The effect of introducing a low emission zone

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Introducing a Low Emission Zone

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by

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SUMMARY

The transportation sector is a great producer of emissions that are harmful for humans and the environment. Over the years we have become increasingly aware that our current production of emissions is not sustainable and changes need to be made. In this thesis the impact of introducing a low emission zone (LEZ) in a densely populated urban area in The Netherlands, where all fossil fuelled cars and buses are prohibited, on reducing emissions of NOx PM10 and CO2 is investigated.

The cars and buses get replaced by electrically powered versions. The reduction of emissions produced during one day within the LEZ is determined. This is done for the emissions produced within the LEZ while driving the vehicles, the direct emissions, as well as for the indirect emission produced when manufacturing a car and producing the fuel or electricity to power them.

The LEZ is assumed to be located in a densely populated urban residential area in The Netherlands, like for instance Rotterdam, because most trips are taken from and towards home and because an area with a high intensity of traffic is needed for this research. The distances travelled, for different purposes, by bus and by car during one day are taken into consideration. Whilst diesel and gasoline cars and diesel buses from different Euro-norms all produce different emissions. The ratio of the contribution of each of them is determined and used to determine the total amount of emission. The emissions get determined for both cars and buses by multiplying the emissions produced by either a bus or car from the corresponding Euro-norm with their estimated traveling distance of one day.

The relative reduction of the direct emissions of NOx and CO2 are 100% since these are not produced by electric vehicles. However the relative reduction of PM10 is determined to be 20,68%. Whilst due to the wear and tear of the road and brakes PM10 is still produced. The reduction of the indirect emissions of NOx and PM10 could not be determined, because data on this was not available. For CO2 the relative change of indirect emissions turned out to be an increase of 36,9%. The total reduction of emissions is for NOx based on only the direct reduction, so this are the same numbers mentioned before. The total reduction of CO2 emissions is 41,8%. With the limitation that the numbers used for the indirect CO2 emissions of buses are the green house gas equivalent of the CO2 emissions, whilst the CO2 emissions of cars only include emitted CO2.

For cars the investment is still very big and manufacturing is still environmentally unfriendly. Concerning the costs there is a big difference between introducing electric cars and electric buses. Owning a car would become almost twice as expensive, this would make driving a car cost around €20,75 a day per person more. Introducing electric buses would only cost €0,23 extra per person per day.

For further research the data needs to be more recent, a more accurate representation of the situation and needs to be acquired in the same way. On top of that more groups of traffic need to be included and the influence on peoples traveling behavior should be investigated in the future.

So based on this research in can be concluded that introducing a LEZ would be a great step forward to reduce air pollution and greenhouse gas emissions overall, but especially for electric cars the process of manufacturing and producing electricity to power them needs to become more environmentally friendly and is still expensive. To determine the exact effect of electric buses on emissions, more data is needed still, but introducing them already reduces direct emissions and is not very expensive and is expected to become even cheaper in the next couple of years.

Preface

To complete my bachelor of science in Civil Engineering I need to write a bachelor thesis. After completing my bachelor I would like to go on studying and want to follow the track of Transport and Planning. That is why I chose a subject in this direction for my BSc thesis. I would like to thank my supervisors Milan Janić, Rolf Koster and Yufei Yuan for there advice and comments on my work.

R.S. Holster
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INTRODUCTION

Over the years we have become increasingly aware of the fact that our current consumption of energy is not sustainable and changes need to be made. According to the European Conference of Ministers of Transport (ECTM) transportation accounted for 24% of the production of C02 worldwide, in 2003 [1].

On top of that studies have proven that the emissions of motor vehicles, like particulate matter (PM10) and nitrogen (NOx), can be harmful to people. Especially in densely populated cities, where high concentration of air pollution can be found, this can cause problems for the public health. It is estimated that on a yearly basis 2300, to 3500 people die, a few days or even months earlier, due to short-term exposure to particulate matter and the effects of long-term exposure are still unclear, but are expected to be even greater than the short-term effects [2]. Reports from the World Health Organisation (WHO) are also showing more evidence of the health effects due to long-term exposure to nitrogen [3].

In an attempt to reduce the emission of green house gasses and limit the negative effects on public health emissions from vehicles cause, some cities have decided to introduce low emission zones (LEZ's). These are areas where access for vehicles is restricted by the emissions standards they were originally designed to meet. LEZ's are mostly used to reduce the amount of particulate matter emissions in the air. Currently the most common LEZ's only restrict heavy duty vehicles (HDV) and very old diesel fueled vehicles, because these cause the most emissions of NOx and particulate matter. But according to some studies LEZ's have only had a limited effect on the improvement of the air quality [4].

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GOAL

In this thesis the effects of introducing a low emission zone, in a fictional urban densely populated residential area within The Netherlands, on the emissions and urban mobility will be investigated. For this thesis it is assumed that all fossil fueled motor vehicles are excluded from the area, except for emergency services that need to reach the area. Introducing a LEZ will not be received well in some regions. Therefore a choice for an area with a higher chance of acceptance is chosen. In the section below the choice for the type of area where the LEZ will be introduced is explained. By considering the population density, the age and level of education of the population and the purpose of the trips people take.

But you cannot introduce a LEZ without offering an alternative. For this thesis two options will be compared.

- Offering electrically powered public transport
- Introducing electric bikes and cars

The most important thing to investigate in this thesis is the change in emissions the LEZ will cause. To be more specific, the emissions that will be looked at are: particulate matter, NOx and CO2. For these emission we will compare the current situation, of the number and sort of cars within the zone, to the amount of emission after the alternatives are introduced.

So to summarise the goal of this thesis is to investigate the effect on the amount of emissions mentioned above, when a low emission zone is introduced. When this zone is chosen the current situation will be compared to the amount of emission when the alternative modes of transportation are introduced. The first one of these alternatives being; providing an electrically powered and reliable public transportation system. The other one being; introducing electrical bikes and cars. So the main research question is: Does the LEZ contribute to the reduction of the emission of particulate matter, NOx and CO2, every day? And is it worth investing in the new electric cars and electric buses?

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DEMARCATION

3.1. DENSELY POPULATED

As mentioned in the introduction, Chapter 1, high concentrations of particulate matter and nitrogen are harmful to people. Whilst more people also means there is more traffic, because people themselves produce more travellers kilometers and more services like delivery of goods are necessary. Moreover in a more densely populated area, more people get affected by the air pollution. On top of that people in urban areas have better access to public transport and the percentage of households that do not own a car is already much higher than in rural areas. This would make introducing an LEZ easier [5]. Therefore in this study an area that would resemble a densely populated area within The Netherlands, so an urban area. In some densely populated neighbourhoods in Rotterdam has around 15.000 inhabitants. So this is the amount of residents that are assumed to live in the LEZ.

3.2. PURPOSE OF TRIPS

Most people take a trip from and towards their homes. Around 94% of the trips taken by people has home as the basis. On top of that is according to a British study commuting the purpose of a trip people would most likely consider taking without a car [5]. This is why for this thesis a residential area is chosen as the basis of the LEZ, from where people travel, to work, school or another activity.

Although the focus for this thesis is on a residential area in a city in The Netherlands there will still be supermarkets and some other shops located in within the LEZ that need to be stocked. On top of that there are mail and package delivering services that want to enter the area. The mail and package delivery services could probably switch to smaller electric vehicles and (electrical) bikes, as some of them are already doing in cities. A case study preformed in Italy has already shown the environmental and social effectiveness and also demonstrated the economic probability of introducing E-bikes and E-scooters[6].

But the big trucks stocking supermarkets and shops pose a bigger problem. A solution could be introducing distribution hubs outside the LEZ. From that point on the goods need to be distributed with electrically powered or at least hybrid vehicles. These hubs should facilitate the bundling of goods, to reduce the amount of trips within the area to a minimum. This solution is based on the report of Natuur & Milieu that sketches a solution for the future of a livable and car free city [7]. For this thesis the focus will be on passenger traffic, but it should be noted that introducing the changes mentioned above are also necessary when a LEZ excluding all motorised vehicles is introduced.

The purpose of trips that will be taken into account can be found in Appendix A. These are used because they account for most of the trips people take. These numbers provides the average distance one person travels every day for a certain purpose. This are the numbers from an urban area in The Netherlands. These urban areas are densely populated and therefor give use-full information. These will be used to calculate the emissions.

3.3. Time of measuring

To make an accurate assumption of the emissions within the area, the emissions that are produced during one whole day are taken into account. It is assumed that on most days the emission will be similar, although this might not be true for Sundays, the amount of trips is much lower than, but the distances travelled are often longer. So for this thesis the average for one day is used.

3.4. Mode of transportation

As said two alternatives will be introduced in the LEZ when fossil fuelled transport is prohibited. For public transport within the LEZ there will be looked at the emissions from busses. Most light rail system are already powered electrically, so those will not have to change. But most buses do need replacement. In some cities in The Netherlands electric busses have already been introduced. In The Hague for instance, these were introduced by HTM, a public transport operator in The Hague, in December of 2018. These bussed in The Hague have proven they work and The Hague wants all busses to be clean in 2030. By powering them electrically or in some other way that is invented in the years to come [8]. Next to that the difference in emissions between driving a fossil fuelled passenger car and an electric car will be investigated.

3.5. Traveling kilometer produced by residents

To determine the traveling kilometers of people that live in the LEZ the average distance for a day from an urban area in The Netherlands are used. To determine the driving kilometers of one day the distances travelled as a driver of a car and by bus will be used. It is assumed that when the LEZ is introduced around 15.000 will be living in the area and get directly effected by it. [9].

