ERASMUS UNIVERSITEIT ROTTERDAM

BACHELOR THESIS URBAN, PORT AND TRANSPORT ECONOMICS

Low Emission Zones in Europe

A Review of the Effectiveness and Consequences

Abstract:

The aim of this paper is to review the effectiveness and consequences of low emission zones in European cities. A literature review presents the general framework and previous research on the topic. The focus of the literature review will be on the causes and effects of air pollution and on the economic consequences of an LEZ. The empirical research will investigate the efficiency of an LEZ in improving the air quality. It does so by reviewing the developments of PM_{10} levels in multiple industries and countries over a five-year period. Additionally, the results of cities with an LEZ are compared to a control group. It is concluded that although the presence of an LEZ seems to have a positive effect on air quality in European cities, no significant conclusions can be drawn about the exact size or nature of the effect.

Author: Dirk van den Beuken
Supervisor: Dr.Giuliano Mingardo

Content

Chapter 1: Introduction

The issue of air pollution, and all the consequences of it, has become more and more pressing on European nations. There is an increasing attention for the effects air pollution has on the environment, on climate change and on the health of the population. Research is being done in multiple areas to address this issue and find appropriate solutions.

In order to make progress in the sector, the European Union has installed strict objectives for itself (Marco & Bo, 2013). These objectives include a maximum number of annual exceedances of particulate matter (PM_{10} and $PM_{2,5}$) levels. Each member state is responsible for dividing its territory in multiple areas and monitoring those areas for air pollution levels (European Commission, 2018). The member state has to report the data on the air quality in its regions to the European Commission. In many cases, the reported data exceeded the standards that were set by the European Commission. In these cases, the member states were responsible for creating a plan to improve air quality and enforcing this. Cities are often sources of high levels of emissions and therefore require particular attention. One of the ways in which the air quality can be improved in these areas is by limiting the emissions from road users with a low emission zone (LEZ). Although LEZ's appear in many different forms throughout Europe, the general idea is the same everywhere. The goal of an LEZ is to limit the access of heavy polluting vehicles to the city centres. European standards have been erected to identify the level of emissions related to certain vehicles. Municipalities that implement an LEZ can then decide what 'EURO level' is required for vehicles to enter their cities.

This paper will look at the LEZ's in a number of ways. It contains both a literature review and an empirical part and will consider both the environmental and economic consequences. Chapter 2 contains the literature review, this presents the literature on air pollution and economic consequences. Chapter 3 then presents some examples and early results, these may be helpful to better understand how an LEZ works in detail, to consider its complexity and to see a first indication of its effectiveness. In Chapter 4, the empirical research is presented. The aim of this chapter is to review the effectiveness of the LEZ's in many European cities in reducing air pollution. It functions as a way to widen the scope of previous research on the matter and incorporate many European cities in an air quality analysis. Finally, Chapter 5 present the conclusion of the paper and further research is suggested here.

As is mentioned above, the aim of this paper is twofold, it considers both the effects on air pollution and the economic effects. More specifically, the aim is to answer the following question:

To what extent are LEZ's effective in improving the air quality in European cities and what are the economic consequences?

This question clearly incorporates the two elements that are central to this paper. Although it is rather broad, this might be the most efficient way to get a good overview of the developments in the still relatively new LEZ's.

Chapter 2: Literature Review

2.1 Air Pollution

Transport and fuel combustion are often linked to health problems and damage to the environment. In order to better understand the effects of transport on air pollution it is important to differentiate between the different substances that are created by transport. In general, the substances can be divided into three big pollutant groups: acidifying substances, ozone precursors and particulate matter (EEA, 2010). The acidifying group contains NOx, SOx and NH_3, this group mainly damages ecosystems, buildings and materials due to corrosion. The ozone precursors group contains CH_4, CO, NMVOC and NOx, this group has a negative effect on human health and ecosystems. The particulate matter group contains NH_3, NOx and PM_{10}, the effects of this group are mainly related to human respiratory problems.

2.1.1 Ecosystems

When considering the influence air pollution has on forest ecosystems, William H. Smith identified three classes of relationships (1974). The class one relationship described the low dosage conditions, class two intermediary dosage and class three high dosage. Smith indicates that our information is incomplete and he states various reasons why we cannot specify nor quantify the various relationships between certain pollutants and forests. Some of these reasons are: individual trees within a species respond very differently, environmental factors largely cause the plants response, most previous research was on conifers, most previous research only incorporated SO_2 and O_3, most previous research put plants in areas of unnatural levels of pollution and most previous research has been on small trees. The idea that environmental factors like precipitation play a role on forest pollution was illustrated in Brazil (Ferreira, Ribeiro et al., 2017). The results of this research showed that the heavy metals coming from the urban area of Sao Paulo caused serious consequences in the nearby Guarapiranga forest. The not so distant Curucutu forest on the other hand had low heavy metal concentrations. This was caused by natural barriers like precipitation. Not all the relevant information was yet available to Smith, but because of the use of the three classes he did manage to provide some relevant results. Class one has a sink function, in this case the small amount of pollution is not noticed necessarily and can even have a fertilising effect. The class two will most likely have noticeable effects and change productivity, alter species composition or cause epidemics. The class three will have a damaging effect on the ecosystem, whether it is rigorously reduced growth or mortality.

As this was back in 1974, much data was not available yet and most of the theory lacked proper empirical evidence. Between 1998 and 2008 there was a shift in the focus of forest science from forest decline to overall forest health (Paoletti, Schaub et al., 2010). This is indicated by the topics of presentations at the IUFRO conferences on 'impacts of Air Pollution and Climate Change on Forest Ecosystems'. While in 1998 this 'Forest decline' was the topic of nearly 50% of the oral presentations, in 2008 this changed to 0% and 'Ozone', 'Nitrogen' and 'Climate change' had taken its place. Above all, this paper indicates the advances that have been made in the forest ecosystem research, but it still stresses the major uncertainties in the area. Current evidence suggests that air pollution contributes to climate change and that its effects on vegetation are made worse by this same climate change.

2.1.2 Climate change

The impact of the air pollution caused by transport on climate change is a very relevant matter. As a result of human activities, the global levels of carbon dioxide, methane and nitrous oxide have increased a lot during the last centuries. Carbon dioxide is the most important greenhouse gas (I.P.O.C., 2007). The measured level of CO_2 in 2005 by far exceeded the natural levels of the last 650,000 years, and the last decade the growth had been the biggest. Transport plays a very big role in this, since 26% of global CO_2 emissions comes from transport (Chapman, 2007). The biggest contributions to this total come from individual road use, road freight and airplanes. In fact, 81% of these contributions come from road transport in the OECD countries.

Not only is the freight truck transport and its resulted carbon dioxide emission very large, the sector seems to be growing faster than other transport sectors (Schipper, Scholl & Price, 1997). In their research, the authors found that the truck freight transport saw the biggest growth due to the fact that this mode of transport is hard to replace; technological and behavioural solutions do not suffice. It is indicated, however, that in an increasingly competitive market slight offsets in costs can create large responses. Hereby suggesting that taxes and other forms of regulations can drastically change the patterns of trade. The exact nature of these taxes and regulations is hard to predict.

A similar approach was used in a research from 2009 (Kamakate & Schipper). This research expanded the timeline that was studied until 2005 to incorporate more recent developments. One mayor conclusion was that overall freight activity is linked to GDP, with the growth of international trade, 'just-in-time' business, e-commerce and intermediate product handling as some of its main drivers. The overall energy use has increased due to a modal shift towards trucking because of its flexibility and speed as was mentioned in the previous paper. Again, the potential reduction in growth is to be found in the logistics, with better truck size and (un)loading capacity. It is explained that traffic situations can be improved by keeping trucks away from congested areas, this is where the LEZ's could prove to be efficient. In a way, the results are very similar to the research from 1997. The truck freight transport sector has increased its market share and it is questionable whether technological or behavioural solutions are sufficient to make a real impact.

Still, innovation is often seen as the instrument to reach long term CO_2 targets and without innovation the set targets will most likely be unreachable (Chapman, 2007). According to Chapman, for the road freight specifically, a global shift is desirable but impossible to achieve in smaller countries. Over time, public awareness can play a part, but this does not offer direct solutions. The direct solutions can be sought in sustainable transportation solutions such as using economies of scale to use larger vehicles and proper planning to reduce empty running. Relying on technology is not sufficient according to the article; behavioural change is the key factor. Chapman indicates that a combination of taxes, regulations, technology and demand restraint is needed. Although not explicitly discussed in this article, the low emission zones are an example of regulations to reduce pollutant emissions in some of the most polluting areas of Europe.

A study from 2010 considered the effects different forms of transport had on climate change as a result of transport (Borken-Kleefeld, Berntsen, Fuglestvedt, 2010). In this research, passenger- and freight transport were separated and different modes of transport were considered. For the freight transport, the modes were light duty trucks (LDT), heavy duty trucks (HDT), ship, aviation and rail. The emissions of these different modes were linked to the global mean temperature change, which was used as the metric for climate change in this research. The research finds that for freight transport, aviation has the biggest climate impact, especially in the short run. This is followed by LDT and then HDT. It is remarkable that the difference between LDT and HDT is quite large. The temperature change per ton-km differs between LDT being 4.5 times as large and LDT being 11.75 times as large as HDT over different time ranges. Although it is concluded that aviation is by far the most polluting form of transport, the trucks show significant results and considering the size and growth of this mode it is a good area to reduce emission.

