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Low Emission Zone in Sarajevo

Development and implementation

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Summary

Sarajevo is facing vast challenges in terms of poor air quality. The sources of pollution are several and emissions from traffic is one of the contributors. The Swedish Environmental Protection Agency has since 2017 been leading a SIDA-funded environmental collaboration with Bosnia and Herzegovina that focuses on improving air quality with regard to both data and measures in Sarajevo and Banja Luka. This report covers the work that has been done to improve air quality through traffic regulations focusing on the implementation of a low emission zone in the central parts of the Bosnian capital.

The purpose of the assignment is to strengthen Sarajevo's capacity in implementing and preparing for air quality improvement measures primarily regarding traffic regulated zones.

The aim of this report is to provide an overview of relevant steps in implementing a low emission zone. Additionally, this report gives an account of the results from the remote sensing measurements carried out in Sarajevo in June 2022 to investigate the real emissions from the vehicle fleet. Furthermore, this report provides guidance in measures suitable for traffic management in the city of Sarajevo. A five-year implementation plan for the low emission zone was developed and further elaborated with suggestions on activities.

Year	Main activity/goal
1 (2023)	Public and political endorsement. Public awareness and information campaign. Complementary measurements of traffic and emissions.
2 (2024)	Political decision, preparations for implementation, education, equipment, staff etc.
2 (2024)	Soft early implementation. No fines at this stage.
3 (2025)	Sharp implementation, noncompliance yields a fine.
3-4 (2026)	Evaluation. Effects on traffic, public acceptance, air quality, vehicle categories, method of control.
4-5 (2026-2027)	Potential tightening of Euro class regulation and/or transition from a manual control system to semi-manual or automated system.

Regarding monitoring and enforcement method, there are several options with varying degree of technical level, all with their own advantages. A recommendation is to start out simple with a more manual option and then later on transition towards more automated monitoring systems.

To further enhance the implementation process and improve the traffic and air quality situation in Sarajevo, additional activities and supporting measures are suggested.

Acronyms

ANPR – Automatic number-plate recognition

CO- Carbon monoxide

DSRC - Radio-frequency identification

GNSS – Global Navigation Satellite SystemHBEFA- Handbook of emission factors for road transport

HC- Hydrocarbon

HGV- Heavy goods vehicle

LCV- Light commercial vehicles

LEZ- Low emission zone

NO- Nitric oxide

NO2- Nitrogen dioxide

NOX– Nitrogen oxides

OBU – On-board unit

RFID- Radio-frequency identification

1 Introduction and background

The purpose of this report is to provide civil servants and politicians of Sarajevo with an understanding for low emission zones and necessary tools to initiate implementation of low emission zones, hereinafter referred to as LEZ. The report will go through essential steps and reasoning behind low emission zones and recommend a way forward.

The report is a compilation of available information from domestic and international sources regarding low emission zones in Europe. Firstly, a short background on LEZ is presented followed by a chapter introducing preparations for a LEZ. The preparations will cover aspects such as public and political acceptance, exemptions, costs etc. Following that, a chapter focusing on implementational aspects such as signage and control and compliance. The chapter on emissions from traffic is based on a remote sensing campaign in Sarajevo 2022 and contributes with data collected within the frames of the project.

This report can be regarded as a continuation of the report *U6505 Traffic regulations in Sarajevo* which is a prestudy investigating traffic related measures to improve air quality in Sarajevo. In this report, the attention will be directed towards low emission zones providing a more in-depth and focused take on background, how the zones are designed, implementation and potential effects.

Many European cities have focused their efforts to tackle air pollution by implementing low emission zones, hereinafter referred to as LEZ.A LEZ is a geographical area within a city where a certain type of vehicle is prohibited to enter, based on emissions. For heavy and light duty vehicles, access is denied for emissions above a specific limit, excluding the most polluting vehicles and thus improving air quality. Emission control technologies improve over time and the design of the zone is therefore based on the exclusion of vehicles that do not comply with the highest, current Euro-emission standards.

A LEZ is a local tool that can be decided and used by cities/regions/cantons in order improve air quality for its inhabitants. By doing so, emission reductions can be made in cities where the cost of emissions is the highest for society. The emission related cost for society is higher in cities where many people live and work, thus more people are exposed to higher levels of air pollution in cities compared to the countryside. Thereby, introducing a LEZ could be a cost-effective way of reducing emissions from vehicles since the following emission reduction will bring benefits to the numerous people living in urban areas in terms of improved air quality.

Though a LEZ will inevitably affect people's and business' everyday life, citizens and companies have several options to how to adapt to a LEZ. Except from buying a car or truck that fulfills the regulation it is also possible for transport companies to relocate trucks. Another possible adaptation strategy for both citizens and companies are to drive around the zone, when possible, thus avoiding entering the zone altogether.

The LEZ can be a powerful alternative in the toolbox for combating air pollution. By targeting the most emission intensive heavy and light-duty vehicles, pollution from those categories can be significantly reduced whilst only affecting a limited number of vehicles (Roth et al. 2021a, Dieselnet, 2019a,b).

Other advantages are:

- Zones extent can be designed to cover a designated area rather than a larger part of the city which can contribute to acceptance from public and local business.
- Effective in mitigating emissions given that regulations are supervised and followed
- Does not require extensive physical changes in the city and thereby no expensive investments

The overall aim and purpose of a LEZ is to improve air quality.

2 Preparations for a low emission zone

There are several things that are important to consider before implementing a LEZ. The following section will provide an overview of relevant aspects that should be considered before proceeding with a LEZ. It does not cover every aspect that might be relevant since all cities are different with their own unique conditions. However, considering the aspects in the following sections will help in starting the process and assist in bringing structure to the work.

2.1 Legislation and decision-making - mandate to act

Involvement of relevant governing bodies with mandate to take decisions must be done. Further, the necessary legal support/legislation also must be in place. With ambition of having a permanent LEZ the implementing parties involved must ensure the survival of the LEZ independently of elections and who currently holds office. Improvement of air quality is a continuous endeavor and not something that can be solved and rectified during one term of office. Therefore, a broad, strong support of LEZ should be secured in order for it to pass successive governments.

Countries and cities with frequent elections and short terms of office should thus consider approaches on how to secure long-term support for LEZ. A cross-party coalition could serve this purpose. And by putting emphasis on health benefits for the population and having arguments based on concern for health impacts of air pollution, support can be gained from different parties.

2.2 Public acceptance and communication

Key points for communication efforts:

- Make an inventory of relevant groups and business that will likely be affected by the LEZ.
- Provide targeted information to affected residents and local businesses.
- Provide meetings to which residents and local business are invited. The meetings should be held years in advance and on several occasions to enable participation.
- Design suitable road signs to mark the area.

To increase public acceptance, communication and public anchoring are vital. Acceptance is also important and other groups such as haulers, delivery services, real estate owners, local businesses, and employers will be affected by the LEZ and should thus be included in communication efforts. There will most likely be an opinion against the implementation, but it is important to raise awareness and support among the public and to find support among companies with a progressive mindset regarding environment and air quality, e.g., taxi companies and real estate owners.

The primary communication effort can preferably be directed towards those who will be the most affected by the zone whereas the continued communication can take a wider approach. In connection with the introduction of the zone more intense communication is recommended.

An analysis of LEZ by Koucky & Partners (2015) account for lessons learned from implementation of LEZ, congestion charges and studded tire bans, emphasizing the need for information campaigns. The information should be adapted to targeted groups and stakeholders and in the form of dialogue (Koucky & Partner, 2015). This entails informing residents and local business within the intended zone area of the future zone regulation. Furthermore, they should also be given the offer and opportunity to attend informational meetings. Preferably, the meetings should be several and held years in advance to enable participation and provide enough time to adapt vehicle purchases and so forth. The meeting is an opportunity for the implementing parties to convey correct information about the LEZ and why it is necessary and to address concerns and questions from the public and business.

In order to succeed, the importance of dialogue has here been emphasized. However, there must also be a plan for how to handle the response. E.g., exemptions, provide alternative transport options for those with cars who are not allowed to enter and so forth. The implementing parties must also be prepared to, when needed, adjust the plan based on the response.

2.3 Size and access

The size of the zone is one of the key elements of designing the zone. The size will be directly linked to the effects on air quality. A small geographical area will not have as significant impact as a larger zone, but a zone that is regarded as too big a risk to affect many people and businesses. Align the ambitions for the zone with what can be acceptable from a political and public point of view without compromising the integrity of the LEZ. Perhaps the zone will have to start out on a smaller scale than what was desired initially and then over time expand geographically. That is for example what is planned in some cities like Amsterdam (City of Amsterdam, 2021).

The geographical borders of the zone should be considered to allow citizens to have access to hospitals and other important institutions regardless of vehicle status. Hospitals and such must be accessible independent of LEZ. This must be kept in mind during the design of the zone to avoid drawing the borders in such a way that they will cut people off.

Another aspect to consider regarding access is which vehicles to exclude from the zone. As for the size and its connection to the effects, the same reasoning applies for excluded vehicles. A stricter approach, excluding less vehicles and having higher demands on technical performance will provide better results in terms of improved air quality. However, this must be balanced against acceptance. The implementing parties are recommended to gather information about the vehicle fleet and map how many vehicles will be excluded based on a certain level of Euro-class. How large share of the vehicle fleet will those excluded vehicles constitute? What will be an acceptable level, both for citizens and political level? For how long will the zone restrictions apply and when can it be suitable to tighten the restrictions to include more vehicles or more Euro-classes? What is the natural turnover for vehicles and how will the vehicle fleet change over time? These questions must be addressed.

3 Affected vehicles and costs

Another of the key questions concerns what type of vehicles should be prohibited in the zone. A stricter approach, excluding more types of vehicles and having higher demands on technical and environmental performance (higher Euro-classes) will provide better results in terms of improved

air quality. Though, setting the restrictions too high and too early can create a situation where many people and their vehicles are cut off from a part of the city risking miscontent, decrease in acceptance and negative effects for local business. Also, a too strict approach will have the risk of having a negative effect on the socioeconomic valuation as it will bring costs in terms of investment costs for vehicle owners when many vehicles must be replaced.

The cost for the introduction and operation of a LEZ also must be considered. Communication, personnel costs, enforcement, traffic signs, traffic measurements and preparations are relevant matters of expense. However, these costs are generally rather modest.

3.1 Exemptions LEZ

In general, it is advised to have as few exemptions as possible to avoid causing confusion and uncertainties amongst the people entering the zone and to not undermine the effectiveness of the measure. Though, it is common to have a set of general exemptions for specific vehicles and professionals. The following chapter will provide an overview of commonly occurring exemptions in various European cities.

3.1.1 Exemptions Sweden

In Sweden, the local regulations are the same for all cities with LEZs. The requirements are based on rules specified in the Swedish Road Traffic Ordinance (SFS1998: 1276 chapter 10), meaning that the European Union's environmental classification of vehicles is used as foundation to determine which vehicles to allow within the LEZ (City of Gothenburg, 2022).

Stockholm has to this date two LEZs. Low emission zone 1 was introduced for heavy vehicles in 1996 encompassing the majority of the capital's central city. In 2020, a new and stricter LEZ (Low emission zone 2) was introduced on Hornsgatan targeting older private cars, light trucks, and buses. As of July 2022, the requirements for Low emission zone 2 were strengthened, diesel-powered cars, light buses, and light trucks now having to meet the technical requirements corresponding to Euro 6 (City of Stockholm, 2022).

Stockholm do not issue any temporary exceptions for travel within the LEZs. All vehicles that wish to enter must comply with the requirements. Though, a few categories of vehicles and professions are exempted:

- Vehicles used in the occupation of a policeman or any other employee of the Police Authority or the Security Police, Customs officer, Coast Guard officer, physician, nurse, midwife, or veterinarian
- Other emergency services
- Transport of sick people to doctors or hospitals
- Emergency vehicles
- Vehicles classified as vintage vehicles
- Vehicles used by staff in the Prison and Probation Service when transporting detainees or in urgent occupation
- Vehicles used in specially arranged transport such as travel service
- Vehicles with drivers or passengers who have a parking permit for the disabled
- Vehicles for which car support has been provided through the Swedish Social Insurance Agency

The city of Gothenburg and Malmö has since 1996 also low emission zones, class 1, targeting heavy vehicles. The exemptions are the same as for Stockholm.

In all Swedish cities with LEZs, the zone is in force 24 hours a day, every day.

3.1.2 Exemptions Germany

Germany has several LEZs, as of 2021 there are 58 low emission zones comprising over 70 cities. As for exemptions, Germany has a set of general exemptions listed below (Urban Access Regulations in Europe, 2022a):

- Mobile machinery and equipment
- Work machines
- Agricultural and forestry tractors
- Two- and three-wheeled motor vehicles incl. "quads"
- Ambulance cars, doctor's cars with the mark "Arzt Notfalleinsatz" (doctor in emergency service)
- Motor vehicles driven by, or carrying persons with serious mobility impairments, helpless or blind persons who have a severe disablement document marked with disability codes "aG", "H" or "Bl"
- Vehicles that may use special priority privileges, such as police, fire brigade, disaster relief or refuse collection vehicles
- Army and NATO vehicles.
- Vintage cars older than 30 years with “H” in the registration number or with a red number plate (prefix 07) for historic vehicles.

There also exist local exceptions which can be issued to residents following an application.

The Senate Department for the Environment, Urban Mobility, Consumer Protection and Climate Action in Berlin (2022) describes how the city has introduced exemptions only applying to the German capital. Since 2010 only vehicles with a green emission sticker are allowed to enter the zone though it is possible to apply for an individual exemption in certain circumstances to alleviate social and/or economic difficulties the driving ban entails. Though, to ensure the integrity of the zone particular conditions must be met to be granted an individual exemption:

- Vehicles belonging to people suffering from impaired mobility (severely disabled persons with the mark “G”) on low incomes.
- Special vehicles with attributed business ideas or with extensive vehicle conversions and low mileage within the low emission zone.

The permit is valid for a maximum of two years, thereafter a new application must be submitted Berlin, 2022).

3.1.3 Exemptions the Netherlands

The Netherlands has several emission zones in place and in the city of Amsterdam there are currently two zones, Amsterdam A10 and Amsterdam City.

The Amsterdam low emission zone affects diesel cars, commercial vehicles, buses, mopeds, motorcycles, and lorries. From January 2022 the minimum standard for diesel cars and delivery vans is Euro 4 and for diesel lorries, buses, and coaches Euro 6. It is possible to purchase a day exemption, 50.90 Euros, for delivery vehicles and trucks if they do not meet the zone criteria (Urban Access Regulations in Europe, 2022b). It is also possible to apply for an exemption permit for motor homes if having to travel to and from sites located in the LEZ (ACL, 2022).

3.1.4 Exemptions France

When the LEZ were introduced in France they only applied for French registered cars. In 2017 this rule changed, and now foreign vehicles are also included. All vehicles travelling within the zone when it is in force must have an environmental decal on the windscreen (Miljödekal, 2022).

In France, the LEZ does not apply all the time. For heavy duty vehicles the LEZ is in operation from 08.00-20.00. Since 2019, light duty vehicles are subject to the LEZ during Monday to Friday between 08.00-20.00. As for vehicle exemptions, the following categories are exempt from the restrictions (Urban Access Regulations in Europe, 2022c):

- Vehicles of public interest as defined by law R. 311-1
- Vehicles of the armed forces
- Vehicles of civil security
- Vehicles of driving schools
- Vehicles of removal companies
- Vehicles of authorized market suppliers
- Vehicles transporting frozen goods and fueling vehicles
- Vehicles specialized vehicles not used for the carriage of goods as defined in Annex 5 of the decree of February 9, 2009, except motor homes
- Vehicles such as authorized exceptional convoys
- Vehicles that have collectible marked on their registration that are over 30 years of age, used as part of a commercial activity for tourism with a sticker of authorization behind the windscreen
- Vehicles with a parking card for people with disabilities

3.1.5 Exemptions Italy

The most common approach is for LEZs to be in force 24 hours a day, 365 days a year. Though, Italy has departed from this practice. The zone restrictions only apply during parts of the day and only during winter when the pollution is most troublesome. However, all vehicles are subject to the restrictions, including motorcycles (Swedish Transport Administration, 2010).

3.1.6 General recommendation

As stated before, it is recommended to have as few exemptions as possible. Making the rules easy to understand will increase the likeliness of compliance.

The report has so far solely covered how other countries have done regarding which groups or vehicles to allow exemptions for. Equally important is to consider which groups not to grant any exceptions. To ensure the validity of the zone and have bearing in the general public, residents and people working within the LEZ should not be exempted from the zone regulations.

Residents and people working within the zone usually constitute a large share of the traffic movements within a zone. By giving those groups an exemption from the regulations would be strongly contra productive and give cause to question the purpose of the LEZ.

The regulations and potential exemptions should be anchored in the overall goal with the zone and furthermore aligned with the previous communication. Exemptions for residents and people working within the zone would have a negative impact on the credibility of the zone.

It is common to exclude vintage cars from the zone regulations and if proceeding with an exemption like that it must first be considered how to distinguish these vehicles during controls and what conditions must be met to be classified as a vintage car. During a compliance check, it must be easy to judge whether a vehicle is vintage or not.