3.6. Emissions taken into account

It is expected that excluding fossil fueled vehicles will reduce the amount of emissions produced within. However introducing electrically powered vehicles does not necessarily mean less emission get produced over all. Making electricity is currently still done mostly by burning fossil fuels. This is also a factor that will be taken into account when comparing the current situation to the new. If it turns out the direct emissions in the LEZ produced by driving a car reduce, but the total emissions in the life-cycle of a car increase, introducing the LEZ might not be considered successful. With the life-cycle emission of a car, the emissions produced when manufacturing the car and producing the fuel for the car are meant.

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Impact on people

Introducing a LEZ will have a large impact on the area. In the chapter below the stakeholders on which the LEZ will have the biggest influence are discussed and after that also the possible change in behavior of people is presented.

Stakeholders

Introducing a LEZ will have a large impact on the area. Not all stakeholders involved will, initially, be happy with its introduction. To make sure the introduction is accepted the stakeholders need to be known and there opinion on the LEZ needs to be monitored. In Figure 4.1 a power matrix of the stakeholders that are mentioned in this chapter is presented. In this figure the power and the interest of the stakeholders is presented. In Appendix G a more elaborate description is given.

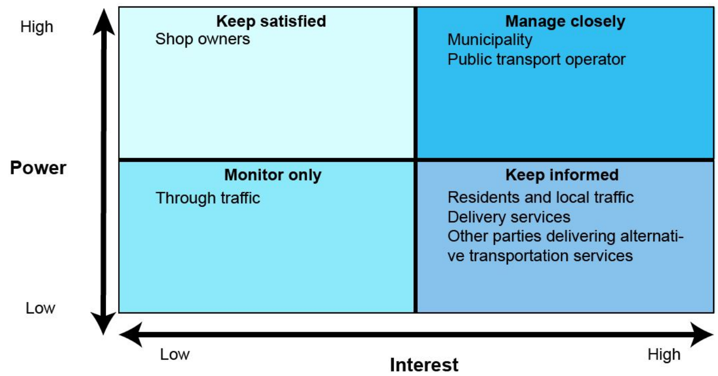

Figure 4.1: Power matrix of stakeholders

The municipality that introduces the LEZ needs to keep the wishes of these stakeholder in mind and than especially the residents of the area and the public transport operator. The most important stakeholders are the residents of the area, because they need to make changes in their traveling behavior by purchasing a new, often more expensive, electric car or swapping to a different mode. But they will also hopefully benefit from the cleaner air. For the public transport operator the LEZ means investments in new electric buses. So they need to be willing to do that and need to know on time that this investment is necessary. The position of the other stakeholders is less important for the scope of this thesis and is therefor explained further in Appendix G.

Redistribution of transportation

By introducing the LEZ, there is a change in certain links in the transportation system, as they are mentioned in the circle of Wegener. The most important changes in this case are probably the change in transportation mode, traveling time, the costs and maybe even the change in accessibility. These factors influence one another as is shown in the picture, of an adapted version of the circle from Wegener, below in Figure 4.2.

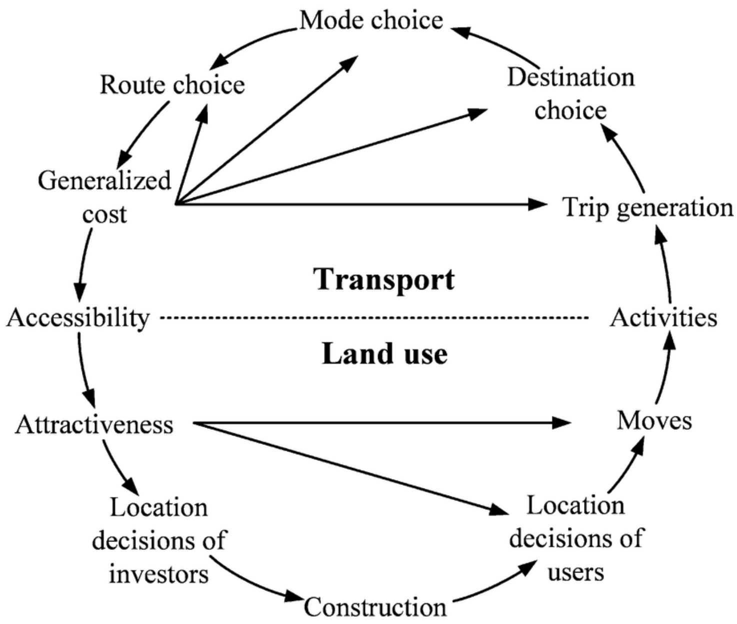

Figure 4.2: The transport-land use feedback cycle (adapted from Wegener, 1996)[10]

This means that even though for now we assume the demand for traveling stays the same and this will also be distributed over the different modes of transportation in the same way, this might not be the case for the different stakeholders mentioned above.

The route choice of through traffic will probably change significantly. They will try to avoid the LEZ, because that is much easier than changing their mode of transportation. This might cause extra strain on the roads surrounding the LEZ and cause more emissions in the surroundings of the LEZ.

5

METHOD

In this chapter the approach to calculate the emissions and the costs of the benchmark case and the new LEZ will be explained. A more elaborate explanation of certain steps is given in Appendix B. In this chapter some terms are abbreviated in the calculations. The Table 5.1 below shows how:

Table 5.1: Symbols used

Term	Symbol
Emissions	E
Driving kilometers	DK
Euro-norm	EU-N

5.1. EMISSIONS IN THE CURRENT SITUATION

To decide if introducing the low emission zone is a success, there needs to be a "benchmark case" to compare it to. The current situation within the area is chosen as this starting point for this thesis. In this chapter the criteria on which the current situation will be judged are explained and all the factors that will be taken into account are determined. First the way in which the types of cars that drive in the LEZ are estimated is shown. Than how the driving kilometers, used to determine the emissions, are calculated is explained. Lastly its is shown how the emissions are calculated.

AMOUNT OF CARS AND BUSES OF EACH TYPE IN CURRENT SITUATION

Diesel powered cars and buses will produce more emissions than lighter gasoline powered cars. However it is important for this study to make a good estimate of the influence of all cars and buses combined in the current situation and also for the gasoline powered cars. There needs to be an estimation made on how many cars of each type, gasoline or diesel powered are driving around and to what Euro-norm they belong. These Euro-norms determine how much emissions a car produces. A further explanation on these Euro-norms is given in Appendix B. For buses it also needs to be determined which buses are driven currently. The assumptions and calculations for this are also shown.

The ratios of the different types of cars are presented in Table 5.2 below:

Table 5.2: Ratio of types of cars

Cars	Ratio
Gasoline/total cars	Amount of gasoline cars/(Amount of gasoline cars + diesel cars)
Diesel/total cars	Amount of diesel cars/(Amount of gasoline cars + diesel cars)
EU-N V/EU-N V and VI	Total DK gasoline EU-N V/(Total DK gasoline EU-N V +Total DK gasoline $EU_N VI$)
EU-N VI/EU-N V and VI	Total DK gasoline EU-N VI/(Total DK gasoline EU-N V + Total DK gasoline EU-N VI)

The way the ratio for the different types of buses is determined is shown in Table 5.3.

Table 5.3: Ratio types of buses

Buses	Ratio
EU-N EEV/total buses	Amount of EU-N EEV buses/(Amount of EU-N EEV buses + Amount of EU-N VI buses
EU-N VI/total buses	Amount of EU-N VI buses/(Amount of EU-N EEV buses + Amount of EU-N VI buses

Driving kilometers

In this section the way the total driving kilometers for one day are determined is explained. Starting with the driving kilometer by car and after that the ones for the buses.

Total DK/day by car= DK by car commuting + DK by car services/care-taking + DK by car shopping + DK by car going to school + DK by car visiting + DK by car leisure activities

In Table 5.4 below the way the driving kilometers for each type of car are determined is shown.

Table 5.4: Driving kilometers for each type of car

Cars	DK/day for each type of vehicle
Gasoline EU-N V	Total DK by car * Ratio gasoline/diesel * ratio EU-N V/ EU-N VI
Gasoline EU-N VI	Total DK by car * Ratio gasoline/diesel * ratio EU-N VI/ EU-N V
Diesel Eu-N V	Total DK by car * Ratio diesel/gasoline * ratio EU-N V/ EU-N VI
Diesel Eu-N VI	Total DK by car * Ratio diesel/gasoline * ratio EU-N VI/ EU-N V

The driving kilometers by bus are presented in the following section.

Total DK/day by bus= DK by bus commuting + DK by bus services/care-taking + DK by bus shopping + DK by bus going to school + DK by bus visiting + DK by bus leisure activities

In Table 5.5 below the way the driving kilometers for each type of bus are determined is shown.

Table 5.5: Driving kilometers for each type of bus

Buses	DK/day for each type of vehicle
EU-N EEV	Total DK by bus * ratio EU-N EEV/ EU-N VI
EU-N VI	Total DK by bus * ratio EU-N VI/ EU-N EEV

Direct emissions in current situation

In the tables, Table 5.6 and Table 5.7 it can be seen which direct emissions are taken into account and the calculations for all direct emissions are presented.

Table 5.6: Direct emission of cars in current situation

Cars	NOx (g) Burning of fuel	PM10 (g) Burning of fuel Wear and tear of road and brakes	CO2 (g) Burning of fuel
Gasoline EU-N V	E NOx * DK gasoline car EU-N V	E PM10 * DK gasoline car EU-NV	E CO2 * DK gasoline car EU-N V
Gasoline EU-N VI	E NOx * DK gasoline car EU-N VI	E PM10 * DK gasoline car EU-NVI	E CO2 * DK gasoline car EU-N VI
Diesel EU-N V	E NOx * DK diesel car EU-N V	E PM10 * DK diesel car EU-NV	E CO2 * DK diesel car EU-N V
Diesel EU-N VI	E NOx * DK diesel car EU-N VI	E PM10 * DK diesel car EU-NVI	E CO2 * DK diesel car EU-N VI

Table 5.7: Direct emissions of buses in current situation

Buses	NOx (g) Burning of fuel	PM10 (g) Burning of fuel Wear and tear of road and brakes	CO2 (g) Burning of fuel
Diesel EU-N V	E NOx * DK bus EU-N V	E PM10 * DK bus EU-N V	E CO2 * DK bus EU-N V
Diesel EU-N VI	E NOx * DK bus EU-N VI	E PM10 * DK bus EU-N VI	E CO2 * DK bus EU-N VI

Indirect emissions in current situation

In Table 5.8 and Table 5.9 presented below the indirect emissions, that are taken into account for this thesis are presented and the way each of them should be calculated.