The transport sector is a major source of pollution. For example, in Australia, the transport is now the third largest source of pollution with 14% of the total and it is increasing at a faster rate than other sources (Stanley, Hensher & Loader, 2011). Of this 14%, 88% consists of road transport. The paper aims to investigate the possibilities to reach two targets. The first target is to have an emission reduction of 20% between the years 2000 and 2020. The second target is to have an emission reduction of 80% between the years 2000 and 2050. The first target is considered the easier one, but considering current estimates show a 35% rise instead of a decline it is still very challenging (Department of Climate Change, 2008). To achieve the ambitious targets, the paper discusses 6 ways to reduce emissions: reduce urban car kilometres travelled, increase the share of urban trips performed by walking and cycling, increase public transport's mode share of urban motorised trips, increase urban car occupancy rates, reduce forecast fuel use for road freight, improve vehicle efficiency. It is clear in this case that a low emission zone can be an efficient tool to achieve the sub targets. Prohibiting access to certain urban areas stimulates people to consider a different mode of transport, or in the freight sector be more efficient with their trips. The writers agree with previous research that says the behavioural changes will have to lead the way in emission reductions, followed by technological progress. It is the job of the government to nudge the population in the right behavioural direction. Examples of this comprehensive road pricing and reallocation of road space to give priority to low emission vehicles. The government could simply increase fuel taxation, but this paper illustrates that the external costs should be taken into account as well, hereby reaching a good resource allocation.

2.1.3 Health

The abovementioned ecosystem and environmental concerns appear to be more general problems and they do not necessarily explain the need for low emission zones. A third consequence of the emissions caused by freight transport is an effect on human health.

Assessing the effect of transport specifically on pollution can be difficult, because of the diverse mix of contributors. Some previous researches have shown that air pollution from traffic is higher in urban areas than in rural areas, but studies on specific polluting substances from transport are scarce. Compared to rural areas, the exposure in urban areas appears to be up to two times as high for most pollutants and next to busy roads even two to three times as high (Sanderson et al., 2005). Even though there is not enough evidence to support elaborate theories on specific population segments, there is a clear connection between where people live and spend much of their time and their exposure to pollutants.

The effect of the transport emissions on the human respiratory system is illustrated by a study in urban areas in Canada (Buckeridge et al., 2002). To measure 'health', 3-year age- and sex standardized hospitalization rates were studied. The ones caused by exposure to $PM_{2,5}$ were compared to the general hospitalized patients for all reparatory problems. This measurement has relatively high accuracy but can still contain errors due to missing data or false data provided by the patients. The $PM_{2,5}$ emissions were estimated using data on traffic volume and vehicle types on some of the main streets in the measured areas during 24 or 8-hour counts. The relative exposure to the $PM_{2,5}$ emissions were reviewed by converting the streets to a series of polygons. The results indicate a relationship between the rate of hospitalization for selected respiratory diagnoses and the exposure to $PM_{2,5}$ resulting from motor vehicle emissions. It appears to be a causal relationship because this effect is larger than the relationship between $PM_{2,5}$ exposure and the hospitalization of all respiratory patients. Even though the research has some limitations, it offers insight in the results of $PM_{2,5}$ exposure and a causal effect with certain respiratory diseases seems likely.

In Southern California, a large research was conducted on the effect of air pollution on birth defects (Ritz et al., 2002). For each pregnancy, they measured the average monthly exposure to carbon monoxide (CO), nitrogen dioxide, ozone and particulate matter <10 μm in aerodynamic diameter. Using different regressions, the odd ratios were tested for different conditions. The results suggest that pregnant women exposed to higher levels of ambient carbon monoxide have a larger chance of having a baby with ventricular septal defects. Pregnant women exposed to higher levels of ozone on the other hand have an increased chance of their baby having aortic artery and valve defects. The results appear to be significant; there is a large sample and the results are supported by how specific the exposure relationship is and by some previous animal data. Since there is hardly any previous data however, further studies are recommended.

Large scale researches have been conducted on the possible relationship between air pollution and lung cancer. In 2002, a research was conducted on the long-term effects of exposure to particulate matter on lung cancer and cardiopulmonary mortality (Pope et al., 2002). Data on individual risk factors and later vital status or cause of death was collected from approximately 500.000 participants. This information was linked to air pollution data and it was found that both fine particulate matter and oxide pollution caused lung cancer and cardiopulmonary mortality. In Europe, a study of cohorts collected data from 17 different cohort studies with the intend of measuring the long-term effect of exposure to pollution on lung cancer incidence in Europe (Raaschou-Nielsen et al., 2013). The substances that were reviewed were PM_{10}, $PM_{2,5}$, PM_{coarse}, soot, nitrogen oxides and two traffic indicators. This very large sample clearly showed that particulate matter concentrations in the air contributed to the incidence of lung cancer in Europe. No association was found with nitrogen oxides.

An article from 2009 considered the impact of short-lived greenhouse pollutants (Smith et al.). Not only do these gasses contribute to climate change as is described above, but they can also directly affect health. The article states that carbon monoxide, non-methane VOC's are directly damaging to human health. Also, results from a research of 18 years in 66 cities in the US provided evidence on different toxins. Black carbon particles, measured as elemental carbon, are not very toxic but can have a larger effect on mortality than fine particles ($PM_{2,5}$). The results are not stable when other pollutants are added. The effect of sulphur is ambiguous, pure sulphur does not appear to be toxic, but it could still have a larger effect on mortality than undifferentiated fine particles independent of other pollutants. The mortality effects of ozone in the long run seems much stronger than in the short run, although the results come from only one large cohort study. In the short run it may have mortality effects that are independent of major types of small particles.

Heinrich et al. (2005) studied many findings from previous studies to come up with an overview on the different health effects of transport related air pollution. The health outcomes that were considered are: allergic respiratory diseases, non-allergic respiratory diseases, cardiovascular diseases, cancer, reproductive outcomes and mortality. The summary contains both population and experimental studies. The different pollutants that enter the air as emissions have several significant effects on human health. Although not all research is conclusive, a lot of information was made available in this research. It was stated that black smoke and particulate matter are causes of cardiovascular diseases, non-allergic respiratory diseases and mortality. Also striking was the strong experimental evidence that identified diesel as a cause of cancer and both types of respiratory diseases.

The effectiveness of technology, in this instance in the form of air filters, on reducing health problems is often researched. The effect is lower than that of a shift from private motor vehicles to active modes of transport (Woodcock et al., 2009). This was calculated by estimating the distributions of physical activities and exposure to pollutants and using these statistics to estimate the change in disease burden with comparative risk assessment. The study concludes that a combination of lower-emission motor vehicles and a reduction in distance travelled by motor vehicles is the most effective approach to prevent conditions such as ischaemic heart disease, cerebrovascular disease, depression, dementia, and diabetes.

2.1.4 Policy and targets

It becomes clear from previous research that emissions and air pollution are damaging to the environment in a number of ways. The focus of this thesis is not on general air pollution, but on the effectiveness and consequences of low emission zones for truck freight transport. The low emission zones are relatively new initiatives and the research about this is not abundant. It may be useful to review the policy and targets that governments have set for themselves.

First, we must consider the background of this policy; the reason it was introduced. Although it is still disputed, in the scientific community there is a general consensus that humans influence climate change (Oreskes, 2004). This has caused 195 countries worldwide to commit to a legally binding climate deal. This ‘Paris Agreement’ sets the target to not let global temperature grow more than 2 degrees above the pre-industrial standards (UN, 2015). The European union takes a leading role in the global climate protection. In order to meet the standards from the Paris Agreement, or even exceed them, the European Union has its own climate policy. As was briefly mentioned in the introduction, this policy includes measuring the levels of certain toxins in the air and setting a maximum concentration for this. If this maximum is exceeded too often, measurements have to be taken. The government of the country where this occurs can, in turn, decide the best way to intervene in the problematic area.

In some countries this is a matter of national policy, but others even go one step further by passing this responsibility along to the relevant municipality. If emissions standards are found to be too high in an area, one of the possible ways to intervene on a local level is to introduce an LEZ.

In the Netherlands, local municipalities are in default responsible for their low emission zone. Although this offers them the freedom to do what is best for their specific case, this can create uncertainty. On a national level, the aim is to reach the European standards, but there is no clear national policy. In Amsterdam, the aim is not only to suffice to European standards, but also to reduce soot and make the air nicer for the inhabitants (Gemeente Amsterdam, 2015). In steps over the years, the aim is to be as clean as possible in 2025. To reach this, the standards will be brought up gradually, whilst making arrangements with local businesses to prevent disruption of their economic activities.

In short, there are certain worldwide targets to reach. The responsibility to act in order to achieve these differ per country. The European Union has its own specific standards that its members must live up to and the LEZ's are a possibility for local governments to improve air quality and satisfy the requirements.

2.2 Economic Aspects

The main goals for the LEZ's in Europe are related to congestion and pollution. When implementing this policy, however, there are more consequences. Like with any policy, there will be costs related to the implementation and the enforcement of the policy by the government or municipality. Besides these costs, the replacement or transition of the vehicle fleet to comply with the new rules bring along significant costs as well. The social costs (or benefits) as experienced by society should also be considered. In a living environment, clear costs do not always paint the complete picture and social factors are important as well. Finally, the competitive nature of the area and the companies located in it is something worth considering. Altogether, the costs for the government and businesses, the social costs and the effects on competitiveness bring a new dimension to the discussion. It is not only about the effectiveness of the LEZ as a tool to reduce emissions, but the economic aspects play a big role as well and will be discussed further in this chapter.