- Have the zone restrictions apply all day. If legislation permits, it could be possible to have zone restrictions on weekdays, but leave Saturday and Sunday without restrictions. The motivation should then be to be able to introduce stricter rules.
- Have the zone strictions apply to all vehicles, domestic as well as foreign, diesel and petrol fueled
- Limit the number of exemptions to police and other emergency vehicles, vintage vehicles, and vehicles for people with permit for disabled.
- Residents and people working within the zone should also be subject to the regulations.

3.2 Costs

In Stockholm, the establishment of the LEZ class 2 for light vehicles cost approximately 175 000 EUR. The costs are divided between internal time for personnel costs, traffic measurements and communication (City of Stockholm, 2021).

Important to take note of here is that these numbers presented for Stockholm presuppose those personnel and necessary competences are in place. Thus, the numbers presented are marginal costs. A country without this foundation will have to start from the beginning, hence the costs for building this competence and foundation will be larger than what is presented here. A city such as Sarajevo will most likely have to allocate more financial means to communication efforts. Estimations of costs are highly dependent on context and conditions. Access to available data will also influence the costs for preparations and traffic measurements.

Internal time cost: 53 500 EUR
Traffic measurement: 35 000 EUR
Communication: 87 000 EUR

4 Signs, control, and compliance

The following chapter will provide an overview of selected countries and how they have chosen to proceed with signs, control, and compliance for their domestic low emission zones. Based on these findings, the final subchapter will present a general recommendation.

4.1 Road signs

The following chapter will cover signage of a LEZ. Since many European cities already have implemented LEZs this text will be illustrated with examples of how other cities have decided to proceed with traffic signs.

4.1.1 Sweden

Traffic regulations issued by local traffic regulations are normally marked with a road sign. However, in chapter 10, section 13 of the Traffic Ordinance there is an exception to this regarding low emission zones. The obligation to put up traffic signs does not apply to LEZs. Nevertheless, in the Swedish cities with LEZs there are other signs that inform about the area, see figure 1 below and figure 2, and since 2020 the Swedish Transport Agency provides a new road sign for low emission zone (The Swedish Transport Agency, 2020).

Figure 1. Sign at the side of the road in Gothenburg. The sign says, "Low emission Zone, Emission limits for heavy vehicles". The sign is not an official traffic sign in that sense but rather an informational sign with the purpose of informing about the LEZ.

The new road signs presented in 2020 comes for three different classifications of LEZ.

- Classification 1 and 2: Emission requirements on heavy and light vehicles
- Classification 2: Emission requirements on light vehicles
- Classification 3: Only electric vehicles, fuel cell vehicles and gas vehicles are allowed

Figure 2 Swedish road signs for LEZ, class 1 and 2, entering and exiting the zone (The Swedish Transport Agency, 2020).

4.1.2 Germany

If travelling by car in Germany, the vehicle should be equipped with an environmental decal to ensure access to the commonly occurring LEZs in German cities. To be granted access the vehicles must have a certain decal, called Feinstaubplakette or Umweltplakette, which is to be placed in the windscreen, clearly visible showing the vehicle's Euro classification. To be allowed access to the LEZs the vehicle must comply with the LEZ standard. This applies not only for domestic vehicles but for visiting vehicles as well. The color of the decal will decide whether the vehicle is allowed to enter the zone, figure 3. The red sticker is reserved for the most polluting vehicles, yellow for slightly less polluting and green is for the least polluting vehicles (German Emission Sticker, 2022).

Figure 3. German emission stickers (German emission sticker, 2022).

The beginning of a LEZ in Germany is indicated by the sign to the left in the figure below, and the sign to the right indicate the zone ending, figure 4. The signs may not be placed on minor roads and streets entering or exiting the zone.

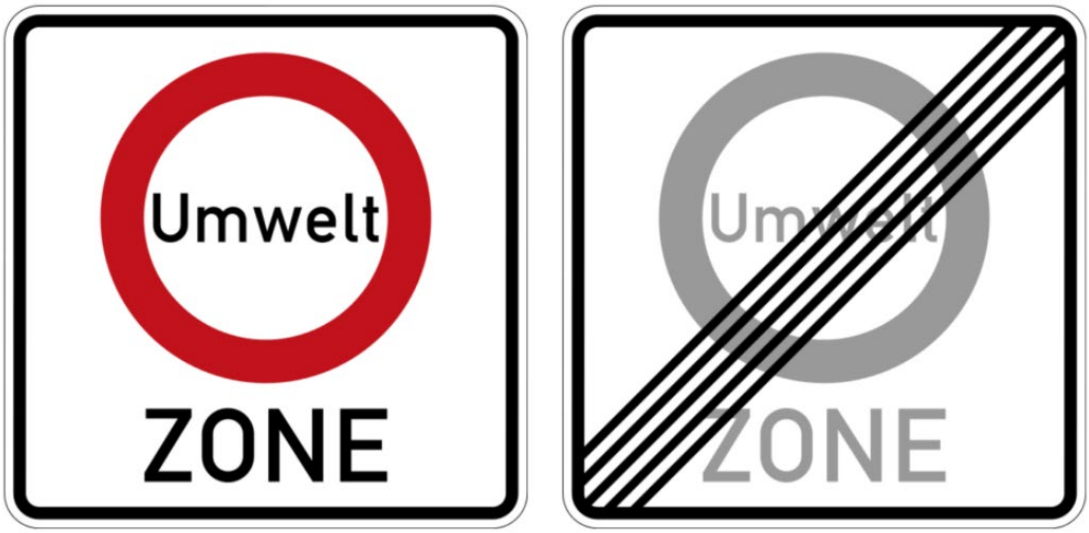


Figure 4. German road signs for LEZ, entering and exiting the zone. (German emission sticker, 2022)

4.1.3 France

The low emission zones are marked with road signs, showing where the zone starts, during which hours it is applied and affected vehicles. Figure 5 below shows an example of road sign for LEZ in France (Miljödekal, 2022).

Figure 5 Road signs for LEZ in France, to the right a sign for entering the zone followed by additional signs showing during which hours it applies and which vehicles are affected (Miljödekal, 2022).

4.1.4 Recommendations

As mentioned in previous chapters, the recommendation to have as few exemptions as possible still applies. Having few exemptions eliminate or significantly reduce the need for additional signs and information in connection to the LEZ road signs. The point of departure for the design of the road signs for the LEZ is to keep it clear and simple. Road users should be able to, by a quick glance at the sign, understand the meaning.

To avoid unintentional zone violations, it is vital that the signs are placed in locations that allow the road user time to see and register the information and if needed, take an alternative route. Thus, the road signs should not only be placed on the exact boarder of the zone but also a bit before.

4.2 Control and compliance of LEZ

To ensure legal compliance within zone regulations it is important to oversee the vehicles entering the zone. This can be performed by the police with support from e.g., parking attendants. Compliance with the regulation improves with proper enforcement and penalties. If a violation of the zone automatically entails a fine, people tend to improve their behavior.

4.2.1 Sweden

In Sweden compliance checks are carried out by the police by checking the registration number of the vehicle. The penalty for illegal driving within the environmental zone is a fine of 1 000 SEK, approximately 100 EUR. In 1997 approximately 95 percent complied with the regulations, in 2007 compliance had decreased to 90 percent (Transportstyrelsen, 2019).

4.2.2 France

At first when LEZ were introduced in Paris, France, there was a transition period. When the police, who were responsible for enforcement, controlled vehicles in the zone and discovered deviations they settled for giving the drivers a reminder of the rules of the zone and the need to have an environmental decal on the windscreen.

Now, however, it can be quite expensive to drive in a low emission zone without an environmental plaque. Since January 2017 the penalty fee has been up to 68 EUR for cars and vans and 135 for heavy goods vehicles and buses. The penalty for drivers who repeatedly violate the regulations will be gradually increased (Miljödekal, 2022).

Recently, LEZ expansions have been presented. A part of that will include increased fine levels from 68 EUR to 750 EUR as well enforcement using automated cameras (The Local, 2022).

4.2.3 The Netherlands

The fine for violating the zone rules is differentiated based on vehicle category. For moped and motorized bikes, the fine is 70 EUR, 100 EUR for cars, taxis, delivery vehicles and coaches. For lorries the penalty is 250 EUR (City of Amsterdam, 2022).

The method for enforcement in the Netherlands is digital with cameras viewing the number plates (Urban access regulations, 2022).

4.2.4 Recommendations

It is recommended for Sarajevo to introduce a LEZ as soon as possible, taking necessary preparation and information into account. Waiting for more advanced technical solutions can cause unnecessary delays in the implementation process and thus delaying the much-needed emission reductions. Instead, it is preferable to introduce the system and make adjustments and adaptations in the coming years.

For example, having a digital and automated system for control and compliance has advantages, but it will require more resources in terms of preparation time, investigations, equipment, systems, and costs. A manual enforcement method, using the local police conducting samples, is therefore recommended to start with as it requires relatively little resources and can be quickly introduced. As local competence and experiences are collected and contribute to increased knowledge capacity, the enforcement method can be developed towards an automated system using cameras and photo identification as basis for issuing a fine.

The penalty fee is important in communicating the importance of the LEZ and can provide a clear signal emphasizing that violations are actions of serious matter. Thus, do not set the level for the penalty fee too low. The penalty fee can with advantage be compared with the fees used in Sweden and the Netherlands with around 100 EUR. A fee around 100 EUR is thus recommended for Sarajevo, it is higher than the corresponding level in Sweden, but not as high as in France.

The results in this report have been based on available data concerning vehicles and vehicles movements in the Sarajevo area, except for the remote sensing-measurement which was carried out in June 2022 in Sarajevo. Before an introduction it is therefore recommended that more vehicle measurements are carried out, especially to determine the number and Euro-classification of vehicles passing the intended zone border.

5 Calculations and measurements of emissions in Sarajevo

The following chapter will give an account of the calculations and measurements of emissions in Sarajevo. Firstly, the calculation process will be presented, and relevant assumptions will be explained. Following that, an account of the remote sensing campaign carried out in Sarajevo in June 2022 will be given.

5.1 Calculation process and assumptions

The general methodology for calculations is accounted for in this chapter. Necessary, and relevant assumptions needed for explaining the results and drawing conclusions are presented in the following sections. For sources of data for the calculations, see Appendix 1.

Input for the calculations constitute of a mix of data from several sources. The data comes from amongst others on-road remote sensing measurements and reports provided by Sarajevo, see Appendix 1 for list of data sources.

The main categories for calculations are the following:

- Vehicle fleet composition
- Traffic flow estimations
- Diurnal variations
- Emission factors
- Emission scenarios

For the vehicle fleet, the composition is described in the data as passenger cars (petrol or diesel), light commercial vehicles (diesel) and buses (diesel). The fleet is analyzed with respect to emission standard, Euro classes 1-6 and pre-Euro class which is described as Euro 0, altogether seven Euro classes. Furthermore, the estimation for the numbers in the vehicle fleet is done for three geographical areas: within the low emission zone, central city (Stari Grad + Centar) and the "whole city" of Sarajevo.

Due to the lack of complete data, the calculation method is based on the principle of using figures from various sources and then assess their accuracy followed by merging them together to create an as complete overview as possible. For a future scenario the fleet composition was computed using an Excel tool developed in a research project in Sweden. By exchanging the Sweden specific data for data from Sarajevo the fleet composition, with respect to light duct vehicles and Euro classes, was calculated for ten years into the future. The rate of vehicle scrapping in Sarajevo is assumed to be the same as in Sweden[1] and new vehicles are assumed to be of emission standard Euro 6.

[1] The annual scrapping rate in Sweden for PCs is an average 1.5-2 percent during the first ten years followed by an average of 14 percent the next ten years. During the first 20 years, the average scrapping rate will be approximately 7 percent. Average life span is 17 years but is dragged down by vehicles that are scrapped early. Typical scrapping age is approximately 19 years.

The estimation of the traffic flow is mainly based on a GIS-file with associated database supplied by Sarajevo City. The file provided information, contained approximately 1800 road links with attached information about vehicle passages per day divided into three categories: light-duty (< 3,5 t), medium heavy-duty (3,5-7,5 t) and heavy -duty vehicles (> 7,5 t). Combined with the link length, the total traffic flow per category was calculated. However, the GIS-file only contained the main roads and excluded smaller roads, though since the main roads typically dominate the total traffic flow in most cities this lack in the data is assumed less dominant. The traffic flow was then transformed into another categorization to match the fleet data and emission factors, which are weighed in, and allowed for emission calculations based on that. It is important to stress that the calculations for the LEZ are based to registered vehicles within a certain geographical area. The emissions are calculated on a fleet based on this but is adjusted for observations made during the remote sensing measurements.

Diurnal variations describe the fluctuations that occur during the day and the variations between day and night. There are 24 different factors used to describe the diurnal variations, one for each hour of a normal weekday. The diurnal variations of the traffic flow were derived from the remote sensing measurements, that was performed at four different locations in Sarajevo, by counting the time registration of the vehicle passages. Since the remote sensing measurements were carried out during a limited time of day, hours outside the measurement time (before 06:20, and after 14:45) were complemented with general factors from Swedish conditions and matched to the relative factors from Sarajevo. The traffic flow outside the measurement hours can be estimated by analyzing the traffic flow variations within the measurement hours, combined with similar data and experience from other cities.

Emission factors for air pollutions from passenger cars (PC diesel, PC petrol) were generally derived from the on-road remote sensing measurements, see chapter 5.2. In some cases, the measurements were assessed as non-reliable and, in these cases, emissions factors were taken from the HBEFA-model[2], which represents the average emissions for a certain euro class and fuel technology. For the remaining vehicle types, MC, LCV, medium heavy, heavy, heavy + trail, heavy buses, bus, articulated bus, emission factors were derived from the HBEFA-model.

In chapter 6, the emission scenarios presented in the graphs are based on the produced numbers described above. The emissions (in grams) were computed by multiplying the emission factors (g/km) and the road lengths (km), which are based on the length of the road links given in the GIS-file. The different scenarios are using the same emission factors as "today". When banning a certain Euro class from the LEZ, it is assumed that 80 percent of the light-duty vehicles and 90 percent of the heavy-duty vehicles will comply within the LEZ; and outside the LEZ will 25 percent and 50 percent respectively comply.

The implementation of the low emission zone will result in a small loss of vehicle kilometers. It is assumed that 20 percent of **the banned traffic flow** will disappear (or be replaced by emission-free vehicles), and the remaining 80 percent will be replaced by an even composition of higher Euro classes that are still allowed.

[2] Handbook of Emission Factors for Road Transport (HBEFA) is a European road emission model developed by INFRAS, a Swiss Research and Consulting company on the behalf of environmental authorities. HBEFA - Handbook Emission Factors for Road Transport

5.2 Measurements of emissions- Remote sensing

As part of the IMPAQ project a pilot study was conducted. By using the method of remote sensing the project aimed to investigate and study the real emissions from traffic in Sarajevo. The following chapter will account for selected results from the remote sensing and how they can be of use for Sarajevo in the city's strive to improve air quality.

Road traffic is often the most important source of poor air quality in urban areas. Although stricter exhaust gas requirements and improved exhaust gas cleaning technology in Europe have led to reduced emissions from mainly petrol-powered vehicles since the early 1990s, problems remain with high emissions of nitrogen oxides and particulates from diesel vehicles, partly because of EU exhaust legislation had major shortcomings, partly when cheating occurred among car manufacturers (e.g., "dieselgate[3]").

The following chapters will introduce remote sensing, its benefits and the results from the measurement campaign carried out in Sarajevo in June 2022. For a full account of the remote sensing campaign and its results, see *Remote Sensing- Measurement of Vehicle Emissions in Sarajevo* (Cha, Y., Sjödin, Å. 2022).

5.3 Introduction to remote sensing

The only technology that allows measurements of emissions in real traffic on large, representative vehicle fleets is so-called "remote sensing". With this technology, the emissions from thousands of individual vehicles can be measured during a normal working day by placing a remote sensing instrument at the roadside. In recent years, remote sensing has become extensively employed in many large European cities, such as London, Paris, Madrid, Berlin, Zürich, Warsaw, and Brussels, to increase the cities' knowledge about the real-world emissions of their local fleets and thereby implementing local tailor-made measures to reduce traffic emissions, improve air quality and reduce the exposure of the city population to health hazardous air pollutants, by means of introducing e.g., low emission zones.

The instrument measures the emissions of CO, HC, NOX (NO and NO2) and particles and can also register the vehicle registration number, hence enabling linking (via the traffic register) the measured emissions to vehicle individuals from specific manufacturers, vehicle model, fuel, model, Euro class, cylinder volume, engine power, etc.

By using the method of remote sensing, it is possible to investigate and study the following:

- The emission performance of the vehicle fleet in Sarajevo in relation to previously calculate/estimated emissions and current legal requirements.
- Need and potential for the introduction of local measures in the road transport sector to improve air quality in parts of Sarajevo such as the introduction of low emission zones.
- How to best design actions and measures.

[3] An industrial scandal in 2015, manufacturers systematically implemented defeat devices in engine's exhaust gas purification system with the result of diesel vehicles emitting more exhaust gases than was accounted for. https://dieselgate.legal/

- Occurrence and significance of high emitters.
- Indications of occurrence of vehicle performance tampering among car owners, i.e., deliberate manipulation of vehicle exhaust purification equipment.

