air are not easy to use for evaluating LEZs due to several factors. Firstly, the challenge to separate the effect of the LEZ compared with other measures (e.g. low sulphur diesel), and changes in the city which have influence on the traffic or other local emission sources. Secondly, the expected change might be smaller than the general variation due to the variation in dispersion conditions and meteorology. Data limitations and the number of stations will also restrict the evaluation and make it challenging (or impossible) to account for all possible external factors.

Dispersion modelling studies in their turn also include several uncertainties, but can, based on the given model input parameters, reveal the emission reduction potential before the introduction. Hence, the modelling studies can guide on the restrictions needed. However, several earlier model studies overestimated the effect of the LEZs. These too optimistic study results can partly be the result of using too low emission factors for vehicles (Holman et al. 2015). Real driving emissions are not the same as the Euro type approval emissions and real emissions have not been reduced as expected when the exhaust emission regulations have become stricter, see also Appendix 2.

Even if emission reductions from the targeted vehicle group can be very good, the actual effect on air quality will be limited if it is a small source for the pollutant. As modelling performed for Stockholm showed: with complete removal off all HDV emissions the expected reduction for NO_x would be 5 – 10 per cent and even smaller for NO_2 (Johansson and Burman 2001).

In many European countries the diesel vehicle share also increased for many years (see Figure 3.5). Such a shift would actually increase NO_x emissions and the difference between estimated emissions and actual emissions would be even larger. Such shifts in fuel technology in the fleet have limited or masked the efficiency of LEZs.

Measurements have indicated in several cities that the NO_2 fraction of the NO_X emission has increased, making NO_2 levels relatively higher at the street level compared with the urban background. This is also explained by changes in emissions from diesel vehicles and an increase in the diesel share. Over the last years better emission factors have been established based on real driving conditions which will lead to higher level of certainty for future emission estimates. Wrong estimates of the overall increase in vehicles and traffic volumes in Europe might also explain discrepancies between model predicted results and observations.

If one look at PM, direct vehicle emissions is only one source among many contributors to the concentrations as discussed in section 1.4. Regional concentrations give a large contribution and non-exhaust sources is also a considerable part of the PM_{10} traffic contribution. Local measures reducing exhaust particle emissions will hence have limited effect for this component. Some studies have therefore looked at the effects on Black Carbon (BC) particulate matter which has a larger contribution from local traffic. Significant effects are more often found for this component and the health benefits from these reductions are often highlighted.

As mentioned, the initial intention of a LEZ is increasing the pace of the renewal of the vehicle fleet and by that reduce emissions. Therefore, one also need to continuously sharpen the requirements to prolong the effect of a zone. Other effects from a LEZ, than increased fleet turnover, can also be sought as direct or indirect consequences, such as reduced traffic in the zone and reduced noise.

4.6 Outlook

The number of LEZs in Europe are increasing. To ease the implementation and enforcement of LEZs, and maybe also to reduce the complaints from the public, it would be ideal to increase the cooperation between existing and new LEZ cities/municipalities. A form of basic European framework might be possible, but there will always be a need for local adaptations. Improving cross-border cooperation would be important when requiring information on foreign vehicle owners and their vehicles Euro standard, but this is complicated partly due to privacy issues. Cooperation would be especially important between neighbouring countries. The EU Directive 2015/413 regulates cross-border exchange of information on road-safety-related traffic offences. If possible it would be an advantage if offences related to LEZs could be included in this Directive.

In the Scandinavian countries, transponders (AutoPASS is one producer of these) are combined with automatic number plate recognitions systems in several toll stations, this type of technology could be of use when enforcing LEZ regulations.

Many countries have set national targets to implement zero-emission vehicles, and the availability of especially electric vehicles are increasing. With the increasing share of zero-emission vehicles in the vehicle fleet, the need for LEZs to tackle NO_2 will hopefully be reduced. More effective type approval methods for vehicles is expected to reduce the emissions from new diesel vehicles in particular. However, studies have shown that tackling NO_2 is quite challenging and fairly large emission reductions are needed (i.e. Høiskar et al. 2017 and AirParif 2018). The regular fleet turnover will in many situations lead to several more years with too high pollution levels, and more measures are in general needed. LEZ is one of the available tools which can target NO_x emissions.

PM pollution from traffic has a large contribution from non-exhaust emissions. Even without use of studded tyres, zero-emission vehicles will reduce the proportion of exhaust related emissions even more. To reduce traffic related PM further in Europe, one need to address the road dust when implementing measures.

A LEZ could however also be used to speed up the introduction of electric vehicles targeting also the reduction of CO_2 emissions from transport. Strict LEZ regulations could also lead to general traffic volume reductions which would reduce emissions of all polluting compounds from traffic. Some cities are opting for car-free zones in the city centres (i.e. Munich and Brussels) and general traffic limiting measures are introduced to tackle other urban challenges such as congestion. In cities experiencing population growth, the urban space is under pressure (UN habitat 2017). Increased population also means increased mobility needs and as a consequence regulating road traffic is anyway considered to be required.