2.2.1 Implementation and enforcement

Although the LEZ's in Europe may contribute to cleaner air and less health problems, they also bring along significant costs. For London alone, it was estimated that it would cost 10 million pounds to implement the LEZ and another 7 million pounds yearly to maintain it (Watkiss et al., 2003). Given the fact that there is no real certainty about the long run effects of the LEZ, this is a considerable investment. In the Netherlands, cities are obliged to follow a step-wise plan, these steps are often outsourced (Maes, Sys & Vanelslander, 2011). Three main groups or phases of costs were considered. The first phase, research and process cost, consists of a number tag database, research on logistics, a simulation on emissions and an economic effects study. This phase is estimated to cost approximately 100,000 euros (Buck Consultants International & Goudappel Coffeng BV, 2009). The second phase covers the implementation costs. For this, small infrastructure changes, communication strategy and basic law enforcement infrastructure need to be incorporated. Finally, there are the operational costs. These costs are mainly due to the fact that law enforcement is necessary.

In many cities, a transition period is used to help people get used to the new system. In Brussels, a transition period of 9 months was in place where people would get warnings instead of fines (LEZ Brussels, n.d., para.4). In Lisbon, the first phase of the LEZ started in the most critical area in the city and expanded step by step from there (Da Silva, Custódio & Martins, 2014). The transition period is helpful as a way of letting people get used to the new situation, but also to test if there are any problems or unforseen complications. At the time of implementation there can be problems due to some 'grey areas' in the new system. An example of this is the Association of Vehicle Recovery Operators, who in 2008 felt that their vehicles should be granted an exemption as 'essential vehicles' in the same way policecars and firefighter trucks enjoy this exemption (commercialmotor, 2008). When issues like this are discovered before the final implementation they can be dealt with for a smooth transition process.

There seems to be a lack of transparency about the evidence for-, and the costs of a low-emission zone. A foundation for classic cars in Rotterdam questions the previously published result that the LEZ in Rotterdam reduced the soot emissions by 20% (Stichting Rotterdamse Klassiekers, 2016). The president of the foundation also requested the costs of the implementation of the Rotterdam LEZ, but this request was denied (Mascini, 2017). According to the president Niels van Ham, the responsible alderman Pex Langenberg has always stated that the total costs could amount to 11,7 million euros, but van Ham expects the total costs to exceed this. Besides the costs mentioned above, van Ham is interested in the total costs of all advertisements and the costs of the lawyers to fight law-suits directed at the municipality of Rotterdam. This lack of transparency gives rise to the question whether the LEZ's are as effective as is sometimes claimed by the municipalities.

2.2.2 Businesses

Even though the LEZ's cost a lot of money, for the government they can be a good tool to work towards their emission targets. Perhaps more interesting to look at is the businesses affected by the LEZ's. The largest costs of the LEZ's come from the fact that the vehicle fleet needs to be renewed. For Germany, the total costs of this process are estimated to be 1,09 billion dollars on vehicle upgrades (Wolff, 2014). Consultancy Steer Davies Gleave (2006) estimated that for the city of London the costs of adapting the vehicle fleet to the new standard would amount to 120-270 million pounds with 140-420 jobs lost. According to the consultancy, 2/3 of these costs will be directly translated to the consumers and the remaining amount will be an extra burden for the vehicle owners/operators. These estimations may not be completely accurate due to some limiting factors and uncertainties, but they give an illustration of the immense consequences from the implementation of an LEZ. Having said this, we can wonder what the effects are on businesses. If the costs are indeed distributed as is expected, both companies and consumers are hurt. Small private businesses may find that they are unable to update their vehicles, causing them to have to close down (Ezeah, Finney & Nnajide, 2015). The article states that German business owners have complained about their sales dropping and that businesses are reluctant to enter the LEZ's with their vehicles. The authors do add however that these negative effects will most likely be temporary, the compliance rates seem to be high and the government should support local business to make the transition. An example of this is the 'slooppregeling' or demolition arrangement that exists in some Dutch cities. As a resident of Rotterdam whose car or light truck will no longer be allowed into the city, it is possible to have it demolished and be rewarded for it (Gemeente Rotterdam, 2018). If the car satisfies the set conditions, a person may receive a compensation of 1000 euros or even 2500 euros for a diesel.

Even more subsidy is granted to those who choose to buy an electric car in return. Additionally, it is possible to apply for an exemption on a permanent or temporary basis. In the Netherlands there is also an initiative called the Green Deal Zero Emission, consisting of the government, 18 municipalities in the region Arnhem-Nijmegen, entrepreneurs- and interest organizations, vehicle producers, fuel suppliers, logistical service providers and shippers and receivers like HEMA and Heineken (VNO-NCW & Koninklijke Vereniging MKB-Nederland, 2015). This group together wants to achieve an emission-free city centre by 2025. Besides looking for ways to achieve this, through the sharing of information the initiative looks for ways to bundle loads and other ways to limit the number of trips through the city centre. Multiple options for the delivery of goods without the prior pollution are being tested. These options include a city distribution, whereas specialized companies take over the goods at the edge of the city, further distributing it to its final destination in smaller and cleaner vehicles.

In London, a survey was used to consider the impact of the LEZ on businesses and it was estimated how companies would respond to the implementation (Browne, Allen & Anderson, 2005). The general assumption was that the interviewed operators had five possible responses to the LEZ: fit abatement technology to existing vehicles, upgrade their vehicles, divert around the area, drive in the area and risk prosecution, change the vehicles for specific deliveries. A total of 35 interviews and 20 questionnaires responses were used to come to conclusions. The participating firms together owned approximately 54,000 vehicles and were active in various sectors, most of the vehicles were big trucks (>3,5T). It was found that most companies would comply to the new regime. The two most likely options were to either modify the existing fleet or to upgrade the vehicles as can be seen in figure 1. Very few companies actually chose to use another route or scale down to smaller vehicles.

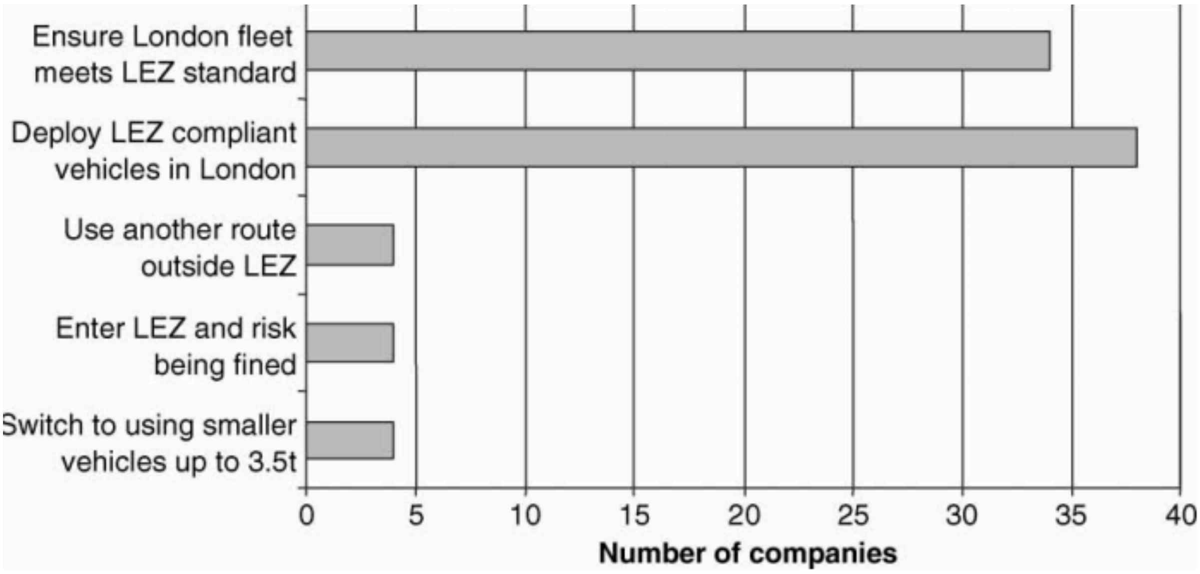

Figure 1. Likely behaviour is LEZ was introduced in London in 2005, reprinted from Low emission zones: the likely effects on the freight transport sector, by Browne, Allen & Anderson, 2005, retrieved from https://www.tandfonline.com

Considering most companies improve their current vehicles or acquire new ones as is seen above, it is not difficult to imagine that adjusting the industry to an LEZ is a costly expense. A survey of the measurements taken as a result of the implementation of an LEZ in Gothenburg estimated that the cost to the industry over the time period 1996-2001 was 14 million euros (Joint Expert Group on Transport and Environment, 2005**).**

2.2.3 Social costs

Although the costs for the industry in an LEZ may be large and the truck may offer some advantages, not all research takes external costs into consideration. This was illustrated in an article about the deeper impact on specific population segments due to the external effects of transport (Forkenbrock & Schweitzer, 1999). The article indicated that some population groups are affected by emissions and noise more than others and that this is something transport planners should look out for. A following article on the comparison of truck and rail freight transport considered the external effects accidents, emissions, noise, unrecovered costs associated with the provision, operation and maintenance of public roads and bridges (Forkenbrock, 2001).