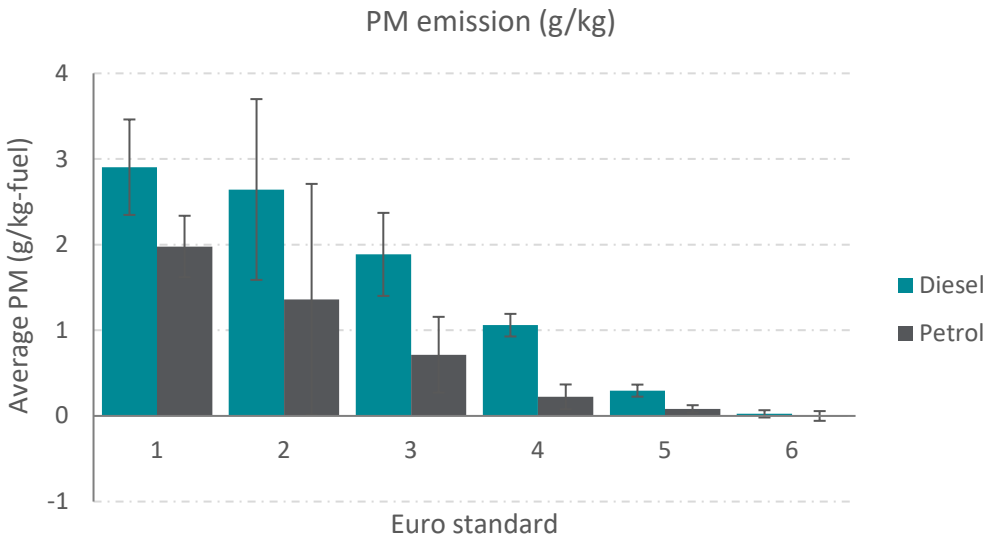
Furthermore, the pilot study generates a baseline that can be used for future follow-up and track how the local vehicle fleet's emission develops over time, e.g., as a result of targeted measures.

5.3.1 Measurements results

For a full account of the measurement results *Remote Sensing- Measurement of Vehicle Emissions in Sarajevo* (Cha, Y., Sjödin, Å. 2022). In the section below, an overview of selected results will be presented.

The one-week remote sensing pilot study in Sarajevo successfully recorded ≈25,000 vehicle passages from which emission measurements of PM, NO_x, HC, and CO were made, split into different vehicle types (PC, LCV, trucks, buses, and motorcycles), fuel types (mainly diesel and petrol) and Euro standards (Euro 1-6). Data capture for heavy-duty trucks was less successful, due to less effective vehicle number plate identification, which is a well-known limitation of remote sensing in this context.

The averages (and 95% confidence interval of the mean) of the emissions from passenger cars were calculated by emission standard and fuel type, as the results illustrated in Figure 6. For PM, the average measured emission decreased from Euro 1 to Euro 6 for both diesel and petrol cars. The average PM emission for Euro 6 was 0.024 g/kg fuel for diesel vehicles, and -0.0005 g/kg fuel for petrol cars. Negative average values indicate the majority of the emissions measured were below the detection limit of the remote sensing instrument. Much lower PM emissions were observed for petrol cars compared to diesel cars for Euro 1-4, while for Euro 6 the difference between diesel and petrol vehicles was small. A large reduction can also be seen for NO_x emissions from Euro 2 (18 g/kg fuel) to Euro 6 (almost 0 g/kg fuel) for petrol vehicles, while for diesel vehicles the change is slower varying from around 17 g/kg fuel (Euro 2) to 8.5 g/kg fuel (Euro 6).



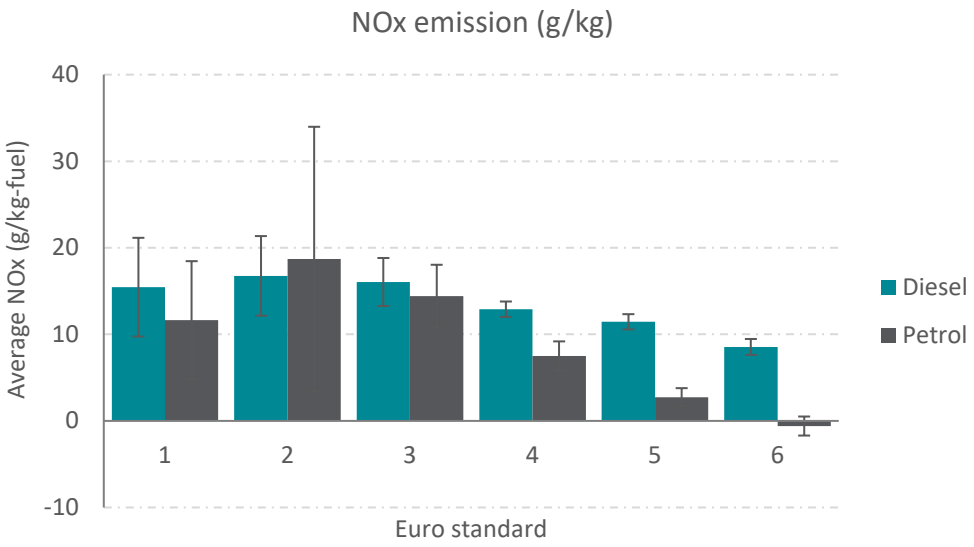


Figure 6 Average fuel specific PM and NO_x, (gram per kilogram fuel) emissions from diesel and petrol passenger cars (PC) by emission standard. Whiskers represent the 95% confidence interval of the mean.

As observed in many other recent European remote sensing studies, the PM emissions from the Sarajevo vehicle fleet have reduced substantially for all vehicle types (on the order of 80-90%), as Euro standards increase from Euro 1 to Euro 6. In contrast, NOx emissions from diesel vehicles have only reduced on the order of around 50%, despite the stricter Euro standards.

Euro 3 – 5 diesel passenger cars contributed 74% of all NO_x emissions from all passenger cars, while accounting for 63% of the number of all passenger cars measured. Similarly, Euro 3 and Euro 4 diesel cars together are responsible for 74% of total PM emissions from all passenger cars, while representing only 40% of all passenger cars measured.

Figure 7 show the average measured fuel-specific NO_x and PM emissions, respectively, of passenger cars in grams of pollutant emitted per kilogram of fuel burned (g/kg) by fuel type and emission standard. Included in these figures are the corresponding results derived from the CONOX database from measurements carried out in 2021 in Switzerland (sites Regensdorf and Gockhausen) and Italy (sites Madre Cabrini and Cilea). In the CONOX datasets, Euro 6 includes Euro 6, Euro 6b, Euro 6c, and Euro 6d.

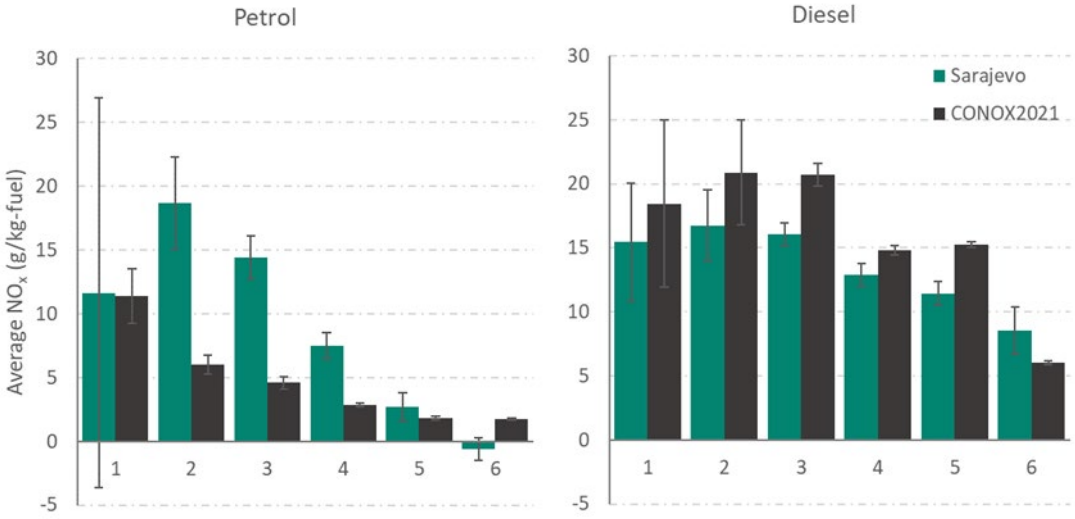


Figure 7 Average fuel-specific NOx emissions from diesel and petrol passenger cars by emission standards for Sarajevo and CONOX database (2021). Whiskers represent the 95% confidence interval of the mean.

As seen in Figure 8, for petrol cars, PM emissions were substantially higher in Sarajevo for all Euro standards, especially prior to Euro 5, except for Euro 6 in which case the average emissions of both datasets were close to 0 g/kg, i.e., below the detection limit of the RS instrument. The average PM emissions for diesel cars in Sarajevo were higher than those of the CONOX dataset for all Euro standards except for Euro 6, but the differences were not statistically significant.

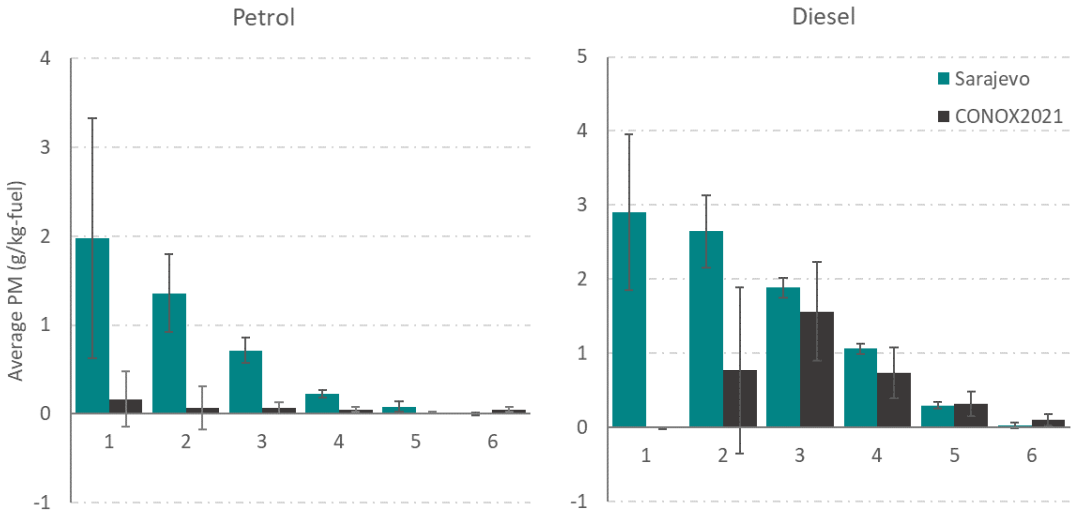


Figure 8 Average fuel-specific PM emissions from diesel and petrol passenger cars by emission standards for Sarajevo and CONOX database (measurements done in 2021). Whiskers represent the 95% confidence interval of the mean.

The following section focuses on the emission measurements of trucks from the Sarajevo campaign. In total 134 measurements (0.5% of total measurements) were obtained for trucks, among which 131 (98%) were diesel-powered and 3 were petrol-powered. The measurements of heavy-duty trucks were less successful, due to vehicle license plate capture. By reviewing a random sample of 300 photographs where license plates were not identified, about 13% could be

manually identified as trucks, indicating the proportion of trucks initially identified was underestimated. Around 85% of all diesel trucks were Euro 3-6, with the remaining 15% made up of older emissions standards than Euro 3. The average fuel-specific emissions of NO_x and PM by emission standard from diesel trucks are shown in Figure 9. Despite the small sample, a significant reduction in both NO_x and PM emissions, especially for PM emission, can be seen for the trucks with the latest Euro 6 emission standards.

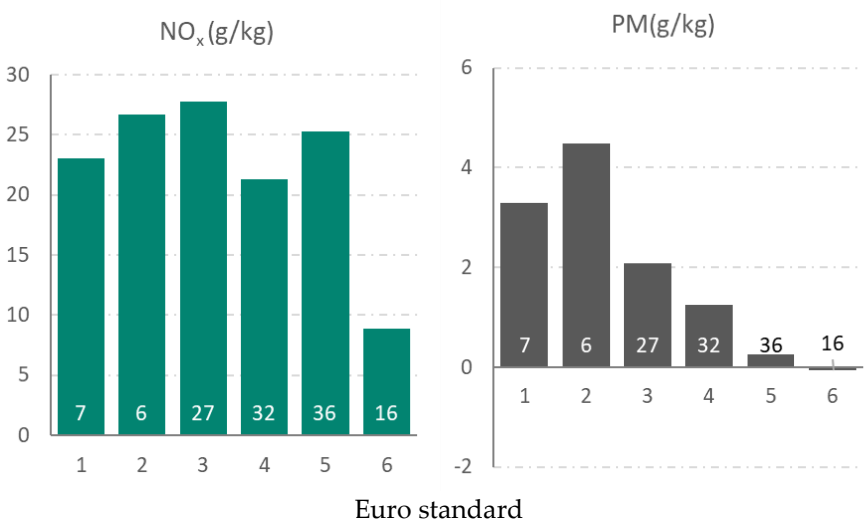


Figure 9 Average fuel specific NO_x, and PM emissions in g/kg fuel burned from diesel trucks by emission standard. The number of measurements is shown inside of each bar.

In conclusion, the emission performance of the Sarajevo vehicle fleet deviates from that of other European fleets, mainly for petrol cars. Emissions of PM, NO_x, HC, and CO were substantially higher for pre-Euro 5 cars in Sarajevo, i.e., older cars, compared to those in other European cities where similar remote sensing measurements have also been performed. The main reason for this observation is the substantially higher share of high-emitting cars within the Sarajevo petrol car fleet.

The latter observation raises the question whether a lower quality of petrol fuel has been (and still is) used in Sarajevo than in the EU, e.g., with higher sulphur content poisoning the three-way catalyst, poor maintenance and /or tampering of the cars, possibly in combination with an inefficient inspection and maintenance program (PTI).

6 LEZ in Sarajevo- recommendation and suggested development

The previous chapters have been focusing on various aspects of LEZs, providing examples and inspiration from several European cities and countries. This chapter will, on the contrary, have its starting point in Sarajevo. Furthermore, this chapter will provide suggestions on which vehicle classes to include in the zone regulations and what a future scale up could look like.

Using data of the road network and registered vehicles, the traffic in Sarajevo has been mapped and this information has been used to calculate and estimate the potential effects of a LEZ in Sarajevo. The calculations are based on data from the remote Sensing campaign, see chapter 5.2, and the HBEFA-model *Handbook Emission Factors for Road Transport* and additional sources provided by Sarajevo, see Appendix 1.

The outline of the chapter follows a structure of first presenting a suggestion for the future low emission zone, followed by calculations of the composition of the Sarajevo vehicle fleet and how it is expected to develop over the coming years. Lastly, a recommendation for which vehicles to cover in the restrictions and calculations of the potential effects of a LEZ in Sarajevo. The effects will focus on the emissions of particles from exhaust, thus particles from road wear are not included in the calculations.

It is important to stress that the calculations for the LEZ are based to registered vehicles within a certain geographical area. The emissions are calculated on a fleet based on this but is adjusted for observations made during the remote sensing measurements.

6.1 Size of the zone

The picture below, figure 10, presents an overview of the suggested zone in Sarajevo. Design and size were developed by the team in Sarajevo with support and suggestions from IVL, Swedish Environmental Research Institute. The suggested area for traffic restriction is approximately 5,6 km², housing 50 000 inhabitants.

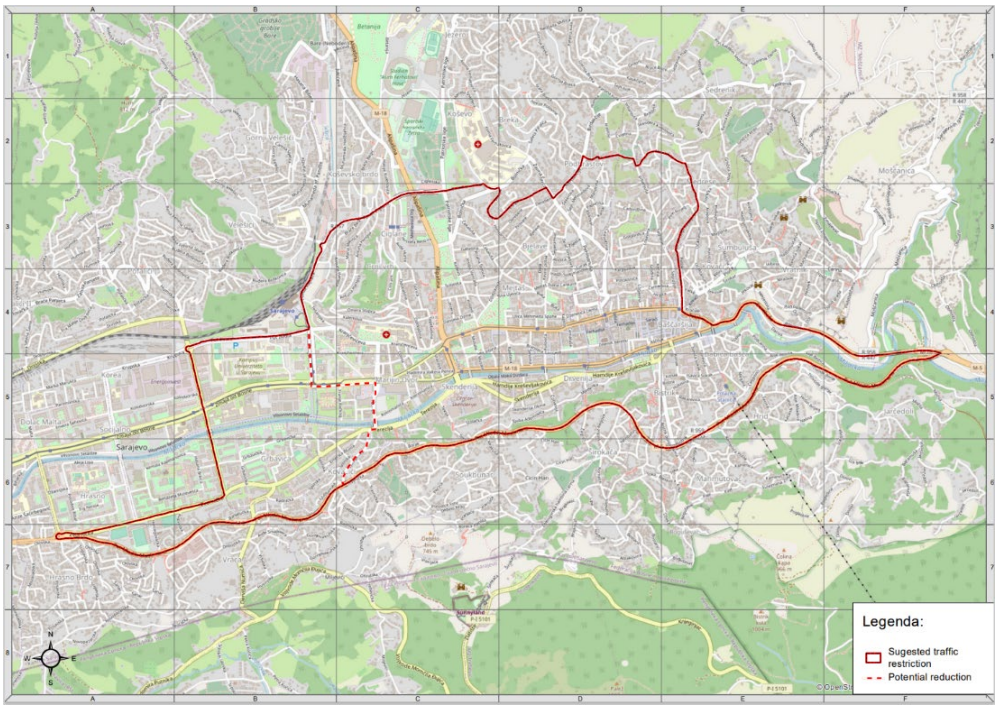
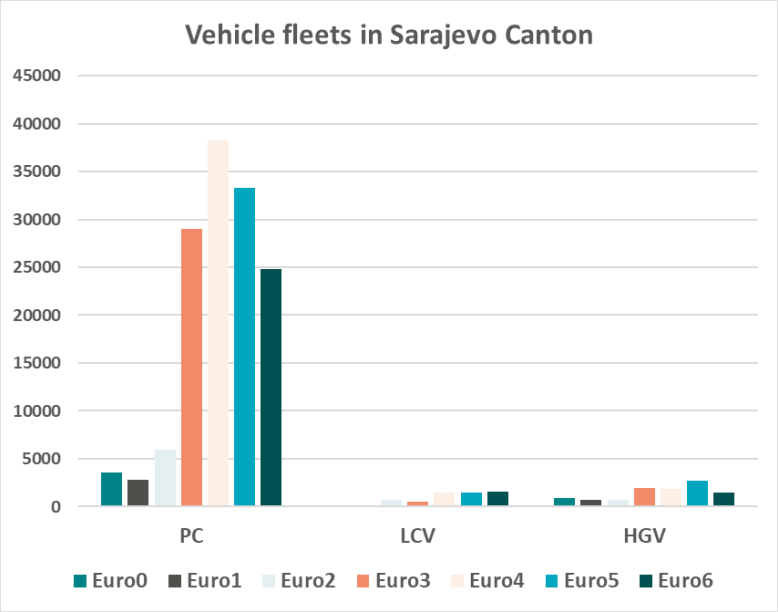


Figure 10 A map of Sarajevo, Bosnia Hercegovina. The red line shows the area for the suggested LEZ.