Table 5.8: Indirect emissions of cars in current situation

Cars	NOx (g) Manufacturing Producing fuel	PM10 (g) Manufacturing Producing fuel	CO2 (g) Manufacturing Producing fuel
Gasoline EU-N V	E NOx * DK gasoline car EU-N V	E PM10 * DK gasoline car EU-NV	E CO2 * DK gasoline car EU-N V
Gasoline EU-N VI	E NOx * DK gasoline car EU-N VI	E PM10 * DK gasoline car EU-N VI	E CO2 * DK gasoline car EU-N VI
Diesel EU-N V	E NOx * DK diesel car EU-N V	E PM10 * DK diesel car EU-N V	E CO2 * DK diesel car EU-N V
Diesel EU-N VI	E NOx * DK diesel car EU-N VI	E PM10 * DK diesel car EU-N VI	E CO2 * DK diesel car EU-N VI

Table 5.9: Indirect emissions of buses in current situation

Buses	NOx (g) Manufacturing Producing fuel	PM10 (g) Manufacturing Producing fuel	CO2 (g) Manufacturing Producing fuel
Diesel EU-N V	E NOx * DK bus EU-N V	E PM10 * DK bus EU-N V	E CO2 * DK bus EU-N V
Diesel EU-N VI	E NOx * DK bus EU-N VI	E PM10 * DK bus EU-N VI	E CO2 * DK bus EU-N VI

5.2. Emissions in the new LEZ

In the LEZ, private cars and other gasoline powered motor vehicles will be prohibited and the alternatives will be introduced. To determine the emissions of electric cars the amount and duration of the trips is needed. For this the same numbers as used in the benchmark case for the traveling kilometers will be used. However there are no longer different types of vehicles, just electric cars or electric buses. So to calculate the total driving kilometer can be used.

Direct emissions in new LEZ

Below the way the direct emissions of electric vehicles are determined are presented in Table 5.10.

Table 5.10: Direct emissions of electric vehicles

	NOx (g) produced while driving	PM10 (g) produced while driving	CO2 (g) produced while driving
Electric cars	E NOx electric cars * Total DK by car	E PM10 electric cars * Total DK by car	E CO2 electric cars* Total DK by car
Electric buses	E NOx electric buses* Total DK by bus	E PM10 electric buses* Total DK by bus	E CO2 electric buses* Total DK by bus

Indirect emissions in new LEZ

For electric cars the indirect emissions are also taken into consideration. The way these are calculated is presented in Table 5.11.

Table 5.11: Indirect emissions of electric vehicles

	NOx (g) produced during manufacturing and for electricity production	PM10 (g) produced during manufacturing and for electricity production	CO2 (g) produced during manufacturing and for electricity production
Electric cars	E NOx electric cars * Total DK by car	E PM10 electric cars * Total DK by car	E CO2 electric cars* Total DK by car
Electric buses	E NOx electric buses* Total DK by bus	E PM10 electric buses* Total DK by bus	E CO2 electric buses* Total DK by bus

5.3. Calculating the costs of ownership

Using a car or public transport costs money. For the public transport you pay a certain price dependent on what the operator determined as the price of using their services. For busses in The Netherlands you pay the basic rate and than a certain rate per kilometer determined by the operator. For a car the costs include the purchasing price, the fuel or electricity, insurance and road taxes. There has been done some research done on the costs of different vehicles these numbers will be used for this thesis. Dependent on the source these are already presented in €/kilometer or need to be recalculated to that form. After that the totals cost can be determined as shown in Table 5.12 and Table 5.13.

Table 5.12: Costs of cars

Cars	Costs (€)
Gasoline	(DK gasoline car EU-N V + DK gasoline car EU-N VI) * cost per DK of a gasoline car
Diesel	(DK diesel car EU-N V + DK diesel car EU-N VI) * cost per DK of a diesel car
Total in current situation	Costs of Gasoline cars + Costs of Diesel cars
Electric (total in new LEZ)	Total DK by car * costs per DK of an electric car

Table 5.13: Costs of buses

Cars	Costs (€)
Diesel (total in current situation)	(DK bus EU-N EEV + DK bus EU-N VI) * cost per DK of a diesel bus
Electric (total in new LEZ)	Total DK by bus* costs per DK of an electric bus

When all the traveling kilometers, car types and bus types are determined the emissions will be calculated the absolute numbers on the emissions and the costs of the benchmark case and the LEZ will be presented in Chapter 7. Next to these absolute numbers the relative numbers of the reduction in the LEZ compared to the total emissions in the benchmark case will also be calculated. In the end these can be compared to the costs of introducing the LEZ.

6

DATA USED FOR CALCULATIONS

In this chapter the data used to calculate all the different aspects of the LEZ will be presented. For the report most data is pretty recent, from 2015 or later, but there might already be better more recent numbers available that were not found or not used, because they were not complete or with reservations.

6.1. DATA ON TRAVELING KILOMETERS

The CBS provides numbers on how far people in The Netherlands travel on average per day for different motives and with different modes of transpiration. These are the average numbers for an urban area in The Netherlands and can be found in full in Appendix A. Those are chosen because the area investigated for the LEZ should resemble an densely populated urban area in The Netherlands. For the buses there were only numbers of bus tram and metro combined. Based on the total driving kilometer per year by bus in The Netherlands ans estimation was made. So like this:

DK by bus per day = (DK by bus in one year / DK by bus+tram+metro in one year) * DK by bus+tram+metro per day

These numbers on the average driving kilometer per day in an urban area in The Netherlands are shown in Table 6.1. To eventually determine the total driving kilometers in the area, by all 15.000 residents, these get multiplied by 15.000 to get the total.

Table 6.1: Average driving kilometer per day in an urban area in The Netherlands [11]

Motive	Transport mode	Distance (km)
Total	Car (Driver)	11,92
	Bus	1,08
Commuting	Car (driver)	4,79
	Bus	0,34
Care taking	Car (driver)	0,35
	Bus	0
Shopping, doing groceries	Car (Driver)	0,81
	Bus	0,11
Following an education, Day-care	Car (Driver)	0,34
	Bus	0,20
Visiting	Car (Driver)	2,25
	Bus	0,20
Sport, hobby, catering visit	Car (Driver)	1,66
	Bus	0,16
Touring/walking	Car (Dirver)	0
	Bus	0

6.2. DATA USED FOR EMISSIONS

The numbers and assumptions that will be used to calculate the different emissions are mentioned in the sections below. A more in depth explanation of this data is presented in Appendix C

DATA ON EMISSIONS OF CARS

As said it is important to know with what car or bus people travel in Table 6.2 below it can be seen how many gasoline and diesel cars were driven in The Netherlands in 2016.

Table 6.2: Amount of cars in The Netherlands in 2016 [12]

Cars	Amount	Amount in the LEZ
Gasoline	6057765	5314
Diesel	1129695	991

In Table 6.3 below the amount of loaded kilometers driven with the different Euro-norms are presented. These loaded kilometers are the amount of kilometers driven with people or goods in a vehicle, either for private use or for business. Based on these the ratio between the Euro-norms was determined.

Table 6.3: Kilometers driven per Euro-norm[13]

Cars	Loaded DK in 1 year in The Netherlands
EU-N V	300 million
EU-N VI	291 million

To determine the direct emissions from the cars the numbers shown in Table 6.4 are used.

Table 6.4: Direct emissions used for cars [14]

Cars direct E	NOx (g/km)	PM10 (g/km)	CO2 (g/km)
Gasoline EU-N V	0,02	0,02	172,7
Gasoline EU-N VI	0,02	0,02	172,7
Diesel EU-N V	0,49	0,017	161
Diesel EU-N VI	0,29	0,017	161
Electric	0	0,016	0

What might be surprising is the low amount of PM10 emissions of diesel cars. Since the introduction of Euro-norm 4 almost all new diesel vehicles have a soot filter, that filters out the particulate matter. Therefor the emissions of particulate matter from diesel cars are currently lower than for gasoline cars. Moreover currently the most particulate matter emissions are produced by the wear and tear of the tires, brakes and the road and not by the burning of fuel in the motor[14].

As said there are also indirect emissions produced by cars the ones used for this thesis are stated in Table 6.5 below. Unfortunately the data for the indirect emissions of NOx and PM10 could not be found.

Table 6.5: Indirect emissions produced by cars [15]

Cars indirect E	NOx (g/km)	PM10 (g/km)	CO2 manufacturing (g/km)	CO2 E fuel/electricity (g/km)
Gasoline	-	-	46	30
Diesel	-	-	46	27
Electric	-	-	64	105

DATA ON THE EMISSIONS OF BUSES

For buses the kilometers traveled by bus need to be known per Euro-norm and the emissions of these vehicles also need to be known. The traveling kilometers are presented in the section above and in Appendix A. The were 1996 buses of Euro-norm EEV and 1611 buses of Euro-norm VI in 2018 [16]. In Table 6.6 the direct emissions of the buses are shown from two different sources for the calculations the average was taken if there were numbers available in both sources.