It immediately becomes clear that in a traditional market, the external costs are not paid for by the users. Despite its advantages, the truck freight transport may not be the social optimum. On top of that, if a reduction in this mode of transport is to take place, it may be useful for the users to be held responsible for the consequences. This is a difficult thing to do, since it is hard to put a price on emission, noise and more. The government can try to limit the social costs or to redistribute them to the ones gaining the benefits by using instruments like taxes and low emission zones. Although he realised it is hard to internalize external costs in monetary terms, Forkenbrock tried to come up with a model to do this (1999). The goal was to internalize the externalities in such a way that the ones who generate the costs compensate the society with the same monetary value. The same four types of general externalities mentioned above were used to come up with a cost figure. The final presented results show that external costs for intercity truck freight are 1.11 cent per tonnes-mile. This substantial number equals 13.2% of the private operating cost for that transportation mode. The aim of the paper was to enlighten the public with the gravity of externalities and perhaps give an indication of the amount truck transporters should be charged to account for their social disadvantages. Important to keep in mind when looking at these numbers is that expressing externalities in monetary terms will always produce uncertainties. While the number of accidents and average cost per accident are still relatively straightforward to estimate, expressing factors like noise in monetary terms is more difficult. The results should therefore be used as an indication rather than absolute results.

2.2.4 Competition

The presence of an LEZ can affect the competitiveness of a region and the companies in it in a number of ways. It is important to take these processes into consideration as they affect nearly everyone in the municipality.

As was discussed in '2.2.2 Business' above, changing the vehicle fleet is a costly expense and this burden will mostly be carried by consumers and the business itself (Steer Davies Gleave, 2006). The disadvantage of the amount of extra costs the company incurs itself is self-explanatory, but letting the consumer pay the price also has consequences. When the stores and transport companies within the LEZ find that they have to increase their prices, their customers might prefer to go to a location outside the region. The price elasticity of a consumer is determined by a variety of factors including the distance to the competition (Hoch, Kim, Montgomery & Rossi, 1995). Even though the company may experience economic hardship at the time of transition, it must be aware of the price elasticity of its specific clientele and make sure they do not switch to a competitor.

Another problem arises in the enforcement of the policy. There is no uniform European system for collecting fines from foreign vehicles that do not comply with the LEZ standards (TLN, 2018a). When foreign vehicles are able to drive in an LEZ without the proper EURO status, this does not only erode the effectiveness of the LEZ but it can also have economic consequences. Foreign companies may have an unfair advantage over local companies and local companies might even decide to relocate to a foreign location to prevent being influenced by the LEZ. Transport and Logistics Netherlands (TLN) pleads for uniformity within the Netherlands and within Europe to prevent both confusion for road-users and abuse of the system. An essential problem is the exchange of information between European member states (TLN, 2018b). In the case of Rotterdam, around 10% of the vehicles on the Maasvlakte is foreign (TLN, 2018c) and during random checks in 2017 at the Maasvlakte, it was found that approximately 27% of these foreign vehicles did not obey the LEZ rules (NOS Nieuws, 2018). Additionally, the percentage of fines from all the traffic related fines by foreign vehicles that was actually paid was between 70% and 80% in 2017 (Grapperhaus, 2018). Clearly, this evasion of justice is undesirable.

2.3 Conclusion Literature Review

As was its purpose, the literature review has provided a general framework and some first insights in the area of interest. Some effects of emissions were studied and the previous literature clearly states that high emission levels have many negative effects. These effects include contributing to climate change, damaging the environment and harming citizens. It was also explained that an LEZ can serve as a tool to reach overarching pollution targets.

While the potential of an LEZ to improve air quality is promising, the costs play a role as well. As is explained above, these costs do not only include the costs for the municipality or state that implements and enforces it, but it can also influence business. The largest part of the costs come from changing the vehicle fleet. The literature review has showed us that these costs are considerable and can damage the industry in the area. Additionally, the competitive position of many firms may be compromised. It is questionable whether all businesses are able to adapt without going bankrupt and to what extent the government should support their activities. Examples of how a government or municipality can facilitate the transition are: providing information, having a transition period for firms to adapt and offering arrangements such as getting a reward for demolishing your old polluting vehicles.

Finally, the literature review indicated that not all costs or benefits can easily be expressed in monetary terms. While it is easier to perform a cost-benefit analysis by looking at developments of the air quality and the implementation costs, this does not explain the complete situation. Factors like noise and accidents are very relevant for the population, especially in the city centres. In this way, the LEZ's may provide a bigger social service than just an improvement in air quality.

This part of the paper explained the general idea, function and consequences of LEZ's by studying previous research. Next, the focus will be on reviewing the efficiency of the LEZ's. First, some examples and early results will be presented. Second, the empirical research will provide answers regarding the efficiency of the European LEZ's in reducing emissions.

Chapter 3: Examples and Early Results

In many European cities, the LEZ has been in place for quite some time now and the first early results are staring to appear. Although the data is not extensive enough to provide us with definitive conclusions, they can offer an insight in the first results of the different LEZ initiatives. In the following paragraphs, some early results will be presented and some cities will be discussed in more detail. The cities that are discussed in more detail are Rome, Rotterdam and London. These three cities were chosen because they have significant differences in the way they operate and can therefore offer insight in the different possibilities. More information on the rest of the cities that were studied can be found in Appendix A.

3.1 Rome

The Rome LEZ is a fairly complicated one because it contains three different zones (European Commission of Mobility and Transport, 2018). As is indicated in figure 2. In all three area's the standards that are upheld are Euro II for petrol and Euro III for diesel. The difference between the zones is found in the time of the year and parts of the day that they are in place. The inner circle, the city centre, maintains the LEZ at all times. The purple railway ring operates from November 20th until October 31st and only from Monday to Friday. The outer ring is only activated when the air pollution limits are exceeded for three, five or eight days in a row, with increasing strictness. Additionally, Rome has multiple 'ecological Sundays' each year, during these days no vehicles are allowed in the city between 7:30-12:30 and 16:30-20:30. These differentiating rules can clearly be confusing and may lead to a reduction in the compliance. An analysis on the effectiveness of the LEZ was performed over the time period 2001-2005 (Cesaroni et al., 2012). Although this is some years ago, it could give an indication of the early results. The results indicate a 3,8% decrease in the total number of cars in the area and a PM_{10} reduction from 7,8μg/m^3 to 6,2μg/m^3. Over such a relatively short time period, these results give the impression that the LEZ has been very successful in its early stage. A side note on a social level presented by the research was that the health benefits related to the reduction in harmful emissions mostly came to the benefit of the most well-off citizens. The reasons for this was their homes' proximity to the city centre and the stricter measures in that area.

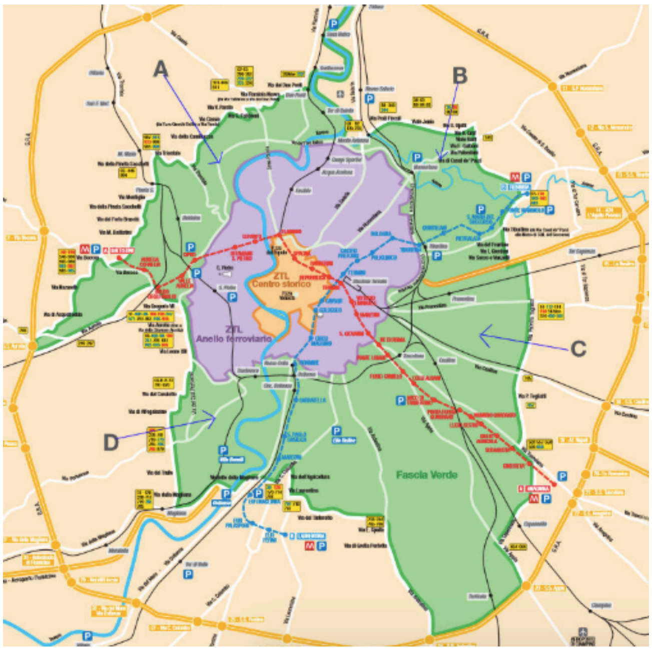

Figure 2. LEZ's in Rome. Source: urbanaccessregulations.eu

Orange – ZTL Centro Storico
Purple – ZTL Annello Ferroviario
Green – ZTL Fasciale Verde

3.2 Rotterdam

Perhaps the most heavily debated LEZ in the Netherlands is located in Rotterdam. The black line in figure 3 shows the initial LEZ for lorries, the red line shows the LEZ in its final form (Gemeente Rotterdam, 2018). The LEZ is in place permanently and is enforced with security camera's that use license plate recognition. The LEZ has been in and out of practice over the last years due to lawsuits and heavy debate among the population of the municipality. However, since the 14^{th} of January 2017, lorries need to have a Euro IV status. Car entrance depends on their date of first admission, indicating the first time they got an EU license plate. For petrol cars this needs to be after the 1^{st} of July 1992 and for diesel cars this needs to be after the 1^{st} of January 2001. Even though Rotterdam has had an unstable start and the enforcement has not been very strict, the municipality has presented results of a research by environmental service DCMR and independent research organization TNO that indicate good effectiveness of the zone (Gemeente Rotterdam, 2016). They indicate that in the period October 2015-June 2016 there has been a reduction of soot in the LEZ of 20%. Additionally, the amount of NO_x has seen a reduction between 5% and 10%.

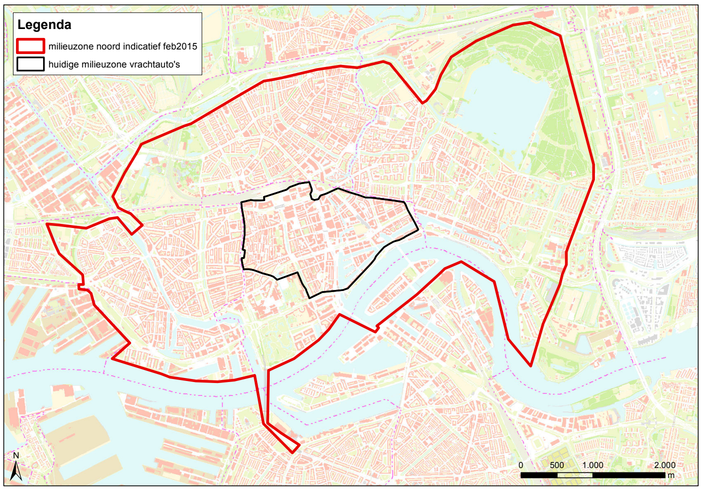

Figure 3. LEZ Rotterdam. Source: Gemeente Rotterdam.