6.2 Composition and development of vehicle fleet in Sarajevo

To decide an appropriate level for the LEZ it is vital to have information of the vehicle fleet and its composition, both within the zone and in Sarajevo city. This information will ensure choosing a level that will not exclude to many vehicles whilst still having the desired effect. The following graphs shows the occurrence of passenger cars, light commercial vehicles and heavy goods vehicles within the proposed LEZ and the whole city, figure 11.



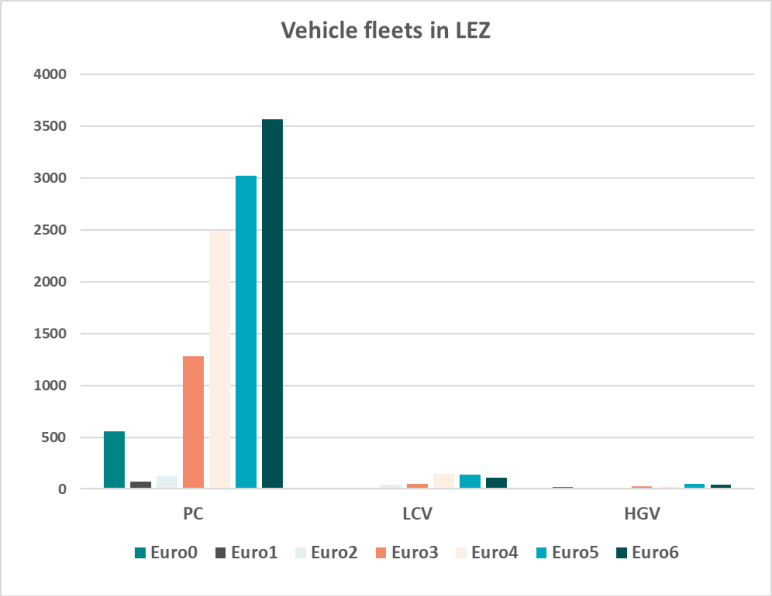


Figure 11 These graphs illustrate the calculated composition of the vehicle fleet in the whole of Sarajevo as well as in the proposed low emission zone. The numbers show that passengers cars are significantly more abundant compared to light commercial vehicles and heavy goods vehicles.

These figures provide a well needed understanding of the vehicle fleet in Sarajevo and its components. Furthermore, they provide arguments for targeting passenger cars in the proposed measures since passenger cars are significantly more abundant than LCV and HGV. Based on these results, the disposition of vehicle types and emission standards, it is close at hand to propose different zone rules for different vehicle types.

The figure below, figure 12, shows the share of euro classes in the vehicle fleet divided into the LEZ, Sarajevo City, and the whole of Bosnia Hercegovina.

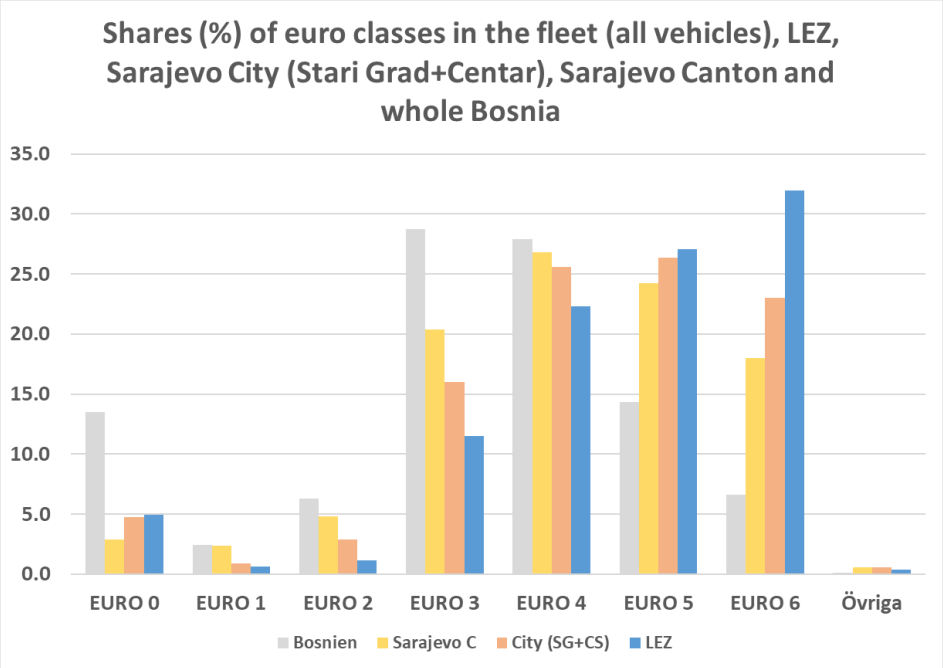


Figure 12 An overview of the Euro- class composition of vehicle fleet in Bosnia Hercegovina, Sarajevo City and in the proposed LEZ.

From a country perspective, this graph implies that a LEZ excluding vehicles with Euro 0, 1, and 2 would affect just a little above 20 percent of the domestic vehicle fleet. Moreover, less than 10 percent of the vehicle fleet in Sarajevo City and in the LEZ will be affected. As an initial step for the LEZ, this level of exclusion is argued to be reasonable and manageable politically and in terms of public acceptance since a majority of the vehicles would still be able to travel within the zone. As mentioned above, these numbers are based on current and historical data.

For the whole Sarajevo fleet, the number of passenger cars and Euro classes are expected to develop according to the graph in figure 13.

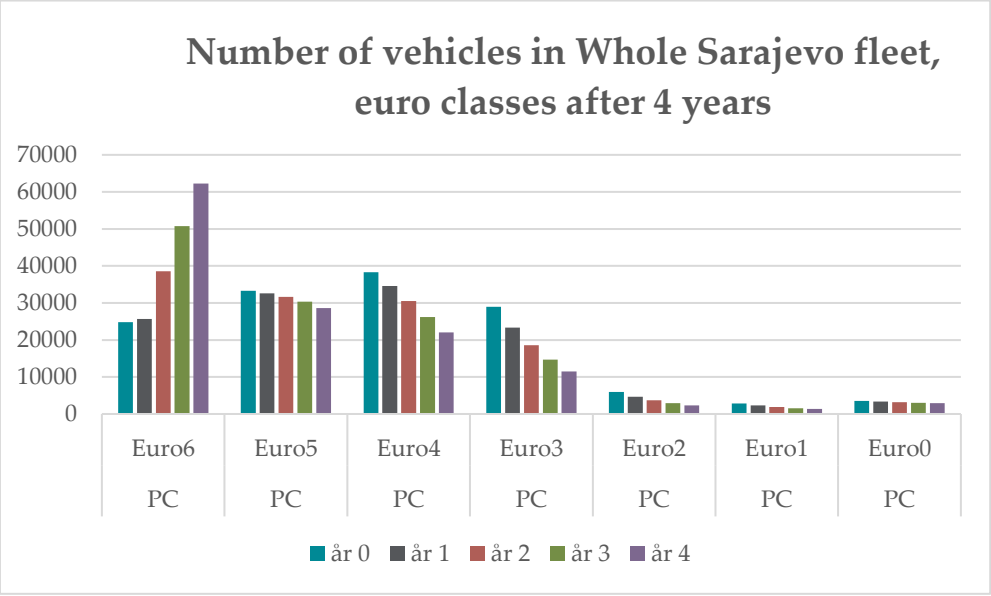


Figure 13 The numbers of passenger cars in the vehicle fleet in the whole of Sarajevo sorted by emission standard and expected development over the course of the next four years.

During the four-year time period passenger cars with Euro 6 is expected to experience a sharp increase whereas the lower Euro classes will decrease. For passenger cars within the proposed LEZ, the current situation and expected development is similar, se figure 14 below.

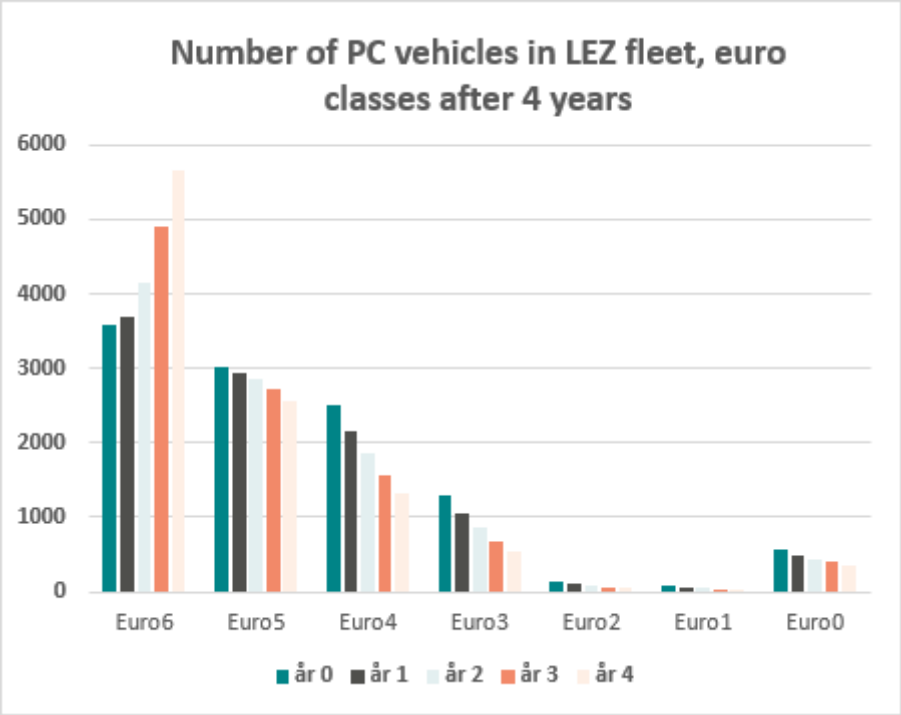


Figure 14 The numbers of passenger cars in the vehicle fleet within the proposed LEZ sorted by emission standard and expected development over the course of the next four years. Euro 4, 3 and 2 are expected to notably decrease whereas Euro 6 will increase.

The natural turnover of vehicles indicates how the number of vehicles with lower emission standards are expected to decrease during this calculated four-year period whereas vehicles with Euro class 6 is expected to increase. This information is relevant to consider should the implementation of the LEZ be delayed. If the LEZ were to be implemented in three- or four-years' time it is advisable to consider the turnover of the vehicle fleet when deciding the Euro class level for the zone.

Taking a longer perspective, the trend becomes more distinct. Passenger cars will consist even more of Euro 6 and the lower emission standards will decrease during the ten-year period, see figure 15 below.

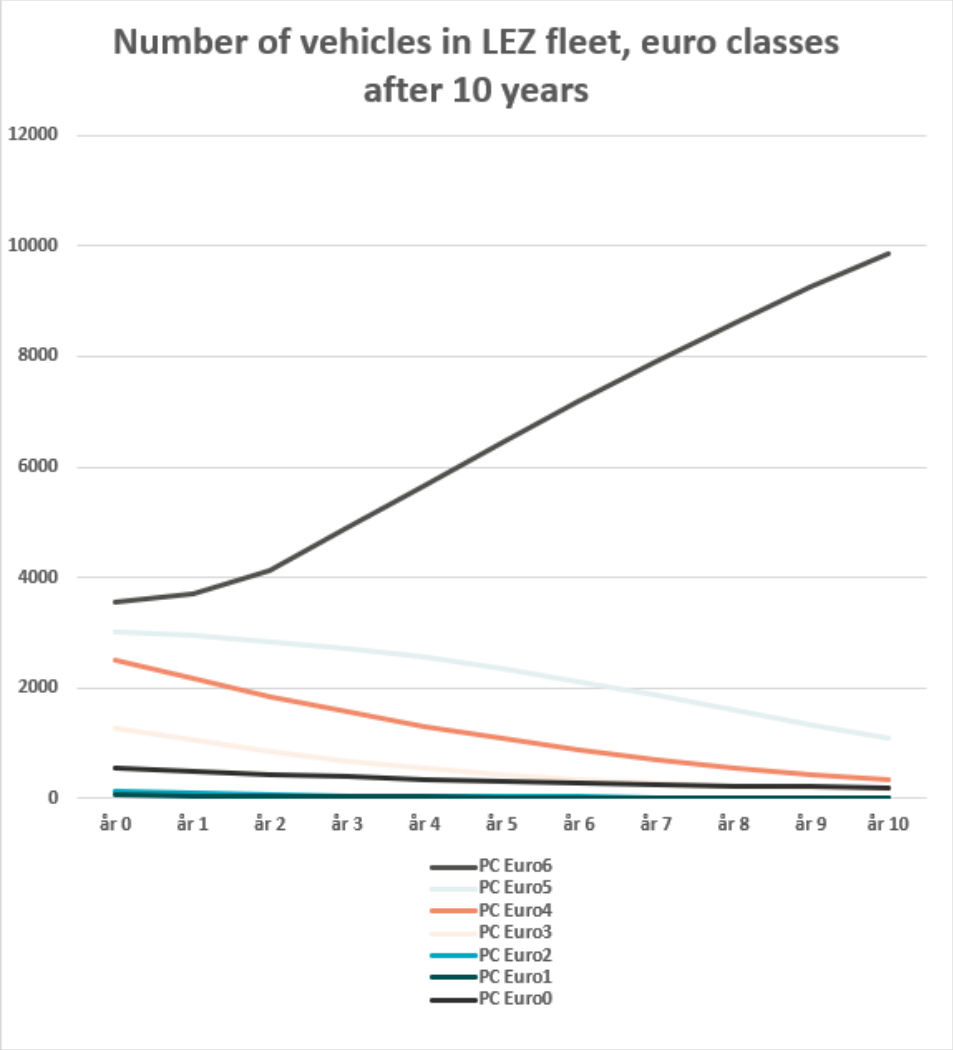


Figure 15 Transformation of the vehicle fleet in the LEZ during a ten-year timeframe. Euro 6 will increase significantly whereas the vehicles with lower emission standards decrease.

The table below provides an overview of the cumulative share of the fleet for passenger cars within the proposed LEZ. If choosing to ban vehicles with Euro class 0, 1 and 2 in year 0 less than 10 percent of the vehicle fleet within the zone would be prohibited from driving, which can be considered a relatively mild and caution approach. However, if the implementation would be delayed several years, the natural turnover of the vehicle fleet will influence the cumulative share of the fleet suggesting to also exclude vehicles with Euro 3 once year three or four is reached. If the implementation is delayed until year four and the restriction is set to Euro 2 less than 5 percent of the vehicle fleet within the zone would be prohibited from driving which would impair the zone's effectiveness.

Table 1 Cumulative share of the vehicle fleet for passenger cars in the proposed LEZ. If implementation of the LEZ is delayed several years, the calculations suggest vehicle restrictions should be adjusted to include higher Euro classes than previously suggested.

LEZ	*PC vehicles*	Cumulative Share of fleet										
Vehicle category	**Technology**	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
PC	Euro6	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
PC	Euro5	67.9%	64.8%	59.7%	52.7%	46.2%	39.9%	34.1%	28.7%	23.8%	19.5%	15.8%
PC	Euro4	40.7%	36.8%	32.0%	26.6%	21.9%	17.9%	14.5%	11.8%	9.5%	7.7%	6.3%
PC	Euro3	18.3%	16.2%	13.8%	11.4%	9.4%	7.8%	6.4%	5.4%	4.5%	3.9%	3.3%
PC	Euro2	6.8%	6.2%	5.5%	4.8%	4.2%	3.6%	3.2%	2.8%	2.5%	2.2%	2.0%
PC	Euro1	5.6%	5.3%	4.8%	4.2%	3.7%	3.3%	2.9%	2.6%	2.3%	2.0%	1.8%
PC	Euro0	5.0%	4.7%	4.3%	3.8%	3.4%	3.0%	2.7%	2.4%	2.1%	1.9%	1.7%

Additionally, this table can be used as guidance as for when to tighten the zone rules. If an exclusion of approximately 20-15 percent of the passenger cars within the zone is regarded as acceptable, it would be recommended to tighten the requirements in year three or four, i.e., from year 2025/2026.