Before implementing a LEZ, scenarios of expected future composition of the vehicle fleet should be performed. How many years will a LEZ be required to be operational? Is the zone targeting the right air pollution components and the right vehicle types to obtain the wanted result? Can the fleet turnover be increased more efficiently with other means? Norway for example has implemented several incentives for buying electric vehicles such as free parking, free use of toll roads, free charging at several public locations and reduced new vehicle registration taxes. In 2017 more than 20 per cent[5] of new cars sold in Norway were electric, and in September 2018 about 50 per cent[6] of new cars registered were electric. The different LEZ solutions and other alternative measures also have a cost of implementation. Costs have not been the scope of this report, but will be important when looking at required measures.

If implementing a camera surveillance system for enforcement of the LEZ, a potential second use of the installed system should be considered. Some of the already existing systems are used in combination with congestion charging or a toll-road scheme. As mentioned above, reducing the number of vehicles entering a major city will likely be just as important in the future even with lower pollution levels.

Even if failed Euro emission standards have undermined LEZs in the past, future LEZs can be based on a better foundation. With better knowledge of actual emissions on the road it will be easier to both predict emissions and concentrations with models, and set the conditions for a LEZ in a manner which will be well targeted to tackle the problem at hand.

[5] NRK January 2018. News article.

[6] ABC Nyheter. October 2018. 52 prosent elbiler i september.

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Appendix 1: Premature deaths due to air pollution in Europe

Table A.1: Premature deaths attributed to air pollution. European countries in 2014. Source EEA 2017

Country	Population (1 000)	$Pm_{2.5}$	NO_2	O_3
Austria	8 507	5 570	1 140	260
Belgium	11 181	8 340	1 870	190
Bulgaria	7 246	13 620	740	200
Croatia	4 247	4 430	300	180
Czech republic	10 512	10 810	550	310
Denmark	5 627	3 470	130	110
Finland	5 451	2 150	40	60
France	63 798	34 880	9 330	1 630
Germany	80 767	66 080	12 860	2 220
Greece	10 927	11 870	1 660	570
Hungary	9 877	11 970	1 210	350
Italy	60 783	59 630	17 290	2 900
Netherlands	16 829	11 200	2 560	250
Poland	38 018	46 020	1 700	970
Portugal	9 919	5 170	610	280
Romania	19 947	23 960	1 860	350
Spain	44 229	23 180	6 740	1 600
Sweden	**9 645**	**3 710**	**130**	**150**
UK	64 351	37 600	14 050	590
Norway	5 108	1 560	190	60
Serbia	7 147	10 770	1 380	190
Switzerland	8 140	4 240	980	220
Euro -28	502 351	399 000	75 000	13 600

Appendix 2: Exhaust emission from vehicles

The two tables are examples on "real-life" emission from different types of vehicles in city traffic. HBEFA is an database collecting data on emission measurement from different European emission labs. The examples used here are emission from different Euro classes of vehicles, in "real-life" city traffic.

For cars the emission of NO_x from petrol cars have been reduced by increasing Euro standards, but when it comes to diesel cars, the NO_x level increases significantly from Euro 4 to Euro 5. For Euro 6 diesel cars, the NOx level is still high compared to Euro 6 petrol cars, but have decreased compared to Euro 5 diesel cars.

The increase in NO_x emission from diesel vehicles, is an effect of the cleaning systems implemented to reach the PM targets for Euro V vehicles. An adverse effect of these cleaning systems was an increased emission of NO_x, but the diesel vehicle now have almost the same low level as the petrol vehicles when it comes to PM.

Table A.2.1: Average emission of exhaust gas from cars and vans in heavy city traffic. Depending on Euro level. Emission in g/km. Source: HBEFA

		Car		Van	
		Petrol	Diesel	Petrol	Diesel
Euro 2	PM	0.0026	0.0684	0.0053	0.0975
	NO_x	0.3409	0.5426	0.3884	0.9334
Euro 3	PM	0.0012	0.0302	0.0019	0.0409
	NO_x	0.0604	0.5617	0.0732	0.8087
Euro 4	PM	0.0006	0.0139	0.0014	0.0223
	NO_x	0.0529	**0.4924**	0.0563	0.5464
Euro 5	PM	0.0012	0.0021	-	0.0011
	NO_x	**0.0259**	**0.7505**	-	0.4939
Euro 6	PM	0.0012	0.0021	-	0.0011
	NO_x	0.0259	0.4136	-	0.1676
Euro 6d	PM	-	0.0021	-	-
	NO_x	-	0.1043	-	-

HBEFA is a European database of emission factors. Average speed of 49 km/h used.
The emission factors in the table are based on a typical Norwegian mixture of vehicle models.

Diesel busses and heavy goods vehicles also had high NO_x level both from Euro IV and Euro V vehicles. But unlike cars, the heavy duty vehicles manage to solve these problems in a better way, and the Euro VI standard vehicles has low emission of both PM and NO_x.