3.3 London

As is illustrated in figure 4, the London LEZ covers most of the city. It is a uniform LEZ that operates permanently, including weekends and holidays (European Commission of Mobility and Transport, 2018). In total, the city of London has 9 different schemes in place, ranging from the 'London Coaches Scheme' to the 'London Lorry Control' to the 'Ultra-Low Emission Zone ' (ULEZ). The 'regular' LEZ has been in place since 2008 and it affects lorries over 3,5 tonnes, buses, coaches, large vans and minibuses. The zone is monitored with both mobile and fixed camera's that read licence plates. Something that is different from the LEZ's in Rome and Rotterdam is the possibility to buy entrance for a limited amount of time. Depending on the type of vehicle, the daily charge is between 130 and 260 euros. One can wonder whether this possibility will not make the LEZ operate as an extra tax rather than an ambitious plan to clean the air. Still, business owners will most likely avoid paying the tax and try to upgrade their vehicle fleet. In 2013, the effectiveness of the London LEZ was reviewed (Ellison, Greaves & Hensher). They concluded from their research that the LEZ has changed the London vehicle fleet. Light commercial vehicles were often used to replace older and bigger lorries and there has been a decrease in vehicles that did not match the Euro III standards. The city has also seen slight reductions in the PM_{10} and NO_x levels. The PM_{10} reductions seem to be larger than outside the LEZ region but the NO_x reduction is similar to areas without an LEZ in place.

Although there are only marginal effects and there are many other systems in place to reduce the emissions in the city, the research concludes that the LEZ at least played some role in the reduction of harmful gases in London.

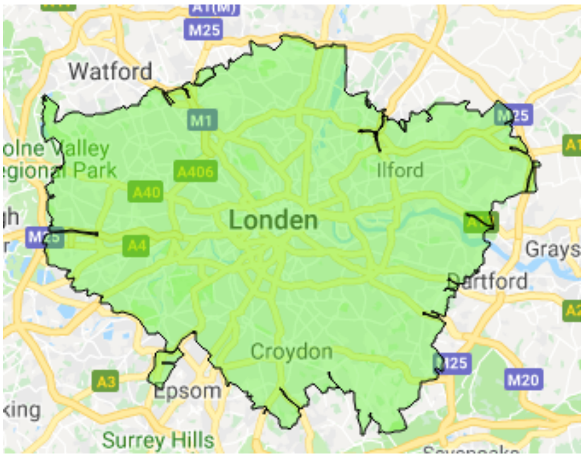

Figure 4. LEZ London. Source: Transport for London

The European Commission on Transport and Mobility (2018) also presented some impacts of LEZ's in European cities. An example of this is Berlin, where it was found that between 2007 and 2010 there has been a 58% reduction of diesel particles, a 20% reduction in NO_x emissions and a reduction of PM_{10} exceedances of the EU norm from 28 to 24. In Cologne, the NO_x and PM_{10} values have decreased more than in the surrounding areas. In Stockholm, $PM_{0.2}$ concentrations decreased between 0.5% and 9% in the suburbs and the city centre respectively.

These statistics seem to suggest that LEZ's are efficient in reducing the air pollution. However, it must be noted that many studies used simple statistical methods that did not properly incorporate all contributing factors (Holman, Harrison & Querol, 2015). This research stated that for German cities, the average reductions of PM_{10} and NO_x were 7% and 4% respectively. Even though the LEZ's may have contributed to this, the other factors that caused this trend should be considered as well. When these other factors are not considered in the statistical methods, the results must be critically assessed. According to the article, studies with more advanced statistical methods have in fact shown that the LEZ can slightly reduce the levels of PM_{10} and NO_x. Additionally, for the case of Rotterdam in particular, the results may have been slightly simplified on purpose in order to get public opinion in favour of the debated

LEZ. Because of this, the presented results may give an indication of the effectiveness of the LEZ's in those cities, but they should be critically assessed on their validity and conclusions that do not incorporate the flaws of a simple model should be rejected.

Chapter 4: Empirical Research

While chapter 2 provided the necessary literary background information, chapter 4 offers an empirical research. The aim of this empirical research is to see whether there is a positive correlation between having an LEZ in a city and the air quality. If this relationship is found to be significant, it can be concluded that the European LEZ's fulfil their purpose. In the research, a number of LEZ's will be looked at and their influence on the air quality will be assessed.

4.1 Data

Data was collected from 134 cities that have an LEZ in the Netherlands, Germany, Belgium, France, the UK, Austria, Italy, Denmark, Sweden, Portugal and Greece. This data, retrieved from the website of the European Commission of Mobility and transport (2018), included the type of zone, the date of implementation, the enforcement and security, the scope and the exemptions. This basic background data gives an initial insight in the types of LEZ's that are currently present in Europe and will then be linked to statistics about the air quality.

Data on the air quality of these cities were retrieved from the website of the World Health Organisation (2018). Not all 134 cities were included in the research. A selection was made of cities with the most reliable and available data. Although it is not the only pollutant that results from transport, PM_{10} was used as an indicator for the changed air quality due to an LEZ. PM_{10} is particulate matter with an aerodynamic diameter smaller than 10μm. This was used as the indicator because of the relatively big part transport plays on its concentration in the air and the relatively big amount of data that was available for it. Not all PM emissions can be attributed to the transport sector. However, a research in Birmingham, which included hourly PM_{10} and $PM_{2,5}$ measurements during a six-month period, estimated that vehicle emissions accounted for 32% of total PM_{10} emissions and 41% of total $PM_{2,5}$ emissions (Harrison, Deacon, Jones & Appleby, 1997). Research in Berlin has led to the conclusion that around 50% of all PM_{10} pollution in a busy street results from transport (Lenschow et al., 2001). This happens in the form of exhaust, emissions, tyre abrasion, resuspension of soil and traffic influence from the city background. Additionally, it was found that concentrations of

PM_{10} are 40% higher in the city centre than in the urban background. Approximately 55% of this additional pollution is the result of vehicle emissions and tyre abrasion. Although there are also other big sources of particulate matter, a change in the emission of transport can have a significant impact on general PM levels.

In order to gain more insight in trends of the different industries and their impact on the emission of particulate matter, additional data was collected on the emission of different industries on a national level. This information can help to identify to what extent the transport sector is responsible for a change in PM_{10} values.

The years that were considered are 2008 and 2013. These years were chosen since this timeframe of 5 years is often a before/after implementation comparison. Even if this is not the case, information on the effects of the environmental zone over time is still valuable. Additionally, a control group of cities in the same countries was used. This extensive control group can be useful to identify trends in PM_{10} emissions that are unrelated to the LEZ's.

4.2 Results

It is clear that not all LEZ's operate in the same way (appendix A). There is a wide differentiation within and between countries. Although with slight differences, the Netherlands, Germany, Austria and Denmark seem to have a national policy whilst the LEZ's in Italy, France and Belgium are more diverse. The scope of the LEZ refers to the requirements of vehicles to enter the zone. This is measured by the European emission standards, ranging from Euro I to Euro VI for now and further in the future. A differentiation is made between light/heavy vehicles and diesel/petrol, table 1 gives an overview of the requirements for certain standards for heavy-duty vehicles.

Table 1. EU Emission Standards for Heavy-Duty Diesel Engines: Steady-State Testing. Retrieved from: https://dieselnet.com/standards/eu/hd.php

Stage	Date	Test	CO	HC	NOx	PM	PN	Smoke
			g/kWh				1/kWh	1/m
Euro I	1992, ≤ 85 kW	ECE R-49	4.5	1.1	8.0	0.612		
	1992, > 85 kW		4.5	1.1	8.0	0.36		
Euro II	1996.10		4.0	1.1	7.0	0.25		
	1998.10		4.0	1.1	7.0	0.15		
Euro III	*1999.10 EEV only*	ESC & ELR	*1.5*	*0.25*	*2.0*	*0.02*		*0.15*
	2000.10		2.1	0.66	5.0	0.10[a]		0.8
Euro IV	2005.10		1.5	0.46	3.5	0.02		0.5
Euro V	2008.10		1.5	0.46	2.0	0.02		0.5
Euro VI	2013.01	WHSC	1.5	0.13	0.40	0.01	8.0×10^{11}	

a - PM = 0.13 g/kWh for engines < 0.75 dm^3 swept volume per cylinder and a rated power speed > 3000 min^{-1}

Some municipalities allow retrofitting to pass the requirements and enter the LEZ while others do not. Retrofitting is the practice of applying new parts to an older vehicle in order to upgrade it and reduce its emission. Even though the vehicle is still old and would normally not meet the requirements, it does now.

There is also variety in the way the LEZ is enforced and what the fines are. Differences in operation include the security, some countries use license plate detection while others use a stickers system. Also, some LEZ's operate permanently and without a possibility to pay an entrance fee, others only operate at specific times, specific months or allow people to buy an access ticket. The fine for not obeying the rules vary significantly as well, ranging from 80 euros in Germany up to a maximum of 2700 euros in Denmark.