The figures presented in the graphs and table in this chapter should be regarded as indications of the vehicle fleet and its composition. The important message is the overall change. Several sources of data from Sarajevo have been used, including vehicle registration statistics and GIS file containing traffic flows. Furthermore, remote sensing measurements and a Japanese consultancy report as well as additional data from the city of Sarajevo. All sources are rated being of good quality but cover different parts. No source is complete in covering all aspects such as vehicle type, emission standard, driving pattern and frequency and so forth. Therefore, available sources have thus been combined to a whole. When necessary, assumptions have been made e.g., regarding the scrapping rate, Swedish data have been applied.

6.3 Recommendation for vehicles covered by restrictions and exemptions

Based on these calculations and measurements presented in chapter 6.1 and 6.2 the recommendation for Sarajevo is to distinguish between passenger cars and LCV and HGV but let the LEZ-restrictions apply to all three vehicle categories.

Provided that the LEZ will be implemented in the near time future the recommendation is to prohibit PC with Euro 0, 1 and 2 and LVC and HGV with Euro 0, 1, 2 and 3. The reason to have a

higher Euro demand for light and heavy trucks are those fleets are not as numerous as passenger cars. Also, trucks usually have a higher culling rate compared to passenger cars. Another argument is that the costs of shifting vehicles can to some extent be forwarded from truck companies and haulers to transport buyers and other end users as shop owners. This will entail exclusion of less than 10 percent of the passenger cars within the proposed zone. Should implementation be delayed until year three or four it should be considered to include Euro 3 for passenger cars in the ban as well. Including Euro 3 within 3-4 years will entail an exclusion of 13-16 percent of the vehicle fleet of passenger cars within the zone.

The rule of thumb is to have as few exemptions as possible. Recommendations for Sarajevo is listed below:

- Have the zone restrictions apply all day. If legislation permits, it could be possible to have zone restrictions on weekdays, but Saturday and Sunday without restrictions. The motivation should then be to introduce stricter rules, e.g., include higher emission standards at an earlier stage. i.e. Euro 3 for passenger cars before 2025/2026.
- Have the zone strictions apply to all vehicles, domestic as well as foreign, diesel and petrol fueled.
- Limit the number of exemptions to police and other emergency vehicles, vintage vehicles, and vehicles for people with permit for disabled.
- Residents and people working within the zone should also be subject to the regulations.

6.4 Potential effects of LEZ in Sarajevo

As has been expressed by project partners and experts in Sarajevo, the emissions of particles are a more urgent issue compared to other pollutants such as NOx. Nevertheless, calculations for NOx have been done and the results from those calculations are presented in Appendix 3.

Potential effects of the low emission zone have been calculated for three scenarios with the aim of highlighting the potential of various approaches and illustrate the change in exhaust emissions when including one more Euro class. The three scenarios are the following:

- **Scenario 1:** Passenger cars Euro 0, 1, and 2 + Heavy goods vehicles and light commercial vehicles Euro 0, 1, 2, and 3.
- **Scenario 2:** Passenger cars Euro 0, 1, 2, and 3 + Heavy goods vehicles and light commercial vehicles Euro 0, 1, 2, 3, and 4.
- **Scenario 3:** Passenger cars Euro 0, 1, 2, 3, and 4 + Heavy goods vehicles and light commercial vehicles Euro 0, 1, 2, 3, 4, and 5.

The recommendation for the LEZ presented in chapter 6.3 is scenario 1, exclude passenger cars with emission standards 0, 1 and 2, and heavy and light vehicles emission standards 0, 1, 2 and 3 assuming the zone will be implemented within the next couple of years. Given those conditions the graph below, figure 16, provide an indication of the diurnal variation of particle emissions in Sarajevo. Note that it is not concentrations presented in the graph but rather changes in emissions varying over time.

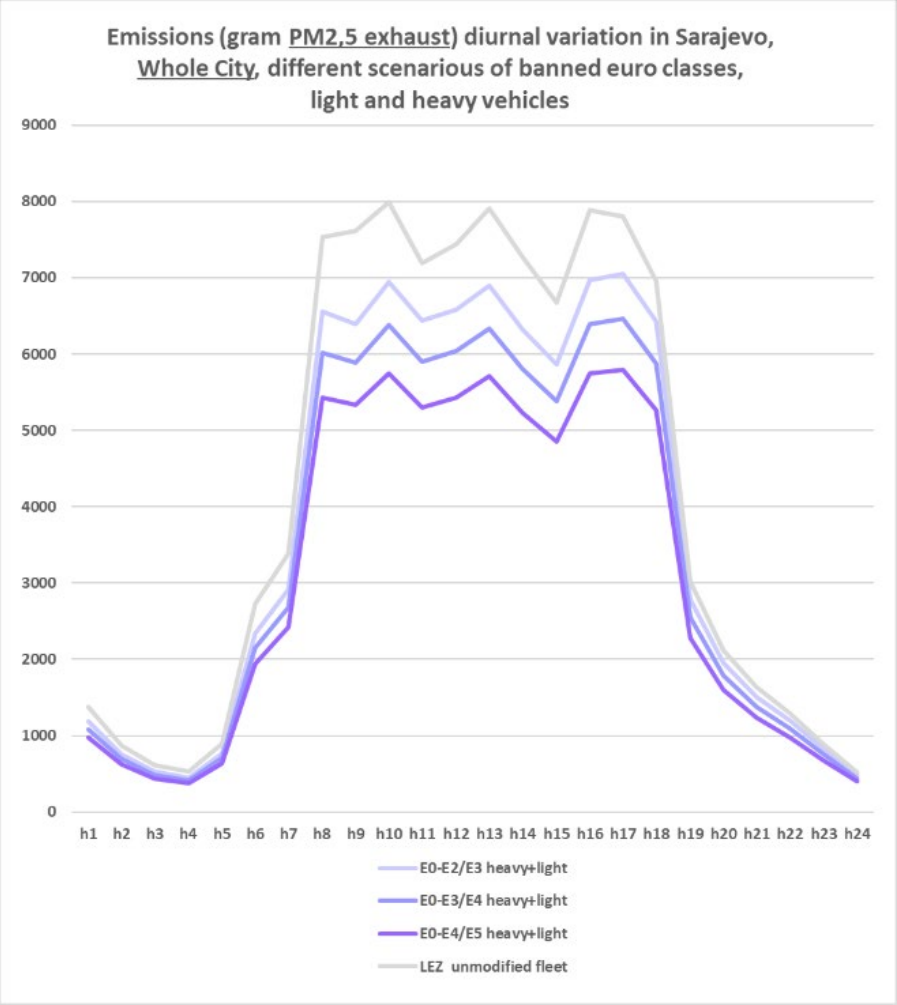


Figure 16 Daily fluctuations in particle emissions in grams from traffic exhaust in the whole city of Sarajevo following implementation of a low emission zone in the central areas of the city. The grey line represents the base line, no zone restrictions, and shows how the emissions vary each hour

The top grey line indicates the emissions of particles from traffic exhaust in the whole of Sarajevo from an unregulated vehicle fleet, i.e., without a low emission zone. Following, the three purple lower lines provides an indication of how the particle emissions will vary with different scenarios for the low emission zone. The lowest line represents a stricter approach and tighter zone rules excluding passenger cars with Euro 0-4 and trucks with Euro 0-5 i.e., scenario 3. Scenario 2 is depicted by the second lowest line and scenario 1, the recommendation for the introduction of the LEZ is represented by the second highest line.

As is conveyed by the scenarios in figure 12, a stricter zone will yield clearer effects. These calculations should not be viewed as an absolute truth and description of reality but more a way of illustrating the potential of different approaches and measures. Accordingly, a stricter approach including more emission standards will thus yield better effects on the exhaust particle emissions.

Zooming in on the proposed LEZ, figure 17, the trend is similar as for the whole of Sarajevo. During peak hours, h10-h15, emissions are markedly lower for all scenarios compared to the baseline.

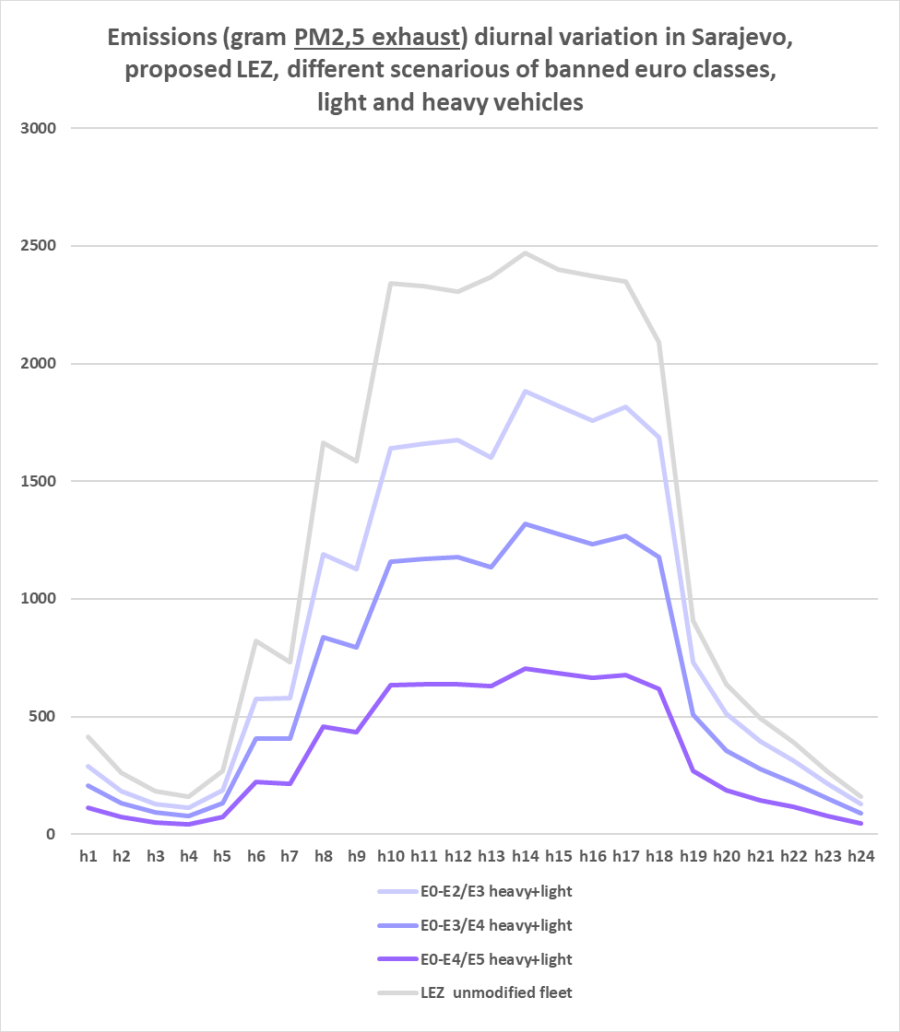


Figure 17 Daily fluctuations in particle emissions in grams from traffic exhaust in the proposed low emission zone in Sarajevo. Emissions during peak hours are markedly lower for all three scenarios. The grey line represents the base line, no zone restrictions, and shows how the emissions vary each hour

6.5 Year of implementation five-year plan

Based on discussions with local project partners and previous experiences and knowledge within the group, a proposal for implementation plan is presented. The plan for implementation spans four to five years and includes initial phases in gaining public and political endorsement, introduction of the LEZ, all the way to a potential tightening of the regulations. The table below provides an overview of the main activities in the implementation plan and during which year they are suggested to be initiated or carried out.

Table 2 Overview of five-year implementation plan

Year	Main activity/goal
1 (2023)	Public and political endorsement. Public awareness and information campaign. Complementary measurements of traffic and emissions.

2 (2024)	Political decision, preparations for implementation, education, equipment, staff etc.
2 (2024)	Soft early implementation. No fines at this stage.
3 (2025)	Sharp implementation, noncompliance yields a fine.
3-4 (2026)	Evaluation. Effects on traffic, public acceptance, air quality, vehicle categories, method of control.
4-5 (2026-2027)	Potential tightening of Euro class regulation and/or transition from a manual control system to semi-manual or automated system.

The implementation plan presented here is a rough draft and should be considered as guide with elements that can be adjusted, not a rigid step-by-step plan. The presented phases have a tendency to flow into each other and some activities, especially those of preparatory nature, are not limited to the phase where they are allocated in this report. The recommended bans of different Euro-levels are based on the vehicle fleet of today (data sources from 2020-2022). If the implementation phases are prolonged, the Euro-levels might be sharpened as described in 6.3.

6.5.1 Public and political endorsement, public awareness, and information

Year 1. The scope of this initial phase is to secure political endorsement and public acceptance. First and foremost, the general public must be made aware of the impact air quality has on their health, life expectancy and so forth. At this stage, the focus is on the adverse impacts of air quality followed by information about its causes and sources. The politics will start to seek out mandate to act and the public will ask for action.

Also, more data about vehicle and movements of people should be obtained, in order to create a decision basis for the political level about concrete zone regulations. Examples of activities are:

- Travel habit survey. Conduct a travel habit survey targeting businesses. This is a method to initiate the necessary dialogue with businesses and will provide an indication of how they travel within the zone. Furthermore, it can help to verify the movements in/out of the zone and indicate how much of the traffic flow is connected to companies operating within the zone. Once the connections are established through the survey it will facilitate further communication with the companies. They can be asked if they wish to participate in additional communication efforts and be part of the communication with their employees.

- Automatic traffic counting at the zone borders in order to update the numbers of affected vehicles.

- Final geographical scope and Euro-levels. During the preparatory phase, the design of the zone must be decided. The geographical scope must be considered as well as which vehicles to exclude. The placement of the zone must not hinder access to important institutions such as hospitals and the number of excluded vehicles must be at a level that will not compromise the goals and integrity of the zone nor affect too many people. This is a consideration of both size and emission standard level. A recommendation is to scale up and tighten the zone when current excluded vehicles constitute less than 20-15 percent of

the vehicle fleet which is considered to be at a level that does not entail too great limitations in the everyday life of the inhabitants.

6.5.2 Political decision, preparations, and education etc.

Year 2. This is the natural continuation of the previous phase and an intensification of the information campaign. Now, targeted communication is applied. This phase is part of the preparation for implementation of the LEZ and includes political decision, targeted information to stakeholders, educational efforts, procurement of necessary equipment, allocation of personnel and so forth. The responses from the dialogue process provide valuable information.

It is important to listen to the stakeholders and address their concerns and wishes. Furthermore, to have a routine for giving feedback to affected stakeholders to further enhance the dialogue. If it emerges in the dialogue that is its justified to make changes, these changes should also be communicated back to the stakeholders.

- Political decision. To go ahead with further work and development, this is the time to have a political decision for the implementation of the low emission zone.

- Procurement of equipment. Start the process of obtaining necessary equipment and systems. For the manual control, the people carrying out the task will need cameras for manual detection. Furthermore, there is also a need to be able to match photographs against the vehicle register to identify any violations. Set requirements for the back office.

- The responsible ministry or institution will have to set aside personnel dedicated to the work with LEZ. These personnel need to get information and necessary education to carry out their tasks.

- Stakeholder involvement is a key element, and screening of potential stakeholders is an important step. Once the stakeholders are mapped and analyzed, further information and campaigns can be adapted to the target group.

- Education. Relevant education must be provided for several categories of people. The occupational group responsible for enforcement and compliance (police). Those with the main responsibility for implementation, e.g., Ministry of Traffic. And lastly, politicians and decision makers responsible for e.g., traffic and environmental issues. It is important for the integrity of the system that the personnel have the right education.

- Signage: The putting up of signs is one of the last activities in the preparation phase. Signs should be placed on major roads entering and exiting the zone and in such a way as to allow road users to choose an alternative route if needed.

6.5.3 Soft implementation

Year 2. During the previous phase, the public, employers etc. have received information about when the zone will be in force, which vehicles that are affected and how control and compliance will be executed. Though, to allow a softer transition, initially noncompliance will during the first months after implementation yield information about the LEZ and not a fine. The information will convey that having this particular vehicle in this area is a violation of the LEZ and urge the owner

to either acquire a new vehicle that meet the criteria of the zone or exhort to not enter the zone with this vehicle in the future. Furthermore, the information will also inform that any violation in the future will yield a fine. It is important to communicate the time plan of the implementation to the public to make them aware of when the soft period of informing will end and when enforcement will start dealing out fines.

The soft implementation phase is recommended to last during a couple to a few months before the sharp implementation. During this time, enforcement will be visible and carry out many controls to signal the importance of the zone and that violations will not be tolerated.

6.5.4 Sharp implementation

Year 3. After a period of soft implementation, the LEZ will go into full force. As with the soft implementation, it is advised to have more controls initially as it will increase the legitimacy of the LEZ and send an important signal to the public. Noncompliance will now yield a monetary fine.