Table 6.6: Direct emissions of buses [14],[17]

Buses direct E	NOx (g/km)	PM10 (g/km)	CO2 (g/km)
Diesel EEV (TNO	4,81	0,1	900
Diesel VI (TNO)	0,37	0,086	900
Diesel EEV (Civitas)	3,5	0,248	-
Diesel VI (Civitas	0,8	0,093	-
Electric	0	0,078	0

The green house gas equivalent of CO2 for the fueling production and manufacturing of buses is presented in Table 6.7. For the manufacturing no numbers were found, but it is assumed this is in the same ratio as for passenger cars as presented in Table 6.2. So in the ratio 27 for fuel production 46 for manufacturing for the diesel buses and 105 for fuel production and 64 for manufacturing of electric cars. For buses the indirect emissions of NOx and PM10 could also not be found.

Table 6.7: Indirect emissions of buses[17]

Buses indirect E	NOx (g/km)	PM10 (g/km)	CO2e manufacturing (g/km)	CO2e E fuel/electricity (g/km)
Diesel EEV	-	-	2356	1383
Diesel VI	-	-	2244	1317
Electric	-	-	433	711

6.3. DATA USED FOR COSTS

As said currently the total costs of electric vehicles are higher, than those of normal vehicles, for cars as well as buses. In the section below the data used to determine the cost per kilometer for all vehicles is presented. The full tables and graphs where the number below come from are presented in Appendix D.

COSTS OF PASSENGER CARS

The numbers for cars are based on research already preformed the numbers in this research assume cars drive on average 14.000 kilometers per year with the car being written of in 10 years. These numbers include the purchasing costs, road taxes the costs for the fuel or electricity and for the maintenance. These are presented below in Table 6.8.

Table 6.8: Costs of passenger cars [18]

Costs cars	Cost/kilometer in €
Gasoline	0,26
Diesel	0,28
Average electric	0,47

COSTS OF BUSES

Based on the buses being written of in 12 years and they drive 220 km each day, that means around 80.000 a year. For the batteries of the electric buses they also took the possibly shorter lifetime of the batteries and the charging systems into account. For the costs for the charging of the buses they also assume the buses recharge themselves by using braking energy[19]. In the Table 6.9 the average costs per kilometer are given. In Appendix D the total overview is given.

Table 6.9: Costs of buses [19]

Costs buses	Cost/kilometer in €
Diesel	0,76
Electric (short range)	0,87

7

RESULTS

The result were calculated with MS Excel. In Appendix E the different tabs are presented. In this chapter the most important outputs will be presented. The rest of the numbers can be found in Appendix E.

RESULTS FOR EMISSIONS

In Table 7.1 total reduction of the emissions are given, including the direct and indirect emissions of both the cars and the buses. The reduction of the indirect CO2 emissions from cars is negative, this means the indirect CO2 emissions of cars increase. As stated before unfortunately the indirect production of PM10 and NO2 is unknown. The CO2 emissions for buses and the total is colored orange, because they are presented in this table together with the emissions of the cars, but they are not determined exactly the same. These include for the indirect emissions the greenhouse gas equivalent of CO2 production.

Table 7.1: Absolute reduction of emissions in the new LEZ compared to the benchmark case

	NOx (kg)	PM10 (kg)	CO2 (kg)
Direct cars	119,943	5,399	261417,395
Direct buses	80,454	1,831	28278,649
Indirect cars	-	-	-143011,437
Indirect buses	-	-	79027,887
Total cars	119,943	5,399	118405,958
Total buses	80,454	1,831	107306,536
Total	200,397	7,229	225712,495

These numbers present the total reduction of emissions, but it is hard to base conclusions on these numbers. That is why in Table 7.2 the relative reductions compared to the production in the 'benchmark case' are presented. The negative numbers mean there was an increase in emissions in these situations.

Table 7.2: Relative reduction of emissions in the new LEZ relative to the total emission in the benchmark case

	NOx (%)	PM10 (%)	CO2 (%)
Direct cars	100	18,07	100
Direct buses	100	42,76	100
Indirect cars	-	-	-123,76
Indirect buses	-	-	68,73
Total cars	100	18,07	31,41
Total buses	100	42,76	74,90
Total direct	100	21,16	100
Total indirect	-	-	-27,753
Total	100	21,16	43,39

Results for costs

In Table 7.3 the extra costs for the total LEZ are presented and what it would cost each person every day if they use that mode of transportation.

Table 7.3: Extra costs of electric vehicles

	Total extra costs per day (€)	Extra costs per person per day (€)
Cars	311268,23	20,75
Buses	3456,28	0.23

8

DISCUSSION

In Chapter 7 the results were presented. In this chapter firstly the results will be discussed more elaborately and after that a critical look at the research done in this thesis is presented.

8.1. DISCUSSION OF RESULTS

A notable finding in the results is that for cars there is an increase in indirect CO2 emissions when you introduce electric vehicles. This can be seen in Table 7.1. That is because currently the production of the cars and electricity is still mostly done with power produced by fossil fuels. So currently manufacturing of the cars and buses is just as polluting for electric vehicles as for fossil fueled cars and buses. But for electric cars and buses the batteries also need to be produced, which is a process where a lot of emissions are produced [20]. Next to this the production of electricity currently produces more CO2 than making fossil fuels from crude oil. This can be seen in Table 6.5.

For buses the indirect emissions of CO2 seem to be much better than the ones from cars. For cars there is an increase in indirect CO2 emissions, but for buses there is a decrease as can be seen in Table 7.1, but this is a distorted result. The manufacturing CO2 emissions for buses are an estimation based on the ratio from cars between the electricity or fuel production and manufacturing. Since there could not be any information found on the manufacturing emissions of buses. But for electric cars the CO2 production for electricity is higher than the CO2 produced during fuel production while for buses this is the opposite. This might be due to the fact that buses use braking energy to recharge themselves, which makes them more energy efficient than cars [21]. On top of that for buses the CO2 production is the green house gas equivalent of CO2 emissions. This gives a much higher emission of CO2, than only CO2 emissions would give. So for buses drawing conclusions could be done, but there are still a lot of gaps that need to be filled in to make them reliable.

Unfortunately nothing can be concluded for the indirect NOx and PM10 since these emissions were not found.

The reduction of direct emissions is quite big. For NOx and CO2 the direct emissions in the LEZ become zero. Which is not a surprising finding, since electric cars do not burn anything while driving. However for PM10 this is a bit different. There will no longer be any PM10 produced by the motor, but the wear and tear of the tires, the road and the brakes make electric cars still produce particulate matter. For PM10 the relative reduction for cars is 18% and for buses it is even higher with 42,7% as can be seen in Table 7.2. In the end the influence of the cars is bigger than the influence of the buses, since cars produced more PM10 to begin with. The total relative reduction of PM10 is 21,2%.

As can be seen in Table 7.3 the cost for electric cars are relatively high compared to the costs of introducing electric buses. According to this research replacing all cars by electric cars would cost all people €20,75 a day and that is not just for the car owners, but if the costs were divided over everyone. So the extra costs for one car would be even higher. However the investment in electric buses is already way more feasible and the predictions for the future are even better for buses as can be seen in Figure B.1 in Appendix B. It is predicted that within 10 years operating electric buses will be cheaper than diesel buses [8]. The only limitation for buses is the reduction in service flexibility due to the limited amount of energy in their batteries [17]. Electric cars are also expected to become cheaper in the next couple of years, but not as much as buses [18].

8.2. Discussion of assumptions and data

The framework to make the calculations are presented in this report, but there is still quite some information missing and some aspects that are not taken into account. In the section below these aspects will be discussed.

Different emissions

Even though the framework to determine all emissions is included in Chapter 6, not everything could be included in the results. Of the emissions of NOx and PM10 emitted during manufacturing of the cars and buses and for the production of electricity no numbers could be found. So these emissions seem to have disappeared almost completely. These will however be produced during these processes.

Next to this there is another problem in the comparison of the emissions. Not all emissions are presented in the same way. The ones for the fuel production of buses represent the green house gas equivalent of CO2. This will probably give a much higher number than the actual amount of CO2 that was produced, since there are much stronger green house gasses included in these calculations, like methane which is 25 times stronger than CO2 and will therefor weigh 25 times heavier in this calculation.

Change in traveling kilometers

As mentioned in Chapter 4 introducing new modes of transportation might also change the traveling behavior of people. More expensive electric cars, might make people choose a different mode of transportation like the bike, bus or another form of public transport. This influences a few different things according to the circle from Wegener. It influences the route choice, mode choice, destination choice and trip generation. Especially mode choice and trip generation influence the traveling kilometers and therefor the emissions. These influences were not taken into account in this thesis. So this might give an inaccurate representation of the actual emissions after introducing the LEZ.

Traffic that was not included

As is being discussed in Appendix G there are more stakeholders involved in introducing a LEZ. Not all of them are also producers of emissions, but they all have an influence or interest for such a project. An important group are the delivery services. These vehicles are becoming more and more important in our society. The amount of packages that are delivered every day have grown extremely fast. In 2017 17% more packages were delivered in The Netherlands as in 2018[22]. The delivery vans that deliver them definitely have a big impact on the emissions in the area. If these are replaced by electric vehicles this might reduce emissions within in the area significantly and currently the amount of emissions is probably higher than presented in this thesis. Next to these delivery vans the big trucks that stock shops and supermarkets were also not included in this report. These could also produce a significant amount of emissions. However they would also be harder to replace with electric vehicles, because these trucks are heavy and use a lot of power and often need to travel large distances.

In this report only the distances travelled by residents of the area were included. But there could also be people traveling through the LEZ, by car or with the buses. This means the emissions of these traveling kilometers produced by this group of people are not included in the estimations.

Problems at the border

When through traffic is included in the research another problem for introducing a LEZ arises. At the border of the LEZ more traffic could be generated that has to change their route, because they cannot go through the LEZ. This might cause very high concentrations of emissions. For NOx and particulate matter this could locally cause extra air pollution. Even if these concentrations do not increase very much it could also cause another problem for the people living at the border and the trough traffic. Introducing the LEZ could cause congestion at the borders due to the increase in intensity of the roads around the LEZ. Especially if the size of the LEZ gets increased further than just one or two neighbourhoods. Like Amsterdam wants to do in the near future.