Finally, there is an important distinction to be made in the question whether foreign trucks are affected. If not, this does not only create a form of unfair competition, but it may undermine the effectiveness of the whole project.

Appendix A also contains data on the levels of PM_{10} in 2008 and 2013, showing the changes over a five-year period. The list nearly exclusively shows decreases in PM_{10} levels over the years, there are only a few slight increases. The average change of PM_{10} levels over the five-year period in the studied European cities was -4,64 μg/m^3. The percental changes per city were then calculated and the average change was found to be -14%, which is very big in a relatively short period of time. The biggest decreases were measured in Berlin (-12,00μg/m^3), Lyon (-11,00μg/m^3), Paris (-10,03μg/m^3), Bologna (-11,75μg/m^3), Modena (-12,98) and Lisbon (-15,30μg/m^3). However, no clear pattern can be seen among the LEZ specific attributes in these cities. The cities have different scopes, retrofitting details, security and fines. Because of this, it may be questioned if the LEZ is the largest causer of the big changes.

To account for general trends in PM_{10} levels in the countries and regions LEZ's are located in, the control group (Appendix B) consist of cities located in the same countries and regions as the LEZ cities. The control group is a sample of 90 cities in different countries and regions, giving a fair representation of the natural trends in the regions of the cities where LEZ's are present. The average PM_{10} change in the control group was -2,84µg/m^3 with an average percental change per city of -10,51%. In this group, the most extreme changes occurred in Lens (-11,30µg/m^3), Montbeliard (-10,90µg/m^3), Toulon (-10,92µg/m^3), Valenciennes (-11,45µg/m^3), Volos (-9,81µg/m^3) and Braga (-15,58µg/m^3). The average decrease of the control group is lower than for the LEZ group, suggesting the LEZ did have a positive effect on the air quality. However, there are still a lot of unknown factors and from these figures alone no definitive statement can be made. Something else worth mentioning is that when comparing the number of cities that actually saw an increase in PM_{10}, a clear difference can be seen. In the LEZ group, only 5 cities (less than 10%) saw an increase in PM_{10} levels while in the control group 19 cities (over 20%) experienced this.

Figure 5 illustrates the percental changes of PM_{10} levels in the cities in the LEZ- and the control group. The numbers on the X-axis correspond to the cities in the order they appeared in the list when sorted from the lowest to the highest values. The numbers on the Y-axis correspond to the percental change of PM_{10} levels in that city between 2008 and 2013. At a first glace it seems that most cities in the control group have seen a bigger decrease than the cities in the LEZ group. However, it must be considered that the control group is significantly larger and its positive results appear further to the right. As is presented in table 2 further on, the LEZ group has a higher average reduction in PM_{10} levels. It becomes clear when looking at this figure that it may be difficult to assess the effectiveness of the LEZ's since many cities in the control group have also enjoyed improvements in air quality. What is striking, however, is the fact that very few cities in the LEZ group have experienced an increase in PM_{10} levels, in the control group this seems more common. What conclusions may be drawn from the empirical research remains to be seen.

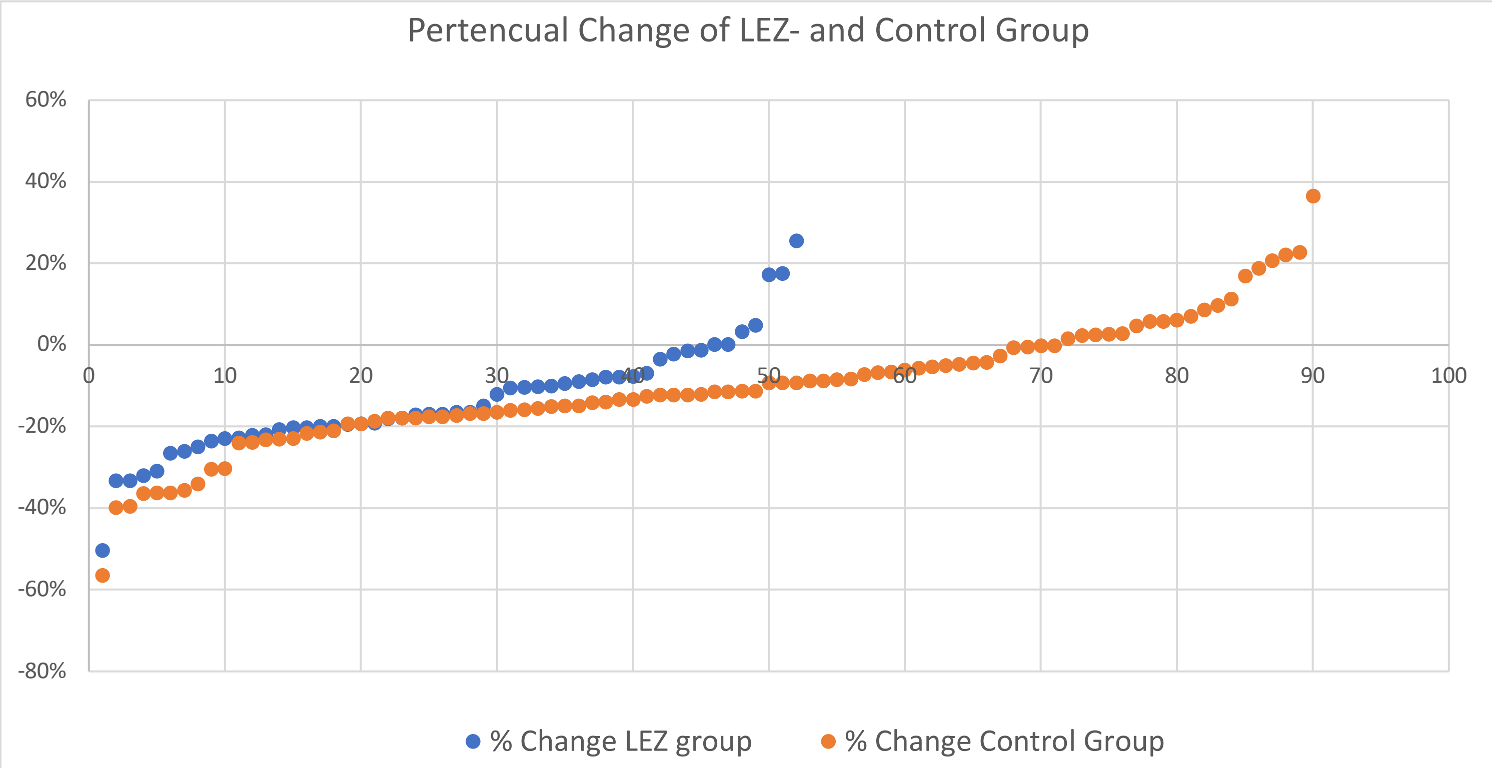

Figure 5. Percental Changes PM10 levels

In some cities there have been very big changes, as can be seen by the outliers in figure 5. It is questionable that these solely resulted from the presence or absence of an LEZ in this five-year period. They are probably (partially) the result of other projects. In order to get rid of these extreme numbers that contaminate the data set, outliers are emitted. For the absolute numbers, all changes bigger than 15 were emitted. For the percental change, all changes bigger than 35% were emitted. The results are presented in table 2 below.

Table 2. Changes in PM10 levels in LEZ- and Control Group

	With outliers		Without outliers	
	Absolute Δ PM_{10}	% Δ PM_{10}	Absolute Δ PM_{10}	% Δ PM_{10}
LEZ group	-4,64μg/m^3	-13,84%	-4,43μg/m^3	-13,12%
Control group	-2,84μg/m^3	-10,51%	-2,70μg/m^3	-8,55%

Neither one of the groups changed very much. Still, it can be seen that the percentage in the control group dropped almost 2% when the outliers were omitted. This shows us that a few outliers have affected the sample in the previous results.

As was stated before, the road transport sector is not the only emitter of PM_{10}. The biggest other sources of these emissions are energy supply and industrial processes. For simplicity, these will be grouped as 'stationary sources'. Together, road transport and stationary sources make up over 90% of all PM_{10} emissions in most countries as is illustrated in table 3.

Table 3. Percental Contribution to PM10 Emission from the Biggest Sources

	2008		2013	
	PM10 emission by road tansport	PM10 emisson from stationary sources	PM10 emission by road tansport	PM10 emisson from stationary sources
Netherlands	27%	65%	22%	71%
Germany	17%	77%	14%	82%
England	18%	72%	15%	80%
Belgium	18%	79%	14%	84%
France	15%	79%	13%	82%
Austria	20%	69%	16%	75%
Italy	14%	78%	12%	81%
Denmark	9%	86%	8%	87%
Sweden	38%	58%	41%	54%
Portugal	8%	91%	7%	92%

The stationary sources clearly play a very large role in the emission of PM_{10}. It can also be seen that the percentage of total PM_{10} emissions of road transport has decreased in all countries except Sweden and that the relative contribution of stationary has grown even further. This tells us that the emission by road transport at least grew slower than the emission of the stationary sources and it may have even decreased. Table 4 illustrates the actual changes in emission of PM_{10} on a national level.

Table 4. Percental Change of PM10 Emissions of the Biggest Sources on a National Level

	PM10 emissions by road transport 2008-2013	PM10 emission by stationary sources 2008-2013	Total PM10 emisions 2008-2013
Netherlands	-33%	-10%	-17%
Germany	-18%	8%	1%
England	-21%	6%	-4%
Belgium	-31%	-4%	-9%
France	-20%	-6%	-9%
Austria	-24%	1%	-7%
Italy	-32%	-18%	-22%
Denmark	-26%	-20%	-21%
Sweden	7%	-9%	-3%
Portugal	-29%	-20%	-20%

It now becomes clear that the total level of emissions has decreased over the time period in the considered countries and that the reduction in PM_{10} emissions has been greater for the road transport than for the stationary sources everywhere besides Sweden. In some of the countries, the stationary sources have even seen an increase in emission. In these cases, it is the road transport sector that played the biggest role in maintaining or decreasing the total emissions.