6.5.5 Evaluation

Year 3-4. To prepare for the development of the LEZ proper evaluation must be done. During implementation, both soft and sharp, information gathered. The effect of the LEZ is investigated and compared to previous data. Questions that should be answered or investigated:

- How is public support and acceptance?
- What is the impact on air quality?
- Changes on the vehicle fleet
- How has the method of control worked?
- How has is it worked with the exemptions that have been?
- When should the zone restriction be tightened to include more Euro-classes? How many vehicles will be excluded based on which Euro standard we choose.

Once the LEZ is implemented, continuous monitoring of air quality on strategic locations within and outside of the LEZ should be conducted.

6.5.6 Potential tightening of LEZ

Year 4-5. Based on the output from the evaluations, the LEZ evolves to encompass more Euro-classes. The change should be communicated well in advance to prepare the public and stakeholders on the change ahead. Depending on the experiences from the manual control, enforcement will either continue as before or initiate a transition towards semi-manual control system.

7 Monitoring: enforcement methods

Each enforcement method has advantages and shortcomings, and different implications for enforcement authorities. Effective enforcement is essential not only to achieve the objectives of the low emission zone, but also to guarantee fairness towards those that have switched to cleaner modes of transport or vehicles.

As with other enforcement issues, the decision about which method to use is linked to the enforcement method as well as to aspects such as the size of the scheme, type of area it covers, planning permission, resources available, number of permit categories and political, economic, and cultural factors.

Enforcement needs to be designed and conducted in a way that is acceptable to the public.

Enforcement should – if possible – be easy to understand, while at the same time it must not be too predictable in terms of where, when, and how it is carried out.

Enforcement should be linked to a well-designed back-office central system, the entire system needs to handle steps like data capture, data process, register data, verify evidence, decision about violation and penalty and notify the violator.

All changes in enforcement regimes should be communicated well in advance and during transition periods between different systems, system owners should be more forgiving towards those who committed violations.

7.1 Methods for identifying vehicles in the LEZ (identifier)

The following chapter will address different methods for identification of vehicles that have the right to stay and be used inside the LEZ.

Low emission zones sometimes require an active permit to be obtained. Others might require an active permit for some vehicles, i.e., exemptions, but not for others, such as most national vehicles (as the needed information is obtained from the national vehicle database).

If the enforcement system is based on number plate recognition, there is no need for a certain permit to be sent out.

In the most basic configuration, all tasks associated with the permit management system are done manually. Applicants submit a request in person at the front office of the LEZ manager (a public authority or a mobility/parking company) and personnel receive and process the application. Depending on the type of permit, this request may include supporting documents (e.g., proof of residence, vehicle registration, medical documents) whose validity should be verified. In the case of a positive assessment of the application, the corresponding permit is issued. Although this is the current reality, the recommendation is to digitalise the process. This would help reduce the administrative burden and be easier for those who may have difficulty getting to permit office, including people with disabilities, the elderly, people caring for dependants and people in full-time work, especially if they are already registered in the area.

7.1.1 Low-tech identifiers

Sometimes printed and visible permanent permits are preferred to virtual ones for reasons of transparency and for easy check/identification by the local police and the community.

7.1.1.1 Windscreen sticker

Windscreen stickers is an easy and "low-tech" way to help authorities to distinguish between complying and non-complying vehicles. In the absence of camera/RFID transponder-based enforcement systems, hologram stickers on permits can help to avoid falsification.

A windscreen sticker needs a separate permit management system where stickers can be ordered etc.

Figure 18 German LEX windscreen sticker (with Hologram)

7.1.1.2 Windscreen letter

A letter with information about the vehicle owner, vehicle number plate, emission standard and what kind of LEZ-permit this vehicle/owner holds. Date of permit. The letter must be placed visible in the windscreen when vehicle is used or resting inside the zone. The letter is possible and allowed to remove.

A windscreen letter needs a separate permit management system where stickers can be ordered etc.

Figure 19 Swedish windscreen letter (for parking)

The difference between a windscreen sticker and a letter is the possibility to remove the letter from the windscreen for increased safety and visibility, after leaving the zone. A letter system is rarely used in other cities.

7.1.1.3 Number plates

According to international agreements, all motor vehicles in traffic must have at least one unique number plate that is clearly visible even from a short distance, even in bad weather and poor light conditions. The registration plate has a connection to the vehicle's registered performance regarding, for example, its type-approved emission classification, but also a connection to data on whether the vehicle is approved for traffic or whether taxes and fees have been paid. It would be entirely possible to use the vehicle's number plate as a basis for identification to determine whether the vehicle has the right to stay and be used inside an environmental zone. There are some advantages to using number plates as a basis for identification (identifier):

• there is no direct additional cost to any party, as the number plates already must be worn for other reasons,

• it should be fairly easy to detect car owners who remove their number plates to make enforcement of environmental zone violations more difficult.

• the possibility of automating the enforcement is very good and there are well-developed technologies for it in a market with many competing players and a high speed of technology development.

There is a minor risk that the demand for fake number plates would increase if these were used for environmental zone monitoring, but there are no international indications where registration plates are used for similar reasons that this had become a severe problem.

7.1.2 High tech identifiers

7.1.2.1 Remote sensing technology

Figure 20 Example of on-board unit for remote sensing (DSRC)

In addition to camera enforcement, so called remote sensing technology can also be used. It measures pollution and noise levels of vehicles in real-time on the road, which also allows for spotting high-polluters and vehicles with defective exhaust after-treatment systems. When combined with licence-plate recognition, individual drivers can be informed about non-compliance or excessive emissions. The technology has already been used in several European cities, and the European Union is currently funding a research project to make its application easier and cheaper. Remote sensing technology may be subcategorised in:

- Radio-frequency identification (RFID): This requires the vehicle to have a transponder (on-board unit) (typical costs are ~€1). The antenna receives and responds to radio frequencies emitted by dedicated roadside equipment (RFID transmitter-receiver devices). RFID is commonly used for toll collection outside of the EU; in the EU, DSRC technology is more common.
- Dedicated short-range communication (DSRC): This is commonly used for electronic toll payment. The system consists of radio communication between roadside equipment and a dedicated on-board unit (OBU) or in-vehicle transponder (typical costs of the device are ~€8-10). The communication can be one or two-way. The system is commonly used for electronic toll collection in the EU, but it also presents potential applications within other ITS and cooperative ITS applications (e.g., parking management, real-time traffic information transmission).
- Global Navigation Satellite System (GNSS)-based enforcement: Vehicles are equipped with a GNSS on-board unit (cost ~€200-300) that allows for the vehicle's position, speed, and local time to be determined. The trip data is used within a low emission zone scheme to detect violations. Processing can be done by the on-board unit or in a back office (where data is sent by Global System for mobile communications). The GNSS system is perfect to combine with a geofencing scheme. Regulations can be defined for low emission zone digitally for the geofenced area and are communicated digitally to the driver through an in-vehicle notification.

In the following parts of this chapter, we focus on RFID and DSRC. We still think that a GNSS system is too problematic to use for low emission zones for privacy reasons.

7.2 Methods for detecting vehicles with permission to enter the LEZ- roadside detection systems

Effective enforcement is essential not only to achieve the objectives of the LEZ, but also to guarantee fairness towards those that have switched to cleaner modes of transport or vehicles. Several types of enforcement are currently used in Europe:

Together with a vehicle identifier an enforcement needs a roadside detection system. There are some main choices in ways to enforce a LEZ-system.

- Manual visual monitoring by, for example, a police officer
    - Without digital support
    - With digital support
- Enforcement run from a specially equipped moving vehicle
- Enforcement from fixed automatic monitoring equipment

7.2.1 Manual enforcement schemes

Manual schemes tend to be cheap to set up, but expensive to operate at levels to achieve reasonable compliance levels.

Manual enforcement is used in many cities but often lacks consistency and does not provide the same data quality to track the progress on an LEZ. Besides, it requires significant staff to enforce the LEZ. If enforcement is carried out manually, it can be combined with checks to enforce parking regulations as it is the case in Berlin.

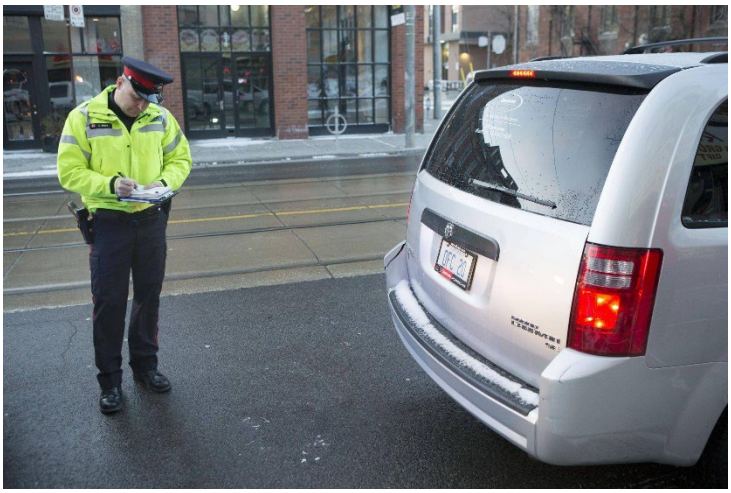


Figure 21 Example of manual enforcement

Each enforcement method has advantages and shortcomings, and different implications for enforcement authorities.

To improve efficiency and to avoid "in street" case handling – which is very sensitive to bribes and threats – there are several digital systems based on a handheld unit to serve the street officer.

The unit will collect, store and process vehicle data and send to a back-office system for further case handling.

Figure 22 Example of handheld unit to support manual enforcement

7.2.2 Automized enforcement

Automatic enforcement (e.g., ANPR) means a higher financial investment at the start, but the automatic system reduces personnel costs during operation, particularly for large schemes.

7.2.2.1 Number plate video recognition:

High resolution cameras with number plate recognition technology, detects banned vehicles entering the zone. Feeds a centralized system with data on unique vehicle entries and exits in a zone. Owners of banned vehicles entering the zone, will automatically get a bill/fine from the canton. This is the same well-used technology solution that are used for road pricing around the world.

Two choices here:

I. Mobile detectors (motorcycles with advanced cameras circling in the zone, not yet tested in full-scale systems)

II. Fixed toll gates (a well-known technology)

The technology to use mobile detectors is in a rapid development. Today you may find parking enforcement by e-bikes, motorcycles, and cars, detecting numberplates on vehicles they pass (both resting and moving vehicles are detected with a high degree.

Figure 23 Example of mobile ANPR enforcement units (e-bikes). For parking enforcement in Newcastle, UK.

Advantages: Monitoring is more effective and allows for better data collection, which ultimately simplifies the tracking of progress. For example, London is able to account for the number of non-compliant vehicles in circulation and track their evolution overtime, thus monitoring the effectiveness of the ULEZ.

Risks: Camera enforcement can give rise to privacy concerns, especially on data collection as it is the case in France or Germany. For example, the French agency in charge of the respect of citizens' online privacy (CNIL) issued a negative opinion on this technology.31 Initially planned for 2022, video enforcement will probably only be implemented with additional safeguards in Paris in 2023.32

Many cities use fixed gantries for enforcing traffic zone regimes (low-emission zones, congestion charges, restricted entry zones etc). This technology is well developed and are very reliable.

Figure 24 Example of fixed ANPR gantry. Congestion tax in Gothenburg.

7.3 Combining identifiers and detection systems – roadside enforcement systems

The task of the different enforcement options is to distinguish between compliant and non-compliant vehicles, and then process the appropriate information to enable penalties to be issued in case of non-compliance. The choice of enforcement option has a significant impact on the overall design of the low emission zone scheme, and the design also affects the preferred enforcement options – i.e., whether the scheme is self-enforcing or needs to be actively enforced. The two most common options for the enforcement of LEZs are Automatic Number Plate Recognition (ANPR), which uses cameras and databases, and manual enforcement, which uses enforcement officers for stationary traffic together with police officers for moving traffic. In this assignment we have discussed some alternative enforcement system design with the Client and in Table 33 you find a map over the specific systems (A-H).

Figure 25 Example of fixed gantry with remote sensing technology. (Road toll in Singapore.)

Table 3 Combining identifiers and enforcement method gives several system variants.

			ENFORCEMENT METHOD		
IDENTIFIER			Manual enforcement	Automized enforcement	
				Mobile enforcement units	Fixed gantries
	Low tech identifier	Windscreen sticker	**System A**	**Not applicable**	**Not applicable**
		Windscreen letter	**System B**	**Not applicable**	**Not applicable**
		Number plates	**System C**	**System E**	**System G**
	High-tech identifier	Remote sensing/OBU	**System D**	**System F**	**System H**

7.3.1 System A: Officer´s visual scanning of windscreen stickers

System A is the combination of windscreen stickers and manual enforcement. Officer (police or parking officer) checks the windscreen stickers on resting vehicles on streets inside the zone. It requires significant staff to enforce. It also needs a separate permit management system where stickers can be ordered etc. This system is possible to combine with checks to enforce parking regulations.

The system is quite flexible to adjustments of zone size and changes in exemption rules. The system is possible to gradually transform to a more automized identifying method or enforcement method but is has no potential to transform into a congestion charging system.

The system does not require any hand-worn technology units to conduct the enforcement. If no windscreen sticker is found on a vehicle, the officer may execute a manual written fee to put on the windscreen or write a report including date, time, place, and vehicles number plate. A back office will then process the detected violation and serve penalty. Since the officer is conducting most of the case-handling on site. (Capture -> process-> register data-> Verify->Decide and Notify) the system is very sensitive for bribes (officers looks the other way). It is also sensitive for false permits and black permit markets.

With this system a rather low degree of violations on low emission zone regulation will be detected.

The windscreen sticker does not have to bear information about car owner, so this system is relatively kind in a privacy perspective. Only information about cars missing stickers will be collected and processed.

7.3.2 System B: Officer´s visual scanning of windscreen letters

System B is the combination of windscreen letters and manual enforcement. Officer (police or parking officer) checks the windscreen letter on resting vehicles on streets inside the zone. The letter is possible and allowed to remove if vehicle is used outside the zone.

If no windscreen letter is found on a vehicle, the officer may execute a manual written fee to put on the windscreen or write a report including date, time, place, and vehicles number plate. A back office will then process the detected violation and serve penalty. Since the officer is conducting most of the case-handling on site. (Capture -> process-> register data-> Verify->Decide and Notify) the system is very sensitive for bribes (officers looks the other way). It is also sensitive for false permits and black permit markets.

The system does not require any hand-worn technology units to conduct the enforcement. It requires significant staff to enforce. It also needs a separate permit management system, where letters can be ordered etc. This system is possible to combine with checks to enforce parking regulations. The system is quite flexible to adjustments of zone size and changes in exemption rules. The system is possible to gradually transform to a more automized identifying method or enforcement method but is has no potential to transform into a congestion charging system.

With this system a rather low degree of violations on low emission zone regulation will be detected.

The windscreen letter often bears information about car owner, if so, this system is relatively sensitive in a privacy perspective since every person passing the vehicle can detect the name of the car owner. Only information about cars missing letters will be collected and processed.

7.3.3 System C: Officer´s scanning of number plates by handhold unit

System C is the rather simple system where officer (police or parking officer) checks the number plates on resting vehicles on streets inside the zone and compares with a list of allowed number plates. This system does not require any equipment or physical LEZ-permits on each vehicle, it is entirely handled in a back-office central system linked to the national vehicle register. It requires significant staff to enforce and probably the staff needs to be equipped with a handhold device for scanning numberplates and comparing with the list of allowed vehicles. This system is possible to combine with checks to enforce parking regulations. The system is quite flexible to adjustments of zone size and changes in exemption rules. The system is possible to gradually transform to a more automized identifying method or enforcement method but is has no potential to transform into a congestion charging system.

The officer is probably conducting most of the case-handling on site, but the system is easy to adapt to avoid on street decisions and notification, if desired. (Capture -> process-> register data-> Verify->Decide and Notify). The system is still rather sensitive for bribes (officers looks the other way).

With this system a rather low degree of violations on low emission zone regulation will be detected.

The number plate does not bear visible information about car owner. Officers are though collecting a huge amount of data including vehicles position at specific times, also vehicles that are allowed to be inside the zone. That may be misused to track vehicles and car owners' behaviour, so this system is relatively sensitive in a privacy perspective. Routines of scrapping information that is not necessarily needs to be in place and be supervised.

7.3.4 System D: Officer´s scanning of on-board transmitter by handhold unit

System D is a combination of a specific remote sensing device in vehicles and officers equipped with a handheld scanning device checking resting vehicles on streets inside the zone. The handheld device give signal if it detects a vehicle that is allowed to be inside the zone. If no signal is given the vehicle is to be investigated as a violator. The officer may execute a manual written fee to put on the windscreen or write a report including date, time, place and vehicles number plate. A back office will then process the detected violation and serve penalty. This system requires specific on-board equipment connected to a LEZ-permit for the vehicle. It requires significant staff to enforce and staff needs to be equipped with a handhold device for scanning remote devices. This system may be possible to combine with checks to enforce parking regulations. The system is quite

flexible to adjustments of zone size and changes in exemption rules. The system has no potential to transform into a congestion charging system.

The officer may conduct the case-handling on site, but the system is better run by letting most of the case-handling be done by a back office (process-> register data-> Verify->Decide and Notify). The system is still rather sensitive for bribes (officers looks the other way).