Diesel cars

People often drive further with diesel cars than with gasoline powered cars, because owning a diesel car will only be financially feasible when more kilometers are driven with it. This is however not taken into account when determining the driving kilometers and therefor also not in the production of emissions of diesel cars. In the research done on the costs of cars it is also assumed that a car drives around 14.000 kilometers a year. It is however unlikely a diesel car is driven this little amount of kilometers.

9

Conclusions and Recommendations

9.1. Conclusions

From the results in this research a point could be made that the investment in electric cars is still too high for the return in terms of reducing emissions, but buses already seem a viable option to introduce and this would already be a great step in reducing emissions within urban areas.

Even though there can only be looked at the result for CO2. It can be seen in the results that manufacturing and charging electric cars is still very environmentally unfriendly. There are more emissions produced with the manufacturing of electric cars than for normal cars, currently still almost twice as much. That is due to the fact that a lot the processes involved in manufacturing of a car are still fossil fuel driven and especially producing the batteries is still an energy consuming process. The further we want to drive with electric cars, the bigger the batteries need to be and the more energy is needed to produce them. Next to this the life-cycle of the batteries is often still shorter than the cars. This means that after a few years a new battery is needed, which again causes more emissions. These two things are still big problems for electric cars.

A way to solve this could be using more green energy in the production process of vehicles and batteries and develop better batteries that have a longer life cycle or that are less environmentally unfriendly to produce [20].

On top of this the electricity that needs to be produced to drive these electric cars is also still mostly produced from fossil fuels. To let introducing LEZ's really have a big impact in the future, more energy needs to be produced cleanly from non fossil sources. Otherwise introducing the LEZ's will only contribute to improving the air quality very locally.

As said in Chapter 8 for buses quite a few assumptions were made and this gives a distorted view. Based on this it could be assumed that electric buses will definitely contribute to less direct emissions, but for the indirect emissions it is still a bit unclear what the exact effect would be. Though it looks like introducing them would decrease the amount of indirect emissions, based on the data currently used. So introducing electric buses seems to already be a good step to take in our cities, based on this research.

9.2. Recommendations

For further research quite some thing could be improved to make the results more reliable and useful to determine if introducing these LEZ's excluding all fossil fuelled vehicles in part of a city has the desired effect to improve air quality in the city and reduce the emissions of greenhouse gasses overall. In the section below some recommendations are given for further research.

To make a better estimation on the reduction of emissions more recent, complete and the same kind of data is needed. The more recent the numbers are, the more accurately they represent the current situation. On top of that quite some data still missing completely and as can be seen with the data for the buses, different sources sometimes present different emissions. To make an accurate estimation for an urban area it would also be useful to use data on emissions for slowly driving and constantly accelerating vehicles and not on an average number, since this could differ from the true emissions quite a lot. Lastly in this research not all data is acquired from the same source, which means it could be measured quite differently. For some emissions this is stated clearly, but even if it is not there could still be a difference. For further research the data needs to be more recent, a more accurate representation of the situation and needs to be acquired in the same way.

In the current research two large groups of traffic are taken into account, the passenger cars of people living within the LEZ and buses used by these people, but these are of course not the only travelers. There are also people traveling by car or bus through the area. After the introduction of the LEZ these people can still use the buses traveling through the area, which would make the increase the reduction of emissions by buses. But if they use their cars, they can no longer travel through the area. This could mean more traffic at the borders of the LEZ, this causes more air pollution at the borders and could also cause congestion at the border on roads that now need to be used more. However it could also mean people change their route or mode of transportation completely. This could also relieve the area even more. There should be looked into this effect in further research.

Next to this group of traffic there are also delivery services and other trucks that need stock shops. In further research the influence of these vehicles and the possibilities to replace these vehicles needs to be investigated.

As was put forward in Chapter 4 introducing the LEZ could influence the amount of trips taken by people, the distances they travel and the mode of transportation they use. This could influence the amount of emissions produced significantly. This impact should be investigated in the future.

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A

TRAVELING KILOMETERS

			Afstan	km
Totaal	Auto (bestuurder)	2016		11.92
	Bus/tram/metro	2016		1.44
	Bus	2016		1.0811431
Van en naar werkadres	Auto (bestuurder)	2016		4.79
	Bus/tram/metro	2016		0.45
	Bus	2016		0.3378572
Diensten/verzorging	Auto (bestuurder)	2016		0.35
	Bus/tram/metro	2016		0
	Bus	2016		0
Winkelen. boodschappen doen	Auto (bestuurder)	2016		0.81
	Bus/tram/metro	2016		0.15
	Bus	2016		0.1126191
Volgen onderwijs/cursus en kin	Auto (bestuurder)	2016		0.34
	Bus/tram/metro	2016		0.27
	Bus	2016		0.2027143
Visite/logeren	Auto (bestuurder)	2016		2.25
	Bus/tram/metro	2016		0.27
	Bus	2016		0.2027143
Sport. hobby. horecabezoek	Auto (bestuurder)	2016		1.66
	Bus/tram/metro	2016		0.21
	Bus	2016		0.1576667
Toeren/wandelen	Auto (bestuurder)	2016		0
	Bus/tram/metro	2016		0
	Bus	2016		0

Figure A.1: Average daily travel distances in an urban area in The Netherlands per person [11]

B

Extra description of the method

Direct emissions in the current situation

To determine if introducing a LEZ is useful one of the most important aspects is knowing if the emissions indeed reduce. As said in Chapter 3 not only the direct emissions from the cars will be used to determine the emissions, but also the indirect emissions. If the total amount of CO2 emissions decreases the LEZ would contribute to a cleaner transport system and this would be a pro to introduce them. For NOx and particulate matter emissions, only reducing the direct emissions could already be a great benefit. If these emissions are not produced within urban areas this would benefit public health. Both these direct and indirect emissions are taken into account.

Traveling kilometers

To determine the direct emissions of passenger cars the amount of kilometer travelled with a car every day are necessary. For this the average distance people travel is used. People travel for different purposes for each of these purposes this distance needs to be determined. The trips taken from home are for: work, going to school, to go shopping, to visit, and for leisure activities. So these will be taken into account to calculate the amount of kilometers travelled by car each day and later also the kilometers travelled by bus. So this differs from the total amount of traveling kilometer, because the numbers for business trips are not taken into account. These are taken from work and not from home. For cars the only the kilometers travelled as driver are used, because counting the passengers would make the emissions count double.

The numbers for the average amount of traveling kilometers made for each motive by bus need to be determined, just like for the traveling kilometers made by car. These numbers will be used to determine the amount of direct emissions. In the paragraphs below it will be explained how the emissions of the buses are calculated.

Determining direct emissions

To determine the direct emissions the amount of cars there are within the area of the new LEZ of each type of car, diesel or gasoline powered and what Euro-norm they belong to needs to be estimated to determine the emissions. What Euro-norm regulations the car or bus complies with determines to what category it belongs. The European Union addresses vehicles a certain Euro-norm if they emit a certain amount of emissions, the higher the number, the less emissions a car produces. Currently Euro-norm VI is the least polluting car. At the moment most cars comply with at least Euro-norm V, so for cars it is assumed that the total fleet consists of Euro-norm V and VI. For buses currently most buses comply with at least Euro-norm EEV this is the norm between Euro-norm V and VI. So for buses it is assumed that the total fleet consists of Euro-norm EEV and VI.

To determine how many cars of a certain Euro-norm are used in the LEZ the ratio for the whole Netherlands can be used which is than reduced to the amount of residents included in the area. Of course there are already some vehicles that are powered differently than with gasoline or diesel currently in use. For instance electrically or on natural gas, but these are only a small part of the current fleet and assumptions of the precise number would be based on nothing. So these are out of scope for now. And the vehicles differently powered than by gasoline are for now assumed to be diesel powered. Data from the CBS shows that in 2018 most vehicles for personal use complied with Euro-norm V and VI as can be seen in Appendix F. So the emissions for these cars will be used according to the ratio of the driving kilometers for private use in The Netherlands. With the total amount of each type of car and emissions produced by these cars the direct emissions can be determined.

Determining the average direct emissions of buses is more difficult, due to the influence of the load on the emissions and the different types of buses. The emissions of the buses will be based on different sources in this report, because they are so difficult to estimate. In follow up research a better estimation needs to be made on the direct emissions of buses traveling within an urban area.

There are also different types of fuels for busses. There are busses that drive on natural gas, but the most common fuel still is diesel, 84% of busses is still diesel powered. According to a report from the Rijksdienst Ondernemend Nederland diesel Euro EEV and VI account for most of the total amount in The Netherlands[16]. So this will be the types of busses used in this thesis to determine the emissions. The ratio used to determine the total amount of emissions will be based on the ratio between Euro EEV and VI. In the end the total direct emissions of busses can be calculated with the total amount of kilometers travelled by bus.

In the end the direct emissions of cars can be determined by using the total amount of driving kilometers and the ratio's mentioned above and multiplying this with the emissions of each type of vehicle as is described in Chapter 6.

Determining indirect emissions

This is all information to determine the direct emissions that are produced within the area. Also the manufacturing emissions and the ones produced during the production of fuel have quite a big impact. So the emissions produced during the manufacturing of the cars and production of fuel also need to be determined for one driving kilometer. Than the indirect emissions of the cars that drive around can also be determined.

The indirect emissions also play a role for busses. For busses there are also emissions produced whilst producing the fuel and manufacturing the buses and by the wear of the road and brakes. These emissions need to be determined for every kilometer a bus drives. Than the distance used to determine the direct emissions of a bus can also be used to calculate the indirect emissions.

Emissions in the new LEZ

The alternatives will be introduced in the LEZ. These were mentioned before Chapter 2. One of them being, introducing electric powered buses. The second one is introducing electric bikes and cars. The direct emissions of CO2 and NOx produced within the LEZ are zero for electric cars and busses. However as said the indirect emissions produced when making electricity are also a factor that need to be taken into account. The amount of electricity necessary in the LEZ depends on the amount and duration of the trips that are made.