As was mentioned before, the role of transport as a source of air pollution may not be the same in all areas. For instance, the air near a busy street may be mostly polluted by that street and an area near a factory by the emission of that particular source. The research in Berlin described under '4.1 Data' on page 25 led to the conclusion that about 50% of the PM_{10} pollution near busy streets comes from the transport there (Lenschot et al., 2001). As can be seen in table 3, this is far above the national average contribution of the industry. In this way, the road transport may play a bigger role in reducing PM_{10} levels in cities than in other areas and more of the progress can be attributed to changes in this sector.

Chapter 5: Conclusion and Discussion

The literature review and the empirical part above have presented a lot of information on the LEZ's in European cities. Information has been provided on both the air quality and the economic aspects. The consequences of high levels of emissions are very serious and should be avoided. The LEZ may be an effective way to reduce emissions from road transport. The early results seem promising, but there is a lot of uncertainty regarding the other factors that may influence the emission levels. The economic consequences were considered as well. Even though this part was limited to a literature review only, it offered insights with respect to the general situation. It has told us that not only the implementation and enforcement costs count, but also the effects on business, the social costs and the effects on a firms' competitive position.

It has also become clear that there might not be one conclusive answer to the question whether an LEZ is worth the investment it requires. Because of this, using the information we have gathered, one must personally interpret the information and form his or her own conclusions. The costs and benefits of an LEZ must be assessed in order to come to a conclusion about its relative efficiency. The costs of the LEZ mostly include two major groups. Namely the costs for governments or municipalities as a result of implementing and maintaining the zone and the costs for businesses when changing the vehicle fleet. Additionally, the non-uniformity of the regulations in LEZ's can cause unfair competition. The benefits on the other hand are mostly related to the positive (or less negative) environmental results of the cleaner air and the health benefits for citizens. On top of that, the social benefits as a result of a cleaner and less noisy city centre should be incorporated as well. When trying to calculate the net effect of the LEZ, two difficulties arise.

The first difficulty is caused by the fact that not all benefits can be expressed in a monetary amount. Using the 'Value of Statistical Life' (EPA, 2000) it was calculated that the health benefits in Germany would amount to 1,98 billion dollars (Wolff, 2014). Of course, this calculation is questionable to begin with as it puts a price on human life. Even when this method is used, it may be even more difficult to put a price on environmental and social benefits. Expressing the value of a human life, noise, smell and environment in terms of money is very unnatural and difficult. The cost side also has its own problems. Even though the costs can be expressed in monetary terms, they may be difficult to predict. Especially the change of the vehicle fleet and the competition effects cannot be predicted in detail. Wolff (2014) roughly predicted a total of one billion dollars would be needed to upgrade the vehicle fleet in Germany. The decision of the entrepreneurs that are affected by the LEZ can however turn out to be different. All in all, the difficult job of expressing all aspects in monetary terms creates a lot of uncertainty about the effectiveness.

The second difficulty arises from the fact that the LEZ's are relatively new and their effectiveness in terms of improving the air quality cannot be stated with certainty. Some researches on early results have been presented in the literature section, especially with a focus on one city or region. The empirical research in this paper has widened the scope to include many cities in multiple countries. This difficulty of not having enough data is a limiting factor of previous- as well as this research. However, unlike the first difficulty, this problem will disappear if the LEZ's will stay in place for a longer period of time and are monitored properly.

In the past, most studies have seen a positive correlation between air quality and the presence of an LEZ. However, as was explained before, some of these studies cannot be trusted due to their simplicity. This paper also fails to take all other air-quality factors into account, but the comparison with the control group is still meaningful. This control group is quite extensive and representative of the areas in which the LEZ's are located. Also, much of previous research has been done on a smaller scale, this paper aims to add to the discussion more information about the broader efficiency since it focussed on Europe in its entirety. The focus of this research was on the following research question:

'To what extent are LEZ's effective in improving the air quality in European cities and what are the economic consequences?'

This research question does not have one decisive answer right now. When answering the first part of the question, one must keep in mind the uncertainty and limitations of the empirical research. Although there seems to be evidence of a positive relationship between air quality and the presence of an LEZ in cities throughout Europe, the size and exact nature of this relationship cannot be stated without doubt.

As far as the second part of the question is concerned; we know where most costs and economic consequences come from, but they are difficult to quantify. To answer the question, the economic consequences mostly consist of: implementation costs, enforcement costs, costs of changing the vehicle fleet, social costs (benefits) and costs as a result of a change in the competitive position.

Clearly, this answer serves more as a general framework and starting point of further research than anything else. Even though there is no definitive answer yet, the research shows the possible potential of LEZ's and the most important consequences it has. These need to be monitored and studied in the future to come up with the definitive conclusions about LEZ's in Europe.

This paper also has some limitations. Although the paper offered a starting point with a wide framework, the statistical methods used are too simplistic to find clear and significant relationships. For simplicity, some variables that may have a major impact on air pollution were omitted from the research. These variables include the weather over the years, the trends in industries other than road transport, other initiatives to limit air pollution and the growth of cities and industries. Another limitation of this research is the choice for a static timeframe between 2008 and 2013, since not all cities introduced their LEZ within this timeframe. Although this can still show a trend due to tightening of the rules and increasing compliance, it is not an optimal situation.

Further research may benefit from a couple of changes to the empirical research above. First of all, it can try to get rid of the initial limitations. This includes incorporating all factors that may have an impact on air quality and using a flexible instead of a fixed timeframe in order to always have a before- and after implementation result.

Also, future research could benefit from larger datasets. This can come from new cities implementing an LEZ and the inclusion of more years in the existing 'LEZ cities'. In this research, the PM_{10} value is the only value effectively studied while it is not the only emission from road transport. The research could also be improved by studying the development of the levels of all pollutants that result from road transport.

Still, the research offers some important insights. Previous studies have provided a general framework for the air quality and economic effects. The empirical research in this paper, with the control group comparison in particular, adds a broadened perspective. Together, all this information suggests that an LEZ does have a positive effect on the air quality. There are, however, many uncertainties regarding the size of these effects and the others consequences of the LEZ's. This is why perhaps the most important thing for the coming years is careful monitoring of all effects, on both air quality and economics. Only then it is possible to, at some point in the future, present final conclusions on the matter.