With this system a rather low degree of violations on low emission zone regulation will be detected.

The on-board unit does not have to bear information about car owner, so this system is relatively kind in a privacy perspective. Only information about an on-board unit will be collected and processed.

7.3.5 System E: Mobile ANPR vehicle (on motorcycle) scanning surrounding vehicles' number plates.

System E is a very interesting combination of a few ANPR equipped vehicles (e-bikes, motorcycles, or cars) that scan number plates on both moving and resting vehicles inside the zone. The ANPR system deliver a list of detected vehicles with information about location, date, time, and number plate. This list can, once a day or once a week, be automatically checked with the national vehicle register to detect violation of the low emission zone regulation.

The officer that drives the ANPR-vehicles are only a driver following a pre-decided route (that can be checked afterwards to avoid corruption). A back office will then process the detected violation and serve penalty. This system requires probably 5-10 well equipped vehicles and drivers. This system may be possible to combine with checks to enforce parking regulations. The system is quite flexible to adjustments of zone size and changes in exemption rules. The systems vehicle equipment has no potential to transform into a congestion charging system, but the back-office system has similarities with what Is needed for a business system for a full scaled congestion charging scheme.

The officer may conduct the case-handling on site, but the system is better run by letting most of the case-handling be done by a back office (process-> register data-> Verify->Decide and Notify). The system is quite unsensitive for misuse, corruption, and bribes (officers looks the other way).

With this system a rather high degree of violations on low emission zone regulation will be detected.

The number plate does not bear visible information about car owner. The mobile vehicles are though collecting a huge amount of data including vehicles position at specific times, also vehicles that are allowed to be inside the zone. That may be misused to track vehicles and car owners' behaviour, so this system is relatively sensitive in a privacy perspective. Routines of scrapping information that is not necessarily needs to be in place and be supervised.

7.3.6 System F: Mobile Remote sensing equipped vehicle (motorcycle) scanning surrounding vehicles' on-board transmitters. Probably also equipped with ANPR.

System F is combination of a few Remote sensing and ANPR equipped vehicles (e-bikes, motorcycles, or cars) that first scan for on-board units in resting and moving vehicles. If no on-board unit is detected the ANPR system register the suspected vehicle´s number plate. The enforcement vehicle delivers a list of detected vehicles (vehicles inside the zone with no detected on-board unit) with information about location, date, time, and number plate. This list can, once a day or once a week, be automatically checked with the national vehicle register to detect violation of the low emission zone regulation.

The officers that drive the enforcement vehicles are following a pre-decided route (that can be checked afterwards to avoid corruption) but do not involve in any case-handling. A back office will then process the detected violation and serve penalty. This system requires probably 5-10 well equipped vehicles and drivers. This system may be possible to combine with checks to enforce parking regulations. The system is quite flexible to adjustments of zone size and changes in exemption rules. The systems vehicle equipment has no potential to transform into a congestion charging system, but the back-office system has similarities with what Is needed for a business system for a full scaled congestion charging scheme.

With this system a rather high degree of violations on low emission zone regulation will be detected.

Neither the on-board units nor the number plate does bear visible information about car owner. The mobile enforcement vehicles are though collecting a huge amount of data including vehicles position at specific times but compared to system E it is possible to avoid collecting information about vehicles with on-board units, only vehicles missing such equipment will be logged and reported. This minimize the risk of misused to track vehicles and car owners' behaviour, so this system is less sensitive than system E in a privacy perspective.

7.3.7 System G: Fixed ANPR system scanning passing vehicles´ number plates

Systems like system G is used in many cities around the world for both LEZ-enforcement but also for road tolls. All zone entries for motor vehicles needs to be monitored by a set of camera gantries. The cameras are collecting information about all vehicles number plates that are entering or leaving the zone. The detection gantries are serving a back-office system with a list of vehicles entering or leaving (location, number plate, time, and date). This list may be distributed to the back-office system once a day or once a week for further case handling.

This system is quite unsensitive for misuse, corruption, and bribes (officers looks the other way). With this system a very high degree of violations on low emission zone regulation will be detected, probably 98-99%.

The number plate does not bear visible information about car owner. The fixed ANPR system are though collecting a data of all motor vehicles entering or leaving the zone – taking pictures of the vehicles, pictures that may reveal the driver´s or passengers' identity. That may be misused to track vehicles and car owners' behaviour, so this system is very sensitive in a privacy perspective. Routines of scrapping information that is not necessarily needs to be in place and be supervised.

The gantries are expensive to build and operate. The system is sensitive to adjustments of zone size but flexible for changes in exemption rules. The system is easy to transform into a congestion charging system, both roadside equipment and back-office system are -more or less the same as for a full scaled congestion charging scheme.

7.3.8 System H: Fixed Remote sensing equipment scanning passing vehicles' on-board transmitters. Probably equipped with ANPR.

Systems like system H is used in a few cities around the world for both LEZ-enforcement but also for road tolls. All zone entries for motor vehicles needs to be monitored by a set of remote sensing and camera gantries. The remote sensing equipment detects vehicles with an on-board unit and let them pass the gantries without any pictures taken. If a vehicle passing the gantry without any remote signal is found, the cameras operate and take pictures of the vehicles number plate. The detection gantries are serving a back-office system with a smaller list of suspicious vehicles entering or leaving (location, number plate, time, and date). This list may be distributed to the back-office system once a day or once a week for further case handling.

This system is quite unsensitive for misuse, corruption, and bribes (officers looks the other way). With this system a very high degree of violations on low emission zone regulation will be detected, probably 98-99%.

Neither the on-board units nor the number plate does bear visible information about car owner. The fixed gantry system is though collecting data of motor vehicles entering or leaving the zone without an on-board unit – taking pictures of these vehicles, pictures that may reveal the driver´s or passengers' identity. That may be misused to track vehicles and car owners' behaviour, so this system is quite sensitive in a privacy perspective. It is however less sensitive than system G. Routines of scrapping information that is not necessarily needs to be in place and be supervised.

The gantries are expensive to build and operate. The system is sensitive to adjustments of zone size but flexible for changes in exemption rules. The system is easy to transform into a congestion charging system, both roadside equipment and back-office system are -more or less the same as for a full scaled congestion charging scheme.

Table 4 A summary of evaluated consequences of the different enforcement systems in this report

	System A	System B	System C	System D	System E	System F	System G	System H
Capital costs								
Labour costs								
Flexible to future geographical adaptions of zone size								
Flexible for simultaneous enforcement of other rules (i.e. parking)								
Privacy matters								
Sensitivity for corruption and misuse								
Efficient data capture								
Possible to evolve to a congestion charging system								

No severe or problematic impact	Impact that needs permanent attention or are related to high costs
Impact that is easy to handle	Severe impacts that may be a reason to choose another option

7.4 Back-office systems

Enforcement should be linked to a well-designed back-office central system, the entire system needs to handle steps like data capture, data process, register data, verify evidence, decision about violation and penalty and notify the violator.

The purpose of the back-office system is to:

- Process the captured data.
- Register and store the captured data
- Verify that the data is correct and link the captured data to the identified vehicle and its owner.
- Decide if the evidence of a LEZ-violation is enough to go further with a sanction.
- Handling exceptions.
- Issue a sanction
- Provide information to car owners
- Handle payments
- Handling appeals

7.5 Future development towards congestion charge system

An initial design of a low emission zone may serve well for a time. While the city and its total vehicle fleet is developing the regulation of the zone needs to be adapted. Perhaps the main problem will turn from emissions to congestion, and if so, the zone might have to be transformed to a congestion charging scheme. Congestion charges is a softer traffic regulating regime than a low-emission zone. Vehicles are charged, not banned.

Congestion charges generates revenues that can be used to finance other traffic or environmentally improving measures. It is possible to combine a low emission zone and a congestion charge with the same system if you choose the right system set in the beginning or evolve to such system designs gradually (especially moving towards fixed ANPR-camera gantries).

It is possible to increase emission effects from a congestion charging system by charge high emission vehicles higher (warning: this might drive investment cost). Congestion charges promotes many adaptive behaviours from car users.

8 Additional activities

The following chapter will give recommendation on additional activities that can be carried out in preparation for the low emission zone. The proposed activities aim to collect data and build competence within the relevant organizations affected by or responsible for implementation.

8.1 Monitoring of vehicles

With the aim to achieve better knowledge and understanding for the traffic flows and furthermore to verify flows in/out of the planned LEZ, activities to monitor vehicle movements is strongly recommended. The intention is to monitor traffic flows, register which types of vehicles and where they come from. Furthermore, if possible, also verify the emission standard of the vehicles as well as their emissions. Additionally, these activities will contribute to verify/refine the data available and provide information on which vehicles are operating/residing within the zone. The following activities are proposed:

- Manual count of vehicles. Employees are placed on strategic points in relation to the proposed LEZ and equipped with photo equipment and means to take notes. Vehicles are then photographed or noted when passing the strategic locations. This method of investigating the traffic flows is relatively staff intensive since it requires employees to be placed on the strategic points to conduct the manual count. However, it does not require any advanced technology and can be carried out without vast preparations. Approximation of cost: the cost will be wages for the staff conducting the manual count.

- Pneumatic tube vehicle counting is another alternative for monitoring vehicles. Conducting pneumatic tube vehicle counting will provide data that will distinguish between heavy and light weigh duty vehicles as well as bicycles though they will not register pedestrians nor emission classifications. One option is to use a mobile radar detector system. It has the same function but is easier to install and move between locations. Another advantage with a radar system is the possibility of also detecting speed. Approximation of cost for ten radar units: 30 000 USD

- Follow-up FEAT (Fuel efficiency automobile test) measurement. A continuation of the Remote sensing pilot executed in Sarajevo in June 2022. This type of measurement will provide information on vehicle type as well as real emissions. Since there are measurements from the summer of 2022, follow-up measurements mean that it will be possible to compare and investigate potential changes and contribute to create a more robust data basis. Approximation of cost: 44 500 USD.

- Travel habit survey targeting businesses. A survey is a way of initiating the necessary dialogue and will provide an indication on how businesses within the zone travels. Furthermore, it can help to verify the movements in/out of the zone and indicate how much of the traffic flow that is connected to companies operating within the zone. Once the connections are established through the survey it will facilitate further communication with the companies. They can be asked if they wish to participate in additional communication efforts and be part of the communication to their employees. Approximation of cost: 30 000 USD

An addition to the business travel habit survey would be to conduct a similar survey targeting the travel habits of regular people. This would further provide valuable information for the LEZ and input on how to design measures.

8.2 Further studies

In preparation for the LEZ, two additional studies are suggested: an extended implementation plan and a deeper study on mobile control and enforcement. Both subjects are addressed in this report but would benefit from a more through and complete review and investigation.

- Extended implementation plan according to IVL. In this report, a suggestion for implementation plan is put forward and the with additional resources the implementation plan can be further enhanced by deeper analysis of consequences for affected parties and citizens, clear time frames, division of responsibilities. Moreover, an extended implementation plan could go further investigating the need for equipment and specify costs. The aim with an extended and enhanced implementation plan is to provide developed stages of the LEZ and connect the improvement of the LEZ with other mobility improvements (investments in biking, walking and public transport) which are part of Sarajevo's Sustainable Mobility Plan. Approximation of cost: 40 000 USD

- Deeper study investigating practical and implementational aspects of the mobile control and enforcement. In the initial stage, manual control and enforcement is recommended. An investigation of how to implement a mobile control and enforcement method in later phases of the LEZ when the euro classification restrictions are sharpened would be beneficial. A study dedicated to development of control and enforcement would pave the way for implementation, help identify areas in need of improvement and provide a plan for how to transition from a manual system to an automized one, adapted to Sarajevo's particular conditions and requirements. Approximation of cost: 25 000 USD

8.3 Capacity building and communication

Capacity building is important for implementation and operation of a LEZ. As is mentioned in this report, the personnel dedicated to the LEZ, decision and policy makers and others must be educated on how a LEZ work, challenges, benefits and so forth. Production and development of educational material is closely connected with communication and these two activities can combined create positive synergies.

- Investigate how much resources in terms of staff the LEZ will engage. The Ministry of Transport will need to set aside personnel dedicated to the work with the LEZ. A proposal for the capacity building is to appoint one person responsible for the questions concerning the LEZ, education, knowledge transfer, support, and training.

- Create an education package targeting municipalities, police etc. Since many parts of society will be affected by the low emission zone, development of educational material adapted to different target groups is required.

- General communication and education on air quality and traffic. Adapt the communication after the target groups and the media channels they prefer.

- Targeted communication campaigns focusing on employers, professional drivers (taxi services, craftsmen, haulage contractors etc.) and property owners to cover residents within the zone. Once again, important to have a two-way dialogue process and a strategy for how to manage the responses.

Important note: the targeted information may be adapted since there is not yet a political decision on LEZ. Public outreach and education are vital to achieve both political and public acceptance. Approximation of cost for communication: 180 000 USD.

9 Recommended complementary measures

Complementary measures are useful for two reasons. Firstly, they are important as they strengthen the introduction of the LEZ and makes the implementation both easier and more acceptable. Also, to improve air quality there is seldom a quick fix or one single measure that will solve the problem. Instead, a mix of measures are required and every little helps. The following section will briefly address different options and complementary measures that could work together with a LEZ.

- Improve conditions for walking and biking. By improving the conditions for walking and biking, conditions, and possibilities for citizens to choose those alternatives for transportation are created. Improved conditions include, but is not limited to, investments in biking and walking infrastructure providing enough space for those alternatives as well as making it a safe option. Improved biking and walking infrastructure can entail dedicated cycle paths, sidewalks, pedestrian crossings, supervised pedestrian crossings, cycle crossings, supervised cycle crossings, bike racks with and without weather protection. Planning of infrastructure that enables cyclists and pedestrians to get around in the city. Additional measures can also include reduced speed for car traffic and reallocate driving lanes, parking areas etc. to areas dedicated for biking and walking. In Sarajevo, improved biking conditions as new biking lanes have been planned to be introduced in year xx. This could be used for planning and communication of the implementation of the LEZ.

- Improve public transport. This is about creating an alternative instead of using the car for transportation needs. As the LEZ is developed and encompasses more vehicles it is important to create alternatives, especially for those who will not or cannot replace their vehicles to match the zone. If the restrictions of the zone are tightened faster than the natural turnover for vehicles it is vital to provide other means of transportation for affected citizens. Important work in this area is already taking place and the recent Sarajevo procurement of buses will contribute to improved public transport. Improved public transport is especially important if implementation of a congestion charge system is considered. In Sarajevo, new buses and buslines are already planned to be introduced in the upcoming years. To further support and improve public transport, space currently dedicated for cars should be reallocated to public transport. This could be used for planning and communication of the implementation of the LEZ.

  Parking measures is one alternative in the traffic regulating toolbox. If a parking strategi is not yet in place, the first step is to develop one. Chapter 5 in *U6505 Traffic regulations in Sarajevo* (IVL, 2021) presents an introduction to parking measures and important aspects to consider when developing a parking policy. Examples of important parking measures that could be relevant for Sarajevo are better enforcement of parking regulations, higher parking fees for central work-place parking and a lowered number of allowed parking places in connection to new apartments and work-places.

- As mentioned in the introduction, measures can favorably be introduced as package. A smaller package containing parking measures and promotion of walking and biking can be suitable to introduce during year 2 of the implementation plan to support the implementation of the LEZ.

- Stricter supervision of exhaust gas testing during inspection. Vehicles that fail to comply with current regulatory legislation and frameworks should be given a driving ban. To avoid these vehicles being allowed to pass the inspection, control of the inspection should be increased. When mismanaged, the permission to carry out inspections should be withdrawn. This would dissuade inspectors to approve underperforming vehicles.

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Appendix 1 – Sources of data for calculations

Sources of data:

- The report: *INFORMACIJA O REGISTROVANIM/REGISTRIRANIM DRUMSKIM/CESTOVNIM VOZILIMA U BIH U PERIODU JANUAR/SIJEČANJ – DECEMBAR/PROSINAC 2020*. (BOSANSKOHERCEGOVAČKI AUTO – MOTO KLUB)
- Vehicle fleet register covering the districts Stari Grad and Centar**,** supplied by Sarajevo city.
- On-road remote sensing measurements, registration of license plates and matching with Bosnia vehicle register.
- The document: *ANALIZA DOSTAVLJENIH PODATAKA O REGISTROVANIM VOZILIMA NA PODRUČJU PLANIRANE ZONE NISKE EMISIJE U SARAJEVU*, supplied by Sarajevo City
- The report: *DATA COLLECTION SURVEY ON PUBLIC TRANSPORTATION IN SARAJEVO CANTON, BOSNIA AND HERZEGOVINA.* (JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) NIPPON KOEI CO., LTD)
- GIS-file with associated database, supplied by Sarajevo City

Appendix 2- Composition of vehicle fleet

Number of vehicles, types of vehicles and emission standard in different areas of Sarajevo (LEZ, central city and whole city).