Currently producing electricity for electric cars and buses is still mostly done with fossil fuels, in The Netherlands. For the indirect emissions again the manufacturing of the cars, producing of the fuel, in this case electricity need to be taken into account. This data needs to be collected and combined with the traveling kilometers of the benchmark case for cars, the indirect emission can be determined.

The reduction of the indirect emission production for buses will be lower than for passenger cars, that is because buses are much heavier and need much heavier batteries. These batteries can weigh up to 26% of the total weight of the bus. Which makes them less energy efficient than cars. However the reduction of the indirect emissions of buses and electric cars can be calculated in the same manner. By using the traveling kilometers by bus and finding estimates for the indirect emissions.

The direct emissions of both buses an cars will still include particulate matter. This is produced by the wear of the road and brakes. For this average number per kilometer need to be found. This can than also be multiplied by the amount of traveling kilometers from the electric cars or buses and the direct emissions that are produced can be determined.

Costs

Using a car or public transport costs money. For the public transport you pay a certain price dependent on what the operator determined as a cost. For busses in The Netherlands you pay the basic rate and than a certain rate per kilometer determined by the operator. For a car the costs include the purchasing price, the fuel or electricity, insurance and road taxes.

Driving an electric car is currently cheaper in The Netherlands than driving a fossil fueled car, because the road tax is lower for electric vehicles. The electricity to charge electric cars is also cheaper than gasoline and diesel. Unfortunately purchasing electric cars is still more expensive than purchasing a fossil fueled cars. The total costs per kilometer of driving a car need to be determined to estimate the costs of driving a car for one day. This needs to be done for both the fossil fueled cars and electric cars. Than it will be possible to compare them to the emissions produced during a day.

For buses the same goes. For the operator purchasing an electric bus is still more expensive than a diesel powered bus, but in the coming few years electric powered busses will become cheaper over their whole life-cycle than diesel powered busses. The prognoses for these costs can be seen in the picture below[23]. The kWh in this picture depict the capacity of the different batteries of buses. Just like for diesel buses, with electric buses it is also difficult to determine how much energy they use per kilometer, because this depends on the weight and the speed of the bus.

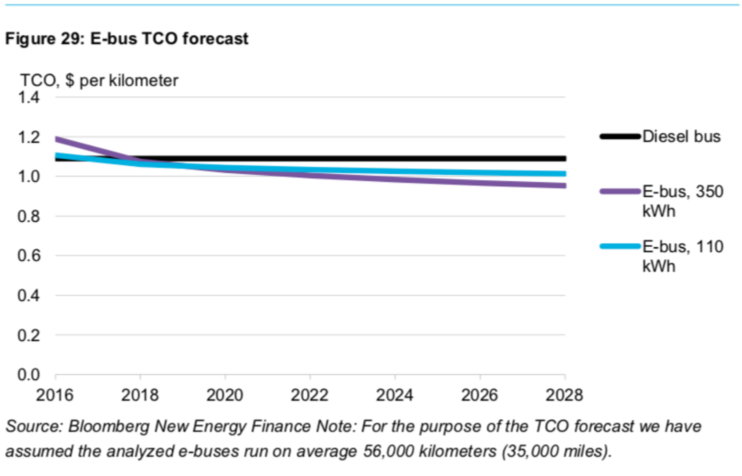

Figure B.1: Prognoses of costs of electric busses compared to diesel [23]

Because the study is about a densely populated living area in an urban area, short range buses with a battery capacity of 110 kWh would be the more logical option. They will travel short distances within the city and can be recharged often enough. Since they are currently also much cheaper they would also be the more financially feasible option. For buses the price per traveling also needs to be determined. This is not the price currently payed by travelers, but the price of operating an electric bus.

C

EXTRA DESCRIPTION OF THE DATA

DATA FOR EMISSIONS

To estimate how many cars there are within the area of the new LEZ of each type of car there are, firstly numbers from the CBS are used. These state the amount of diesel and gasoline powered cars in The Netherlands, in different neighbourhoods. The most recent numbers on how many gasoline and diesel powered vehicles there were in The Netherlands are from 2016. There were 6057765 gasoline powered vehicles and 1129695 differently powered vehicles, that are assumed to be diesel powered as said in Section 5.1, in 2016 [12].

Data from the CBS also shows that in 2018 vehicles for personal use complied with Euro-norm V and VI in driving kilometers with the ratio 300 to 291, as can be seen in Appendix C. These numbers from 2018 were chosen for this, because they are the most recent numbers and the Euro-norms cars comply with are changing fast. So the emissions for these cars will be used according to this ratio. The amount of direct emissions a car produces can be seen in the table in Appendix B. Unfortunately these numbers do not take into account the effect of the speed on the emissions of the car.

In 2015 the CO2 emission of the production, use of the vehicle and the production of the fuel for vehicles was determined by TNO. As can be seen in the picture below.

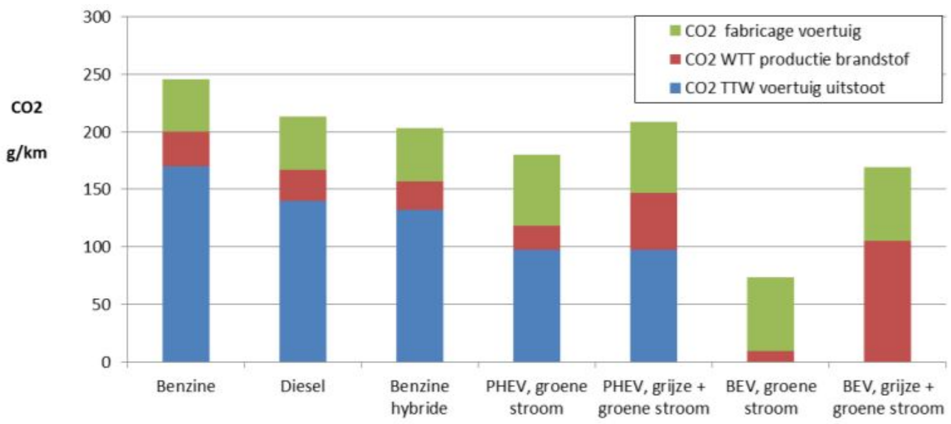

Figure C.1: CO2 emissions of fuel, driving and producing a car[15]

The numbers for the production are based an the use of a car for 220.000 kilometers. These numbers will be used to determine the indirect CO2 emissions of the cars, based on the total amount of traveling kilometers. For NOx and particulate matter there have not been numbers found yet to determine the indirect emissions, but this can be done in the same way as the indirect CO2 emissions once these are found or estimated.

For electric cars the direct emissions of CO2 and NOx produced within the LEZ are zero. But as mentioned before there are still some direct emissions of particulate matter produced by the wear of the road and brakes. The direct production of particulate matter from electric cars is 0,016 g/km. For the indirect emission the picture seen in Section 5.1 can also be used to determine the indirect CO2 emissions of the electric cars. Again for NOx and particulate there have not been numbers found yet to determine the indirect emissions.

The numbers for the average amount of traveling kilometers made for each motive by bus, tram or metro are also shown in Appendix A. In the paragraphs below it will be explained how the emissions of the busses are calculated. According to a report from the Rijksdienst Ondernemend Nederland diesel Euro EEV and VI account for respectively 1996 and 1611, in The Netherlands in 2018[16]. So this will be the types of busses used in this thesis to determine the emissions. The ratio used to determine the total amount of emissions will be based on the ratio between Euro EEV and VI. The data from the CBS on traveling kilometer are for bus, tram and metro combined, this is 815,67 million kilometer. There are no separate numbers for buses. But there are also numbers on the total amount of kilometers travelled by bus. This is 612,4 million kilometers. So about 75% of these kilometers are assumed to be travelled by bus[11]. With this ratio the total traveling kilometers are determined.

The emissions of these buses are presented in Appendix B. There are two tables for presented with numbers from different sources, Civitas and TNO. The CO2 emissions are not comparable, because the once from Civitas are about well to tank emissions and the once from TNO about tank to wheel. So for the direct CO2 emissions the TNO numbers will be used. However the NOx and particulate matter emissions are both tank to wheel emissions and from these emissions the average can be taken to determine the emissions. In the end the total direct emissions of busses can be calculated with the total amount of kilometers travelled by bus.

The indirect emissions also play a role for busses. For busses there are also emissions produced whilst producing the fuel and manufacturing the busses. The so called well to tank (WTT) CO2 equivalent emission for diesel busses are 1383 g/km for Euro V and 1317 g/km for Euro VI. This expresses the equivalent of all green house gasses produced in CO2. That is unfortunately different from the numbers used for the passenger cars, but these are the available for busses and will give a good indication of the indirect CO2 emissions. These WTT emissions are depended on the energy production method and are based on the current EU mix of electricity production [17].

For the manufacturing emissions no numbers have been found yet. If these are not available this is a factor that needs to be researched in follow up research. For the indirect NOx and particulate emissions the same goes, if these numbers are found the NOx emissions can be determined in the same way as the indirect CO2 emissions.

Determining the emissions of electric busses is quite similar to that of the electric cars. Again the direct emissions of particulate matter due to wear of the road and brakes needs to be taken into account and that is 0,071 g/km [14].

To calculate the total reduction of indirect emissions numbers on the well to tank and manufacturing emissions are needed. The well to tank equivalent for CO2 emissions of electric busses with the current EU mix of electricity production is 711 g/km. For this number the same goes as for the diesel powered busses this is the CO2 equivalent of all greenhouse gasses produced during the electricity production [17]. As said in the paragraph on the diesel powered busses, no numbers on the manufacturing emissions of busses have been found yet and neither have the indirect NOx and particulate matter emissions.