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Appendices

Appendix A. Selection of 'LEZ cities' with most available data

Country	City	Local Name	Date implementation	LEZ scope	Retrofitting	hours per day	security	fine	Foreign trucks affected	PM10 2008	PM10 2010 (2013)	PM10 diff
Netherlands	Amsterdam	Milieu zones	09-10-08	Diesel Euro IV	no	permanent	Number plate recognition cameras	€ 230	no	23	21	-2,00
Netherlands	The Hague	Milieu zones	16-04-08	Diesel Euro IV	no	permanent	Number plate recognition cameras	€ 230	no	23	21	-1,80
Netherlands	S'-Hertohenbosch	Milieu zones	01-09-07	Diesel Euro IV	no	permanent	Number plate recognition cameras	€ 230	no	27	21	-5,20
Netherlands	Tilburg	Milieu zones	01-09-07	Diesel Euro IV	no	permanent	Number plate recognition cameras	€ 230	no	27	21	-6,40
Netherlands	Utrecht	Milieu zones	01-07-07	Diesel Euro IV	no	permanent	Number plate recognition cameras	€ 230	no	26	21	-4,40
Germany	Augsburg	Umweltzones	01-06-16	Diesel Euro IV and Petrol Euro I	yes	permanent	Stickers, police	€80 (plus adm.)	yes	25	23	-2,00
Germany	Berlin	Umweltzones	01-01-10	Diesel Euro IV and Petrol Euro I	yes	permanent	Stickers, police	€80 (plus adm.)	yes	36	24	-12,00
Germany	Bremen	Umweltzones	01-07-11	Diesel Euro IV and Petrol Euro I	yes	permanent	Stickers, police	€80 (plus adm.)	yes	26	20	-6,00
Germany	Frankfurt	Umweltzones	01-01-13	Diesel Euro IV and Petrol Euro I	yes	permanent	Stickers, police	€80 (plus adm.)	yes	27	27	0,00
Germany	Karlsruhe	Umweltzones	01-01-13	Diesel Euro IV and Petrol Euro I	yes	permanent	Stickers, police	€80 (plus adm.)	yes	21	19	-2,00
Germany	Mainz	Umweltzones	01-02-13	Diesel Euro IV and Petrol Euro I	yes	permanent	Stickers, police	€80 (plus adm.)	yes	21	21	0,00
Germany	München	Umweltzones	01-10-12	Diesel Euro IV and Petrol Euro I	yes	permanent	Stickers, police	€80 (plus adm.)	yes	26	21	-5,00
England	London	LEZ	04-02-08	Diesel Euro IV	yes	permanent	Number plate recognition cameras	€ 650,00		29	22	-6,38
Belgium	Antwerp	Lage-emissiezone	01-01-17	Diesel Euro III and petrol Euro I	yes	permanent	Number plate recognition cameras	€ 125,00	yes	23	27	3,91
Belgium	Brussels	Lage-emissiezone	01-01-18	Diesel Euro II	no	permanent	Number plate recognition cameras	€ 350,00	yes	28	26	-2,52
Belgium	Gent	Lage-emissiezone	01-01-20	Diesel Euro V and petrol Euro II	yes	permanent	Number plate recognition cameras	€ 125,00		25	30	4,43
France	Grenoble	ZCR	01-01-17	Diesel Euro IV and Petrol Euro I	no	Monday 6:00 - Friday 19:00	stickers, police	€ 135,00	yes	28	24	-4,26
France	Lille	ZPA			no	NOx limit	police	€ 135,00	yes	29	22	-7,36
France	Lyon	ZPA			no	NO2limit	police	€ 135,00	yes	33	22	-11,00
France	Marseille	ZPA			no	NO2limit	police	€ 135,00	yes	31	29	-2,16
France	Paris	ZCR	01-01-17	Diesel Euro IV	no	Monday 8:00 - Friday 20:00	stickers, police	€ 135,00	yes	38	28	-10,03
France	Strasbourg	ZPA			no	NOx limit	police	€ 135,00	yes	20	25	5,08
Austria	Graz			Euro III	yes	permanent	police	€90-€2182	yes	30	25	-5,49
Austria	wien		01-01-08	Euro III	yes	permanent	police	€90-€2186	yes	25	26	1,17
Italy	Bergamo									40	32	-8,03
Italy	Bologna	ZTL	01-01-16	Diesel Euro IV and Petrol Euro II	yes	Monday-Friday 8:30-18:30	handbook, police	€75-€450	yes	37	25	-11,75
Italy	Brescia	ZTL	15-10-2017 (winter Seasonal)	Diesel Euro III and petrol Euro I	yes	Monday-Friday 7:30-19:30	handbook, police	€75-€450	yes	41	37	-4,26
Italy	Cremona	ZTL	16-10-2017 (winter seasonal)	Diesel Euro III and petrol Euro I	yes	Monday-Friday 7:30-19:30	handbook, police	€75-€450	yes	39	35	-4,16
Italy	Firenze	ZTL		Diesel Euro II and Petrol Euro II	yes	8:30-12:30 and 14:30-18:30	handbook, police		yes	35	26	-9,20
Italy	Forli	ZTL	01-01-16	Diesel Euro IV and Petrol Euro II	yes	Monday-Friday 8:30-18:30	handbook, police	€75-€450	yes	30	24	-5,82
Italy	Genova	ZTL		Euro III	no		handbook, police		yes	23	21	-2,34
Italy	Milano	ZTL		Diesel Euro III and Petrol Euro I	yes		handbook, police		yes	44	37	-7,34
Italy	Modena	ZTL	01-01-16	Diesel Euro IV and Petrol Euro II	yes	Monday-Friday 8:30-18:30	handbook, police	€75-€450	yes	42	29	-12,98
Italy	Napoli	ZTL			yes	depending on zone	handbook, police		yes	44	35	-9,22
Italy	Novara	ZTL		Diesel Euro III and petrol Euro I	yes	8:30-11:30 and 15:00-17:00	handbook, police	€75-€450	yes	28	28	-0,66
Italy	Parma	ZTL	01-01-16	Diesel Euro IV and Petrol Euro II	yes	Monday-Friday 8:30-18:30	handbook, police	€75-€450	yes	34	34	-0,49
Italy	Perugia	ZTL	10-12-2017 (winter seasonal)	Euro I	yes		handbook, police	€25-€210	no	24	22	-2,48
Italy	Prato	ZTL		Euro I	yes	8:30-12:30 and 14:30-18:30	handbook, police		yes	29	29	-0,46
Italy	Ravenna	ZTL	01-01-16	Diesel Euro IV and Petrol Euro II	yes	Monday-Friday 8:30-18:30	handbook, police	€75-€450	yes	33	27	-5,44
Italy	Reggio nell Emilia	ZTL	01-01-16	Diesel Euro IV and Petrol Euro II	yes	Monday-Friday 8:30-18:30	handbook, police	€75-€450	yes	37	31	-6,33
Italy	Rimini	ZTL	01-01-16	Diesel Euro IV and Petrol Euro II	yes	Monday-Friday 8:30-18:30	handbook, police	€75-€450	yes	35	31	-4,33
Italy	Rome Green zone	ZTL		Diesel Euro III and petrol Euro II	no		handbook, police	€ 70	yes	35	28	-6,99
Italy	Rome Rail ring	ZTL	20-11-17	Diesel Euro III and petrol Euro II	no	Monday-Friday	handbook, police		yes	35	28	-7,11
Italy	Rome city centre	ZTL		Diesel Euro III and petrol Euro II	no		handbook, police		yes	35	28	-7,11
Italy	Torino	ZTL		Diesel Euro III and petrol Euro I	yes	Mon-Fri 8:30-14:00 and 16:00-19:00	handbook, police		yes	47	39	-8,52
Italy	Trento	ZTL	01-11-2016 (Winter seasonal)	Diesel Euro III and petrol Euro II	yes	7:00-10:00 and 16:00-19:00	handbook, police		no	29	24	-4,87
Denmark	Århus	Miljøzone	01-09-10	Euro IV	yes	permanent	stickers, police	up to €2700	yes	27	21	-6,23
Denmark	Copenhagen	Miljøzone	01-09-08	Euro IV	yes	permanent	stickers, police	up to €2700	yes	26	27	0,82
Sweden	Göteborg	Trängelskatt		All, charging scheme		Monday-Friday 06:00-18:29	number plate recognition cameras	500 SEK	yes	24	19	-5,29
Sweden	Stockholm	Trängelskatt		All, charging scheme		Monday-Friday 06:30-18:29	number plate recognition cameras	500 SEK	yes	28	26	-2,26
Greece	Athens	Green Ring	30-10-17	weight > 2.2T		Monday-Friday 07:00-15:00	police		no	41	40	-1,50
Portugal	Lisbon	ZER	01-07-11	Zone 1: vehicle after 2000, zone 2: vehicle after 1996	yes	Monday-Saturday 07:00-21:00	police			30	15	-15,30

Appendix B. Selection of Control Group Cities

Country	City	PM10 2008	PM10 2013	PM10 dif 2008-2013
Netherlands	Dordrecht	25	24	-1
Netherlands	Heerlen	22	23	1
Germany	Bielefeld	23	20	-3
Germany	Chemnitz	23	20	-3
Germany	Cottbus	29	24	-5
Germany	Dresden	31	27	-5
Germany	Gera	24	20	-3
Germany	Göttingen	21	13	-8
Germany	Hamburg	23	21	-2
Germany	Ingolstadt	21	22	1
Germany	Kassel	24	24	-1
Germany	Leverkusen	21	20	-2
Germany	Lübeck	21	18	-3
Germany	Ludwigshafen a	21	22	1
Germany	Nürnberg	23	23	0
Germany	Potsdam	25	23	-2
Germany	Saarbrücken	21	19	-2
Germany	Solingen	20	20	0
Germany	Wolfsburg	17	14	-3
United Kingdo	Birmingham	16	19	3
United Kingdo	Edinburgh	15	14	-2
United Kingdo	Glasgow	24	23	-2
United Kingdo	Liverpool	16	14	-2
United Kingdo	Manchester	20	18	-2
United Kingdo	Southampton	21	21	0
Belgium	Charleroi	27	23	-4
Belgium	Liège	26	22	-4
France	Aix-en-Provenc	29	24	-6
France	Ajaccio	28	24	-5
France	Amiens	26	21	-5
France	Angers	18	19	1
France	Angouleme	24	20	-4
France	Annecy	25	21	-4
France	Antibes	34	26	-8
France	Avignon	25	22	-4
France	Bayonne	20	19	-1
France	Besançon	23	22	-1
France	Bordeaux	22	22	0
France	Brest	24	20	-4
France	Caen	23	20	-3
France	Cayenne	27	33	6
France	Chambery	26	20	-6
France	Clermont-Ferra	19	17	-2
France	Dijon	19	14	-4
France	Douai	26	21	-5
France	Fort-de-France	24	33	9
France	La Rochelle	25	24	-1
France	Le Havre	28	20	-9
France	Le Mans	18	17	-1
France	Lens - Liévin	28	17	-11
France	Limoges	18	15	-3
France	Lorient	20	19	-1
France	Maubeuge	27	19	-8
France	Metz	19	22	3
France	Montbeliard	30	19	-11
France	Montpellier	23	20	-3
France	Mulhouse	25	20	-5
France	Nancy	21	23	2
France	Nantes	21	19	-2
France	Nice	33	29	-4
France	Nimes	21	21	0
France	Orléans	24	19	-5
France	Pau	21	22	1
France	Perpignan	22	17	-5
France	Pointe-a-Pitre	25	23	-2
France	Poitiers	22	18	-3
France	Reims	23	19	-4
France	Rennes	18	20	1
France	Rouen	25	21	-4
France	Saint Brieuc	18	23	4
France	Saint Denis	22	19	-3
France	Saint Nazaire	21	24	2
France	Saint-Etienne	26	17	-9
France	Toulon	31	20	-11
France	Tours	24	24	0
France	Troyes	23	19	-4
France	Valenciennes	31	20	-11
Austria	Linz	29	26	-3
Austria	Salzburg	24	25	1
Italy	Cagliari	26	31	6
Italy	Campobasso	20	22	2
Italy	Livorno	26	23	-3
Italy	Padova	43	34	-9
Italy	Taranto	27	22	-5
Italy	Venezia	36	32	-3
Sweden	Malmö	18	20	1
Sweden	Umeå	22	14	-8
Greece	Patra	44	40	-4
Greece	Volos	42	32	-10
Portugal	Braga	28	12	-16