City= Stari Grad + Centar

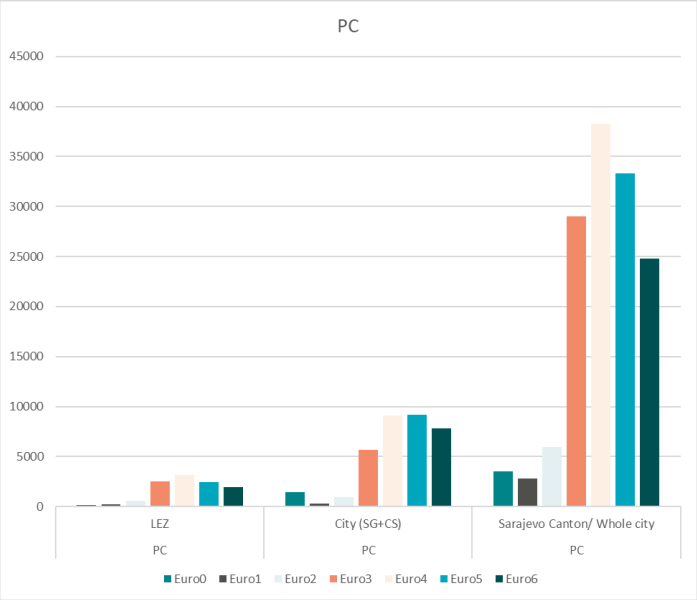
Vehicle type	Area	Euro0	Euro1	Euro2	Euro3	Euro4	Euro5	Euro6
PC	LEZ	202	240	579	2556	3162	2430	1954
PC	City (SG+CS)	1474	312	979	5701	9125	9207	7859
PC	Sarajevo Canton/ Whole city	3525	2840	5966	28979	38277	33303	24813
LCV	LEZ	0	2	39	45	142	139	110
LCV	City (SG+CS)	15	9	69	157	335	459	437
LCV	Sarajevo Canton/ Whole city	55	31	732	558	1449	1516	1560
HGV	LEZ	18	10	5	26	29	50	37
HGV	City (SG+CS)	51	14	30	144	95	146	75
HGV	Sarajevo Canton/ Whole city	883	743	743	1983	1859	2726	1487

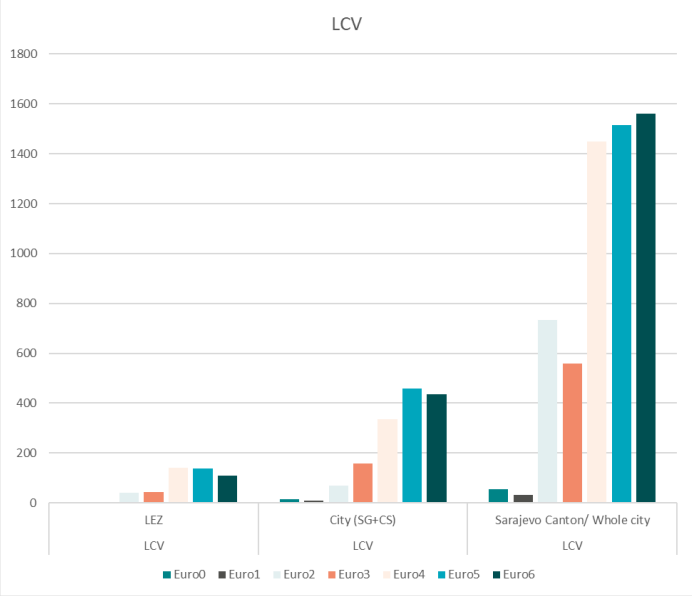
Ten-year development of vehicle fleet for passenger cars within the LEZ.

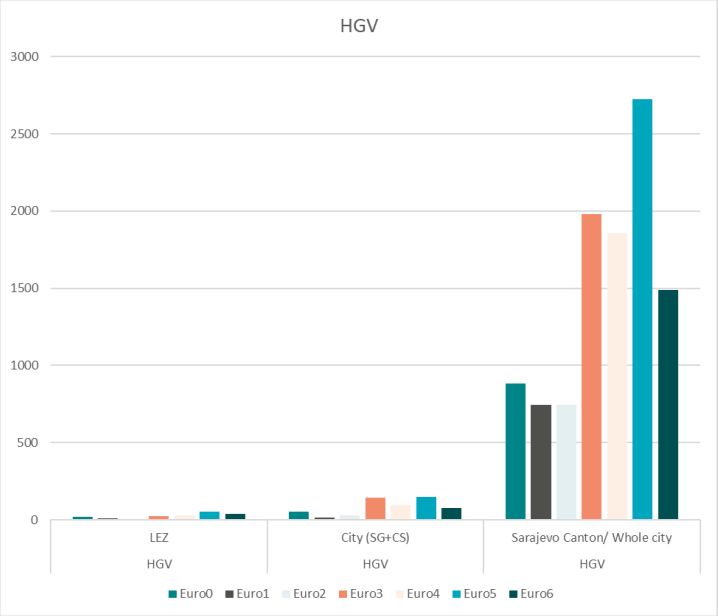
LEZ	*PC vehicles*											
Vehicle category	**Technology**	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
PC	Euro 6	1954	2969	4071	5108	6074	7044	7942	8772	9533	10224	10844
PC	Euro 5	2430	2376	2305	2211	2089	1937	1757	1555	1342	1130	931
PC	Euro 4	3162	2857	2519	2166	1819	1496	1211	966	764	600	471
PC	Euro 3	2556	2061	1640	1294	1016	797	626	494	393	316	257

PC	Euro 2	579	453	357	282	225	182	150	126	108	95	86
PC	Euro 1	240	194	159	134	115	101	91	83	77	73	69
PC	Euro 0	202	192	183	175	167	161	155	149	143	138	133

The following three graphs illustrate the calculated composition of the vehicle fleet in the whole of Sarajevo, a selected part of the city as well as in the proposed low emission zone. The numbers show that passengers cars are significantly more abundant compared to light commercial vehicles and heavy goods vehicles.





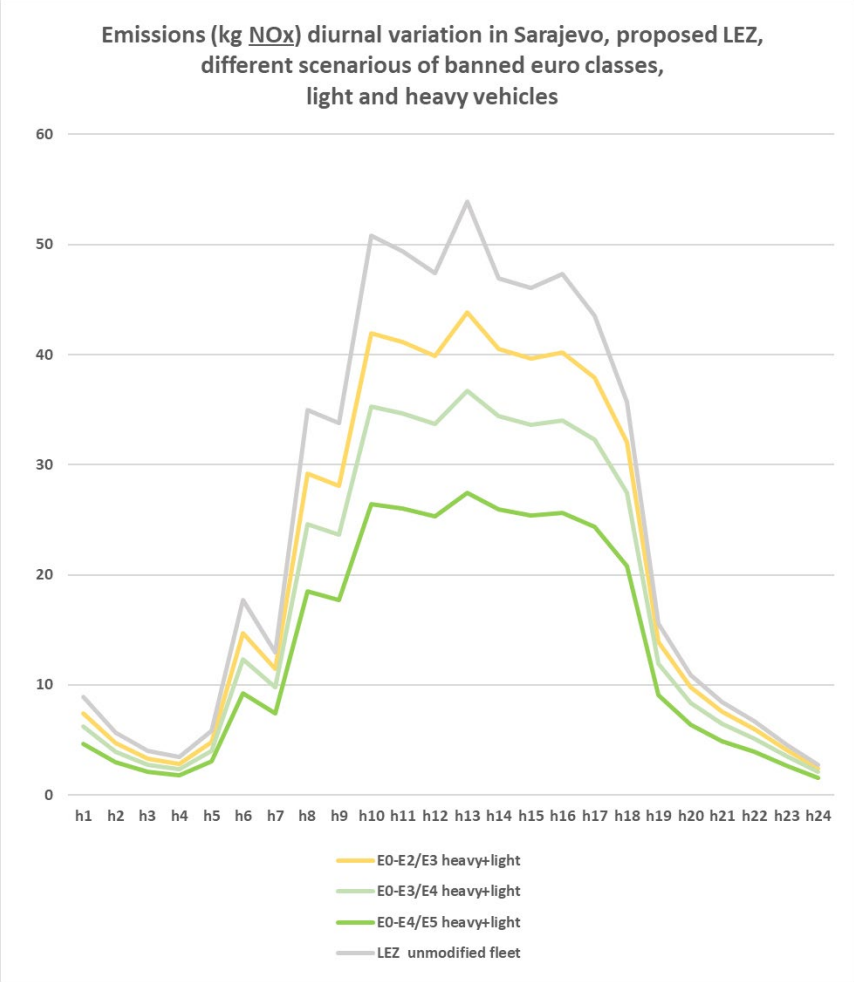

HGV
3000
2500
2000
1500
1000
500
0
LEZ
HGV
City (SG+CS)
HGV
Sarajevo Canton/ Whole city
HGV
Euro0
Euro1
Euro2
Euro3
Euro4
Euro5
Euro6

Appendix 3- NOx calculations and results

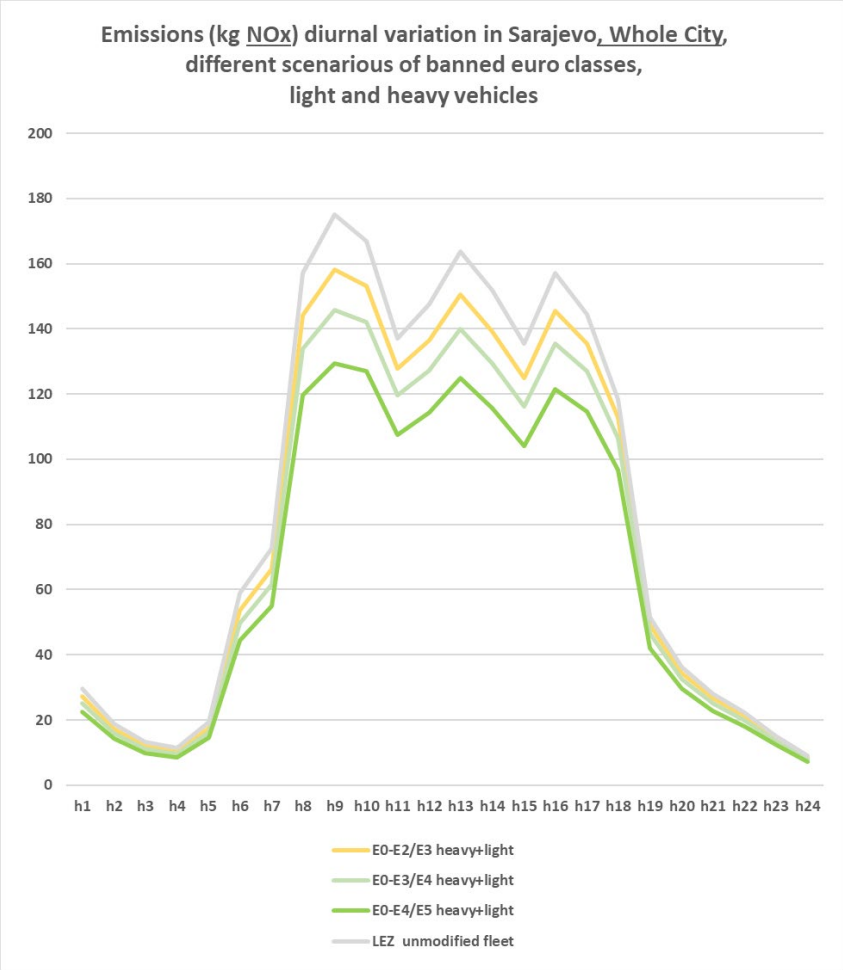
The calculations are based on the following three scenarios:

- **Scenario 1:** Passenger cars Euro 0, 1, and 2 + Heavy goods vehicles and light commercial vehicles Euro 0, 1, 2, and 3.
- **Scenario 2:** Passenger cars Euro 0, 1, 2, and 3 + Heavy goods vehicles and light commercial vehicles Euro 0, 1, 2, 3, and 4.
- **Scenario 3:** Passenger cars Euro 0, 1, 2, 3, and 4 + Heavy goods vehicles and light commercial vehicles Euro 0, 1, 2, 3, 4, and 5.

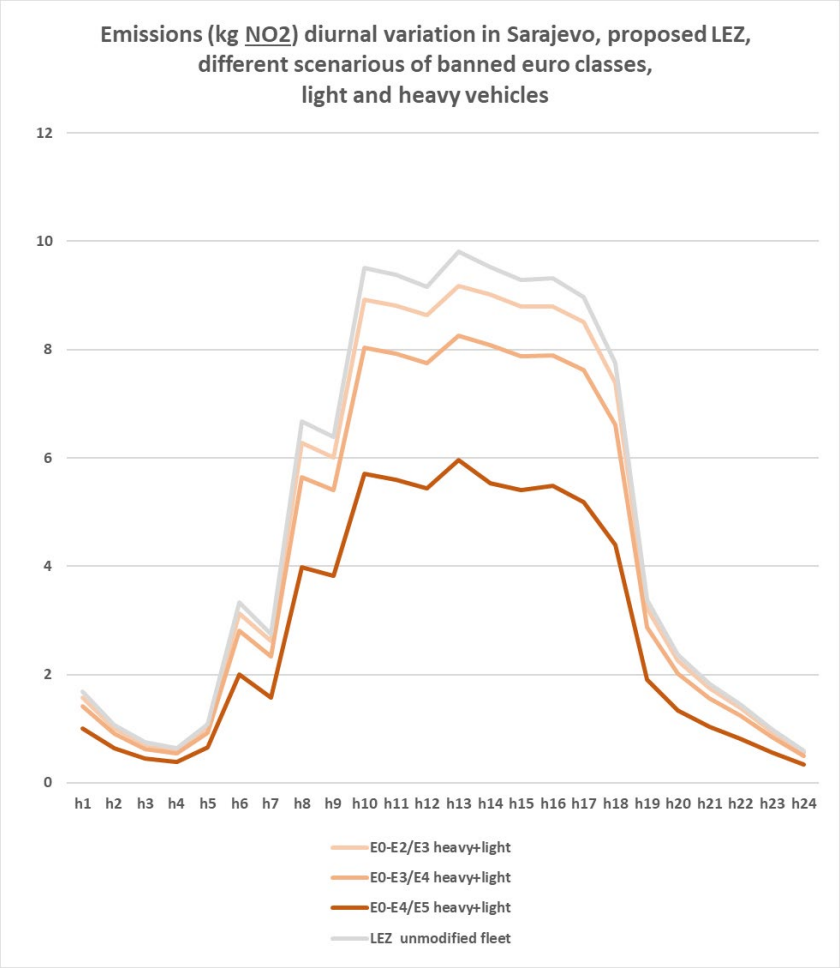
NOx emissions and diurnal variations in the proposed LEZ in Sarajevo. The different lines represent variations in scenarios.



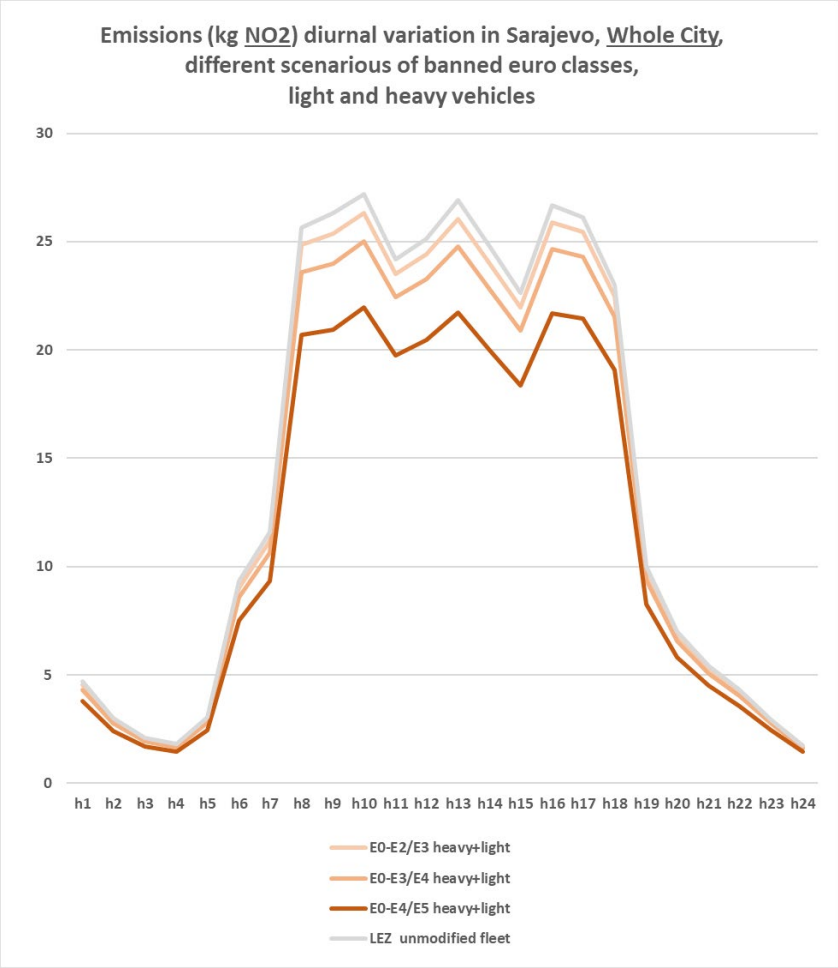
NOx emissions, in kg, and diurnal variations in Sarajevo, whole city. The different lines represent variations in scenarios.



NO_2 emissions and diurnal variations in the proposed LEZ in Sarajevo. The different lines represent variations in scenarios.



NO_2 emissions and diurnal variations in Sarajevo, whole city. The different lines represent variations in scenarios.



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