Data for costs

In Appendix D the annual costs of passenger cars can be found. These are from a study that compared the price of driving a compact electric 5-seater to a similar fossil fueled car. These cars included the Volkswagen Golf, Ford Focus, Renault Megane, Toyota Corolla and Opel Astra. They found that electric cars would still cost at least €800 a year more than the reference cars that were, diesel or gasoline fueled and this is an optimistic forecast. Currently the reality is still much higher. They estimated this based on a car that drives 14.000 kilometers every year and is written off in 10 years. They compared cars with different battery weights and power from different brands. In the study they also take into account the purchasing costs, the maintenance, taxes, and a social discount rate 5% for driving an electric car. For the price used for the electricity they also differentiate between the price of electricity during the day and the cheaper electricity during the night. [18].

Because the emissions are calculated based on the driving kilometers of one full day the extra costs of an electric car should also be determined per day. This will be done by determining the price per kilometer, the price is based on the assumption that the car drives 14.000 kilometers a year and then calculating the costs of a whole day worth of driving kilometers [18]. To determine the average costs for electric cars it is assumed that all the different types with different batteries, are equally driven in new situation in the LEZ. So for this the average of the costs presented is taken.

In Appendix D the costs of a bus are stated. These are not build up in the same way as the costs for the cars. For the busses the price per kilometer is determined and for the electric busses the costs of the new electric infrastructure is also taken into account. This is not the case for the passenger cars.

A few different scenario's have been investigated in this research. There are long range and short range busses included. The shorter range busses, eBus type 2, already have a price that can compete with the diesel powered busses. These buses have a smaller battery and need to be charged during the day. As said in Appendix B these are the buses used for this thesis. Next to these different types they also made different scenario's, a baseline, an optimistic prediction and a pessimistic prediction. For this thesis the baseline expectation will be used[19].

D

COSTS OF CARS AND BUSES

The numbers in the table below are based on the assumption that the cars drive 14.000 kilometers per year and are depreciating over 10 years and include a social discount of 5% and the taxes.

Vehicle configuration	Annualised purchase	Maintenance	Diesel/petrol	Electricity	TCO (€/year, VAT only)
Regular Diesel	2770	610	570	0	3940
Regular Petrol	2480	570	630	0	3690
BPEV CM 2010	7240 ± 890	610	0	110 ± 41	7960 ± 900
BPEV CM 2015	6480 ± 750	610	0	110 ± 38	7200 ± 750
BPEVWM 2015	5700 ± 700	610	0	100 ± 34	6400 ± 700
BPEV WM future	4050 ± 360	610	0	90 ± 31	4750 ± 360

Table D.1: Annual costs of passenger cars [18]

In the figure Figure D.1 below the costs of different types of buses are presented. Among which the baseline EEV diesel and eBus 2 LTO baseline, that were used in this thesis.

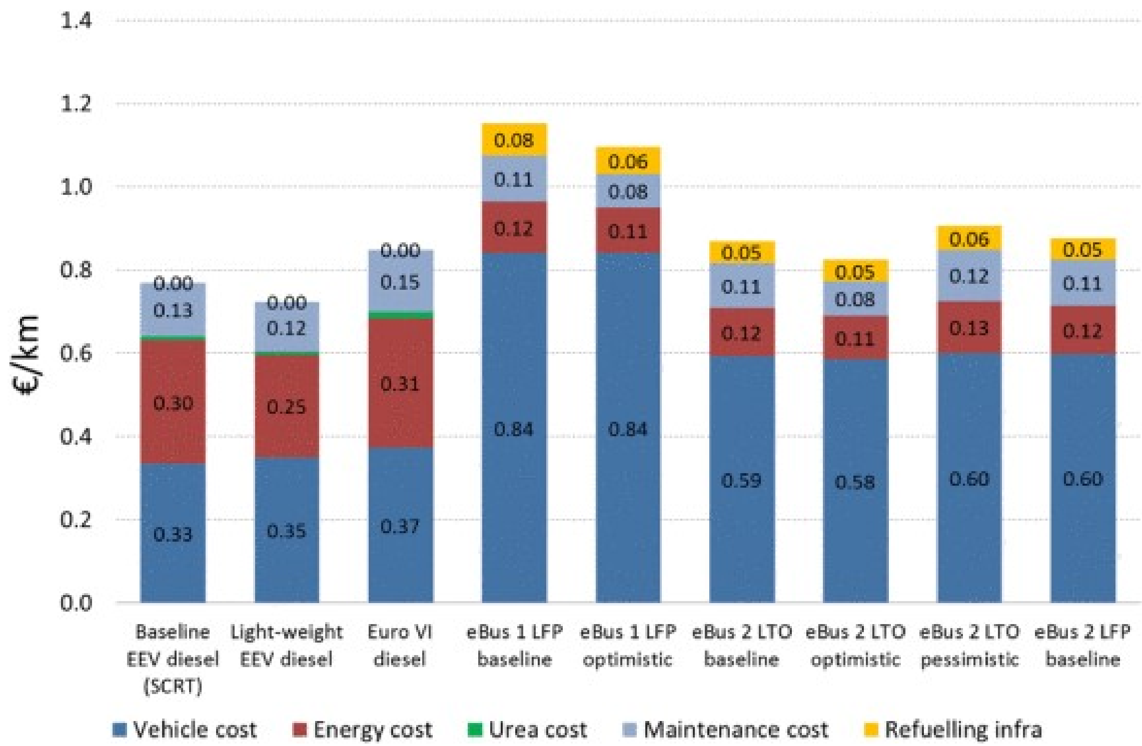

Figure D.1: Costs of busses per kilometer [19]

E

EXCEL WORK MAPS USED FOR RESULTS

			Afstan	km	per jaar			
Totaal	Auto (bestuurder)	2016		11.92	4 797		inhabitants in The Netherlands 2016	1710000
	Bus/tram/metro	2016		1.44	477		km/jaar per bus/tram/metro	815670000
	Bus	2016		1.0811431				
Van en naar werkadres	Auto (bestuurder)	2016		4.79			km/jaar met de bus	612400000
	Bus/tram/metro	2016		0.45			Ratio met de bus	0.7507938
	Bus	2016		0.3378572				
Diensten/verzorging	Auto (bestuurder)	2016		0.35				
	Bus/tram/metro	2016		0				
	Bus	2016		0				
Winkelen. boodschappen doen	Auto (bestuurder)	2016		0.81				
	Bus/tram/metro	2016		0.15				
	Bus	2016		0.1126191				
Volgen onderwijs/cursus en kin	Auto (bestuurder)	2016		0.34				
	Bus/tram/metro	2016		0.27				
	Bus	2016		0.2027143				
Visite/logeren	Auto (bestuurder)	2016		2.25				
	Bus/tram/metro	2016		0.27				
	Bus	2016		0.2027143				
Sport. hobby. horecabezoek	Auto (bestuurder)	2016		1.66				
	Bus/tram/metro	2016		0.21				
	Bus	2016		0.1576667				
Toeren/wandelen	Auto (bestuurder)	2016		0				
	Bus/tram/metro	2016		0				
	Bus	2016		0				
Bron: CBS								
Traveling kilometers	Per person/day	Per day						
Car	10.2	1530000						
Bus	2.094714774	31420.72						

Figure E.1: Calculated traveling kilometers

Cars					
		Total amount of cars in The Netherlands	Cars within the LEZ	0.354255	Gasoline cars/person in The Netherlands
Gasoline	Total	6057765	5313.828947	5313.829	Total amount of gasoline cars within the LEZ
	Euro-norm V	3075007.614	2697.3751		
	Euro-norm VI	2982757.386	2616.453847	0.066064	Diesel cars/person in The Netherlands
Diesel	Total	1129695	990.9605263	990.9605	Total amount of diesel cars within the LEZ
	Euro-norm V	573449.2386	503.0256479		
	Euro-norm VI	556245.7614	487.9348784	17100000	inhabitants in The Netherlands 2016
Part of gasoline cars	0.842824169				
Part of diesel cars	0.157175831				
	Ratio				
Euro V/total	**0.507614213**				
Euro VI/total	**0.492385787**				
	Traveling kilometers for each type				
Gasoline Euro V	654579.1768				
Gasoline Euro VI	634941.8015				
Diesel Euro V	122070.5694				
Diesel Euro VI	118408.4524				
Buses					
Euro EEV	1996				
Euro VI	1611				
Ratio		Traveling kilometers for each type			
Euro EEV/total	**0.55336845**	17387.23603			
Euro VI/ttal	**0.44663155**	14033.48559			

Figure E.2: Calculated ratios

Cars			
Direct	NOx g/km	PM10 g/km	CO2 g/km
Gasoline Euro-norm V	0.02	0.02	172.7
Gasoline Euro-norm VI	0.02	0.02	172.7
Diesel Euro-norm V	0.49	0.017	161
Diesel Euro-norm VI	0.29	0.017	161
Electric	0	0.016	0
Indirect	CO2 fuel prodcution g/km	CO2 manufacturing g/ km	
Gasoline	30	46	
Diesel	27	46	
Electric	105	64	
Buses			
Direct	NOx g/km	PM10 g/km	CO2 g/km
Diesel V	4.81	0.1	900
Diesel VI	0.37	0.086	900
Source: TNO			
Diesel V	3.5	0.248	
Diesel VI	0.8	0.093	
Source: Civitas			
Average direct	NOx g/km	PM10 g/km	CO2 g/km
Diesel V	4.155	0.174	900
Diesel VI	0.585	0.0895	900
Electric	0	0.078	0
Indirect	CO2e fuel production (g/km)	CO2e manufacturing (g/km)	
Diesel V	1383	2356.222222	
Diesel VI	1317	2243.777778	
Electric	711	433.3714286	

