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IMPACT OF INTRODUCTION OF LOW EMISSION ZONES IN THE CITY OF ZAGREB

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RESEARCH ARTICLE

ABSTRACT: Despite significant improvements in vehicle technology in recent years, vehicle emissions remain a major influencing factor on air quality. Although air quality in the City of Zagreb is still relatively acceptable, official standards, i.e. limiting values are under threat. More than ever, policymakers are actively exploring options for new vehicle emission control and local fleet management policies, as well as the new monitoring technologies to support these activities. The goal of the research was to assess the influence of the introduction of Low Emission Zone on the total emission from the road traffic in the City of Zagreb. To make a model of emissions from road traffic, emissions on selected roads in the City of Zagreb using measured traffic activity data and adequate vehicle fleet characteristics description are calculated. Traffic activity data were obtained from traffic study of the City of Zagreb, while vehicle fleet characteristics are extracted from the database maintained by Center for Vehicles of Croatia and the Ministry of the Interior of the Republic of Croatia. The database contains all the data collected during the homologation process of the vehicles registered in Croatia as well as the data collected during the vehicle periodical technical inspection.

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It is important to note that the database contains exact data on the date, time and site of periodical technical inspection. Fleet data for vehicles registered in Zagreb was compared with the fleet data for the entire Republic of Croatia. The comparison shows the sensitivity regarding the fleet characteristics and that it is possible to improve air quality with simple regulation, i.e. introduction of the Low Emission Zone.

KEY WORDS: vehicle emissions, air quality, low emission zone, road traffic, vehicle fleet

UTICAJ UVOĐENJA ZONA NISKIH EMISIJA U GRADU ZAGREBU

REZIME: Uprkos značajnim poboljšanjima tehnologije vozila u poslednjih nekoliko godina, emisija vozila ostaje glavni faktor koji utiče na kvalitet vazduha. Iako je kvalitet vazduha u gradu Zagrebu još uvek relativno prihvatljiv, službeni standardi, tj. granične vrednosti su kritične. Više nego ikada, zakonodavci aktivno istražuju opcije za novu kontrolu emisije vozila i lokalnu regulativu kontrole voznog parka, kao i nove tehnologije za praćenje koje podržavaju ove aktivnosti.

Cilj istraživanja je bio da se oceni uticaj uvođenja zone niske emisije na ukupnu emisiju saobraćaja u gradu Zagrebu. Da bi se formirao model emisije od drumskog saobraćaja, merena je emisija od saobraćaja na odabranim saobraćajnicama i proračun je izvršen na osnovu karakteristika voznog parka. Podaci o prometnoj aktivnosti dobijeni su iz predmetne studije grada Zagreba, dok su karakteristike voznog parka izdvojene iz baze podataka koju vodi Centar za vozila Hrvatske i Ministarstvo unutrašnjih poslova Republike Hrvatske. Baza podataka sadrži sve podatke sakupljene tokom procesa homologacije vozila registvonavih u Hrvatskoj, kao i podatke prikupljene tokom periodičnog tehničkog pregleda vozila. Važno je napomenuti da baza podataka sadrži tačne podatke o datumu, vremenu i mestu periodičnog tehničkog pregleda. Podaci o voznom parku vozila registrovanih u Zagrebu su upoređeni sa podacima voznog parka cele Hrvatske. Poređenje pokazuje osetljivost u pogledu karakteristika voznog parka i da je moguće poboljšati kvalitet vazduha jednostavnom regulacijom, tj. uvođenjem zone niske emisije.

KLJUČNE REČI: emisija vozila, kvalitet vazduha, zona niske emisije, drumski saobraćaj, vozni park

IMPACT OF INTRODUCTION OF LOW EMISSION ZONES IN THE CITY OF ZAGREB

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1. INTRODUCTION

According to the European Environment Agency (EEA), around 30% of total carbon dioxide emissions comes from traffic-related activities [1]. Air pollution represents a significant problem for environment and human health and traffic-related activities are major contributing factor. Harmful emissions (tailpipe gases and particulate matter) which occur after fuel combustion in vehicles internal combustion engines cause respiratory, cardiovascular and neurological diseases [2]. Beside the air pollution, studies have shown that traffic-related pollution is the reason for the increase in global mean surface temperatures. For example, simulations performed in [3] suggest that German transport emissions induce an increase in the global mean surface temperature of the order of 10 mK during the 21st century. With the goal of reducing air pollution, the European Parliament and Council have adopted Directive 2008/50/EC on ambient air quality and cleaner air for Europe. The Directive 2008/50/EC state that the public has a right to demand from local authorities to provide a quality environment for life, meaning that authorities should ensure that the air pollution is within permissible limits, which are set within the Directive [4].