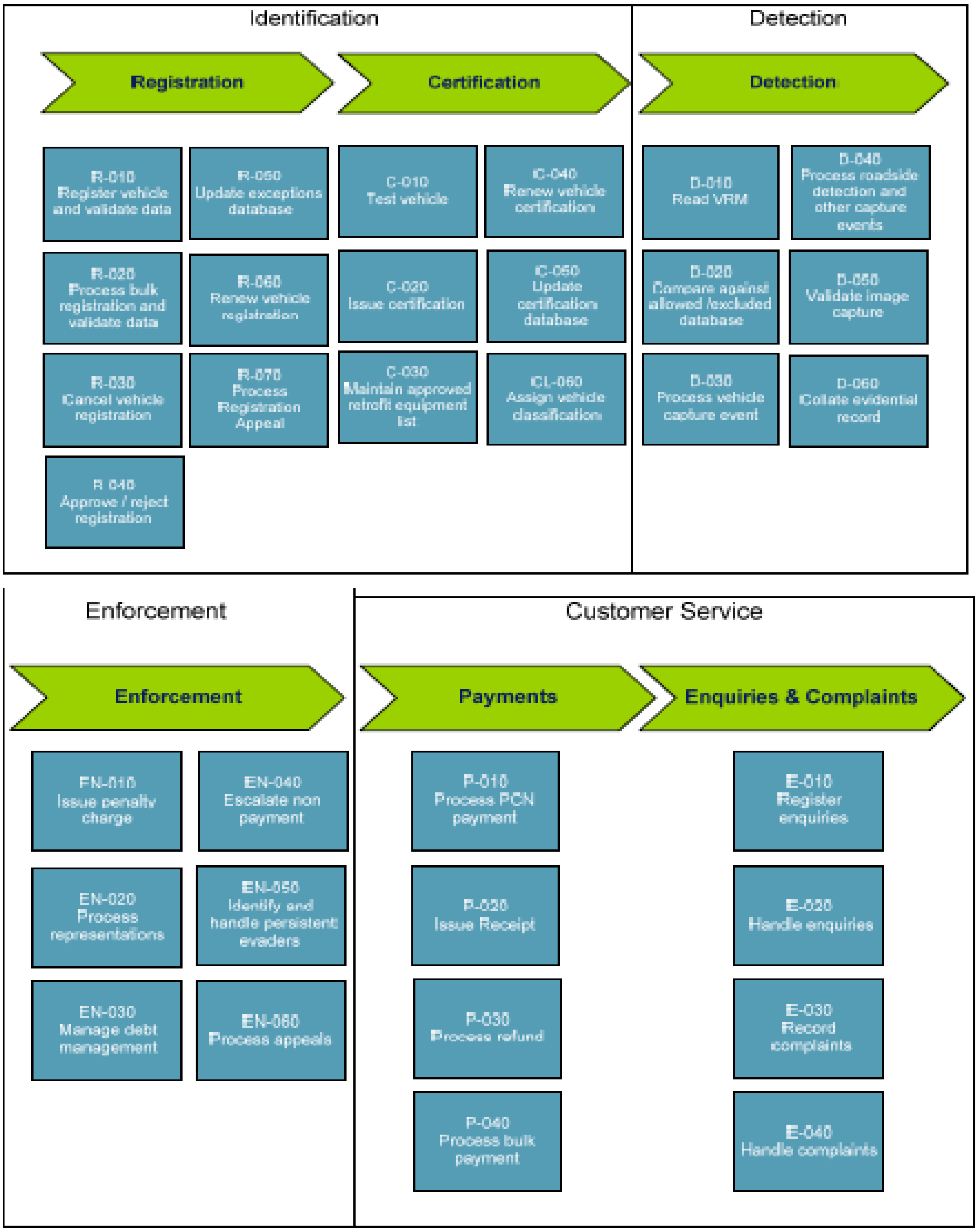
Table A.2.2: Average emission of exhaust gas from buses and HGV in heavy city traffic. Depending on Euro level. Emission in g/km. Source: HBEFA

		Bus (diesel)	Heavy goods vehicle (diesel)
Euro II	PM	0.1516	0.1952
	NO_x	8.37822	9.7971
Euro III	PM	0.1628	0.2006
	NO_x	6.4591	8.8310
Euro IV	PM	0.0350	0.0486
	NO_x	5.9168	5.9424
Euro V	PM	0.0044	0.0450
	NO_x	**4.8359**	**3.9321**
Euro VI	PM	0.0045	0.0045
	NO_x	**0.3907**	**0.2851**

HBEFA is a European database of emission factors. Average speed of 37 km/h used.
The emission factors in the table are based on a typical Norwegian mixture of vehicle models

Appendix 3: Example of operational processes

Table A.3: Possible LEZ operational processes needing to be developed. Example from London LEZ. Source: Deloitte 2005



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Visiting and postal address:
Institute of Transport Economics
Gaustadalléen 21
NO-0349 Oslo

+ 47 22 57 38 00
toi@toi.no
www.toi.no