Total cars			
Direct	NOx (g)	PM10 (g)	CO2 (g)
Gasoline Euro-norm V	13091.58354	13091.58354	113045823.8
Gasoline Euro-norm VI	12698.83603	12698.83603	109654449.1
Diesel Euro-norm V	59814.57903	2075.19968	19653361.68
Diesel Euro-norm VI	34338.45118	2012.94369	19063760.83
Electric	0	24480	0
Indirect	CO2 fuel prodcution (g)	CO2 manufacturing (g)	Total indirect CO2 (g)
Gasoline	38685629.35	59317965	98003594.34
Diesel	6492933.588	11062035	17554968.59
Electric	160650000	97920000	258570000
Total Buses			
Direct	NOx (g)	PM10 (g)	CO2 (g)
Diesel V	72243.96569	3025.379068	15648512.42
Diesel VI	8209.58907	1255.99696	12630137.03
Electric	0	2450.816286	0
Indirect	CO2e fuel production (g)	CO2e Manufacturing (g)	Total indirect CO2e (g)
Diesel V	24046547.42	40968191.91	65014739.33
Diesel VI	18482100.52	31488023.11	49970123.63
Electric	22340133.07	13616843.01	35956976.08

Figure E.3: Calculated emissions

Reduction direct emissions			
	NOx (g)	PM10 (g)	CO2 (g)
Cars	119943.4498	5398.562935	261417395.4
Buses	80453.55476	1830.559743	28278649.45
Reduction indirect emissions			
	NOx (g)	PM10 (g)	CO2 (g)
Cars	-	-	-143011437
Buses	-	-	79027886.88
Total	NOx (g)	PM10 (g)	CO2 (g)
Cars	119943.4498	5398.562935	118405958.4
Buses	80453.55476	1830.559743	107306536.3
Total	200397.0045	7229.122677	225712494.7

Figure E.4: Calculated reductions

Cars	costs/year in €	cost/kilometer in €			
Regular diesel	3940	0.281428571			
Regular gasoline	3690	0.263571429			
Average electirc	6577.5	0.469821429			
Bus	Vehicle costs €/km	Energy costs €/km	Maintenance costs €/km	Refuelling infra €/km	Total €/km
Diesel	0.33	0.3	0.13	0	0.76
Electric	0.59	0.12	0.11	0.05	0.87
Total costs			**Extra costs for electric**		pp/day
Cars	Total price per day (€)		Cars	311268.2318	20.75122
Regular diesel	67677.66756		Buses	3456.279378	0.230419
Regular gasoline	339880.8864				
Average electric	718826.7857				
Bus					
Diesel	23879.74843				
Electirc	27336.02781				

Figure E.5: Calculated prices

	NOx	PM10	CO2		%	NOx	PM10	CO2
Car direct	1	0.180683	1		Car direct	100	18.06835	100
Car indirect	-	-	-1.23756677		Car indirect	-	-	-123.757
Car total	1	0.180683	0.31409419		Car total	100	18.06835	31.40942
Bus Direct	1	0.427563	1		Bus Direct	100	42.75634	100
Bus indirect	-	-	0.687289482		Bus indirect	-	-	68.72895
Bus total	1	0.427563	0.749015116		Bus total	100	42.75634	74.90151
Total Direct	1	0.211626	1		Total Direct	100	21.16257	100
Total Indirect	-	-	-0.27753361		Total Indirect	-	-	-27.7534
Total	1	0.211626	0.433862687		Total	100	21.16257	43.38627

Figure E.6: Relative reduction of emissions

F

LOADED DRIVING KILOMETER PER EURO-NORMS

Vervoerstroom	Beroeps- en eigen vervoer	Perioden	Voertuigkilometers, beladen								Ritten, beladen							
			Totaal	Euro 0	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5 en EEV	Euro 6	Totaal	Euro 0	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5 en EEV	Euro 6
			mln km								x 1 000							
Totaal	Beroeps- en eigen vervoer	2018*	5 484	0	5	30	201	147	1 803	3 298	53 194	6	90	688	3 390	2 145	19 355	27 520
	Beroepsvervoer	2018*	4 505	0	0	10	109	93	1 408	2 884	39 634	4	20	214	1 701	1 167	13 589	22 940
	Eigen vervoer	2018*	979	0	5	20	92	54	394	414	13 560	2	69	475	1 689	978	5 766	4 580
Binnenlands vervoer	Beroeps- en eigen vervoer	2018*	3 037	0	5	23	149	107	1 081	1 672	44 410	6	88	633	3 171	1 982	16 603	21 927
	Beroepsvervoer	2018*	2 309	0	0	7	75	65	781	1 381	31 931	4	20	194	1 562	1 060	11 214	17 878
	Eigen vervoer	2018*	728	0	4	16	74	42	300	291	12 478	2	68	439	1 610	922	5 390	4 049
Internationaal vervoer	Beroeps- en eigen vervoer	2018*	2 447	0	0	8	51	40	722	1 626	8 785	0	2	55	218	163	2 752	5 593
	Beroepsvervoer	2018*	2 196	0	0	3	34	28	628	1 503	7 703	0	0	20	139	107	2 375	5 062
	Eigen vervoer	2018*	251	0	0	5	17	12	94	123	1 082	0	2	36	79	57	377	531

Figure F.1: Euro-norms CBS[13]

G

INFORMATION ON DIFFERENT STAKEHOLDERS

In Chapter 4 the stakeholders were briefly discussed and presented in a power matrix, presenting their interest and power. In this section their views are discussed more elaborate.

RESIDENTS AND LOCAL TRAFFIC

Residents and local traffic are the people living in the LEZ. They currently use their private cars or some other mode of transportation within the area, like public transport or bikes. They currently make trips within the zone, or travel through the zone towards another destination. These people will experience the benefits from the LEZ directly, but will also need to adapt to a new lifestyle. Below the benefits for the residents will be mentioned and afterwards the changes they need to make will be explained.

The LEZ will be less crowded by cars. This means the air in the area will hopefully get cleaner, because there are less emissions. But excluding cars will also create more frees space in the area. This extra space can be used for the development of the neighbourhood. It might be used to create more green areas or better bicycle paths. And lastly, not owning a private car will probably be cheaper for the residents, of course the prices of the new transport modes should not be too high to achieve this.

However as said before people living in the area will need to change their traveling behavior and whilst they enjoy the most benefits of the LEZ. When the zone is first introduced it is not likely everyone will be happy with it. Older people tend to be more conservative, whilst young people will probably accept the introduction of the LEZ more easily. Especially if they have more liberal political beliefs. This can be seen in the results of the last round of elections for the Tweede Kamer in The Netherlands. Young adults voted for the political parties that have more liberal and progressive beliefs, like D66 and GroenLinks. But this is not the only reason young adults appeared to vote for the more progressive parties. According to the study done on voter behavior, most young adult voters have, or are following a higher education. This is also a group of voter who tend to vote for more progressive parties[24]. There might also be other demographic factors that influence the success of the introduction of the LEZ, but this is not researched further for now.

The opposing group will have concerns, like is the public transport reliable? And will their always be enough shared rides for everyone to use. It will be important to listen to these concerns and take them into consideration, whilst developing the new transportation system in the area.

THROUGH TRAFFIC

The through traffic are the people that would usually travel through the area with any mode of transportation. With the introduction of the LEZ they will need to take another route avoiding the zone, or switch to another mode of transportation that is allowed within the area.

These people will probably find the LEZ inconvenient, because it means they may need to take a longer route in the future. For them the benefits of the introduction of the LEZ will be less important, because they only want to pass through the area. This is a group that will therefor probably resist the introduction of the LEZ.

On the other hand if the area is not too big and the alternative routes are not much longer the might not find the introduction of the LEZ a big hinder.

Municipality

In the past few years municipalities in The Netherlands have started to introduce LEZ's over different areas. Some only prohibit heavy duty vehicles powered by diesel, but last year the municipality of Amsterdam presented their to wish to make the densely populated inner-city a car free zone.

For municipalities the introduction of a LEZ has some benefits. These are mentioned below. Firstly it reduces the emission of particulate matter and nitrogen, which improves the livability of the city. According to a report of Natuur & Milieu it will also create more space in the city. Currently the parked private cars occupy a great amount of space in the city, by introducing shared rides and stimulating car pooling up to 38 % of the parking spaces can be removed [7]. This creates extra space to develop more housing within the city.

These are great positives, but not all political parties in a municipality will agree with plans to introduce a LEZ. The concerns these people have should be taken seriously and the discussion on the success of the introduction of this zone should be continued throughout the years.

Public transport operator

The public transport system in some cities is already slowly introducing electric powered vehicles. It is easier to invest in new vehicles for public transport operators than it is for individuals. These operators have a big collection of vehicles and there are always some vehicles that are too old and need replacement. If the transportation get informed in time, they need to invest in eclectically powered vehicles this transition can happen gradually.

At this moment electric buses are still more costly than diesel powered busses. That is mostly due to the costs of the batteries. It is expected that these will become cheaper in the next couple of years [21].

To cover these costs there are two options. Make public transport more expensive, or subsidise it. To make it acceptable for the public, making it more expensive is probably not a good option, unless the alternatives turn out to be much cheaper, than owning a private car.

Shop owners

For the shop owners it is important they can still stock their shops and that this does not become way more expensive. And they will want to keep their customers. The first two problems are quite easily solved by making a solid plan for the transportation of these goods. The second problem is not that simple. This is dependent on the change in behaviour of people, which get influenced by a lot of factors.

Delivery services

As mentioned there are smaller delivery vehicles for the delivery of packages and larger trucks that need to supply the shops in the zone. Both parties will not be great supporters of the introduction of the zone, it is mostly inconvenient for them they have to switch transport modes.

Other parties delivering alternative transport services

For parties that offer shared ride services this LEZ might be a good new business opportunity. They can expand their business in this area and make an example of how shared ride services can work. They will however need to invest in electric powered vehicles that are, for now at least, more expensive than gasoline powered cars.