Main products of combustion within internal combustion engine can be split into two distinctive groups, those which are harmful to human health and those who are not. Carbon dioxide (CO2) and water vapour (H2O) are not harmful to human health, but are closely related to the Greenhouse Gasses and global warming, while carbon oxide (CO), nitrogen oxides (NOx) and particulate matter (PM) are. Today, major attention is given to the reduction of GHG and minimisation of those which are harmful, especially nitrogen oxides and particular matter. Emission of nitrogen oxides (NOx) occurs in an engine cylinder by oxidation of atmospheric nitrogen typically at temperatures higher than 1,800 K [5]. They can further be divided into nitrogen monoxide (NO) and nitrogen dioxide (NO2). Nitrogen monoxide converts to nitrogen dioxide in the atmosphere which can later form acid rain. Furthermore, nitrogen oxide can contribute to forming low-level ozone which is also harmful to human health. Alongside with harmful influence on the environment, nitrogen oxides have a negative influence on human health, causing eye and lung irritation, fatigue and nausea. With long-term exposure, there is an increased chance of asthma occurrence and permanent lung and nervous system damage, and may even cause genetic disorders. Nitrogen oxides, like the carbon oxide (CO), can also prevent the normal flow of oxygen throughout the human blood system. Particulate matter (PM) mostly consists of soot. According to its average diameter, it is divided into PM10 and PM2.5. PM10 represents particles whose medium diameter is smaller than 10 micrometres, and PM2.5 represent particles with a medium diameter smaller than 2.5 micrometres. Such fine particles are severely hazardous to human health because they can infiltrate human respiratory and cardiovascular system [6]. It is proven that particulate matter increases mortality by causing chronic obstructive pulmonary disease (COPD), ischemic heart disease and lung cancer [7].

1.1 Low Emission Zone (LEZ)

In its wider meaning, Low Emission Zones (LEZ) represent areas in which traffic is regulated according to vehicle category or emission standard. Restriction implies fully banning certain vehicles or charging their entrance into the zone. LEZ can include from a few main roads up to wide city areas. They are implemented in the areas where air pollution represents a significant threat to human health. Since the grates threat is from particulate matter and nitrogen oxides which are common for diesel-powered vehicles, LEZ often has stricter regulations for those types of vehicles. Studies have shown that heavy duty vehicles (HDV) which commonly run on diesel fuel have up to 30 times greater emission of PM2.5 and up to 26 times greater emission of nitrogen oxides (NOX) than light-duty vehicles (LDV) [8]. Therefore, those kinds of vehicles are often not allowed to enter LEZ, or their entrance is regulated in some way.

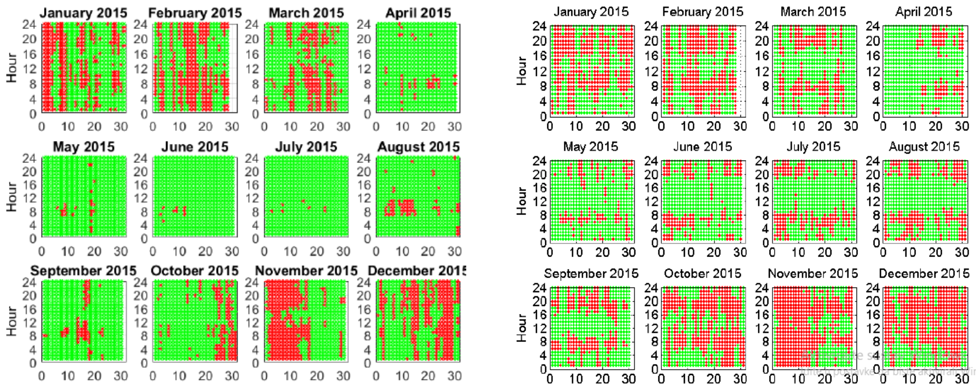
World Health Organization (WHO) states that air pollution is responsible for the premature death of nearly 310,000 people in Europe which is more than deaths involved in traffic accidents. Besides air pollution having an adverse impact on human health, it consequently causes great financial losses. Cost of treatment for people with air pollution-related diseases is estimated somewhere between 427 and 790 billion EUR annually [9].

As mentioned earlier, a great number of LEZs ban or regulate the entrance of heavy-duty vehicles with great emissions, while some even ban or regulate the entrance of coaches, passenger vehicles and motorcycles. Most of LEZs are active throughout the entire year, while other are active only occasionally, e.g. in the rush hour, in winter or in summer. Currently, there are 258 Low Emission Zone in 23 European countries with over 230 major access regulations and 14 charging schemes [9].

1.2 Air Quality in the City of Zagreb

In Zagreb, capital of the Republic of Croatia, there are six stations for continuous measurement and monitoring of air quality. Locations of the station can be seen in Figure 2. The measuring station Zagreb 1 is very interesting because it is located near to the crossing of Vukovarska and Miramarska Street which represents crossing with one of the densest traffic in the city because it is located near the centre of the city.

By using the developed application, the data from all measurements stations in Zagreb have been collected and analysed from January 1st 2015 to December 31st 2015. The greatest attention was given to the following pollutants: nitrogen oxides (NOx) and particulate matter (PM). A limit value for PM2.5 according to Air Quality Standards is 25 μg/m3, while the PM10 is defined with the limit value of 50 μg/m3, and the permitted exceedances each year is 35 times.



Green dots represent values below the limit, red dots represent values over the limit.

Figure 1. Hourly exceedances (shown as red dots) of PM in measuring station Zagreb 1 (left) and exceedances of NOX in measuring station Zagreb 3 (right) during 2015 [10]

As graphically represented in Figure 1, analysis has shown that the limit for PM10 is exceeded more than 35 times, but it is also evident that pollutant concentrations of PM are lower in those months when Zagreb's inhabitants are using their vacations [10].

2. METHOD

It is well known that for calculation of vehicle emissions it is necessary to know vehicle emission factors and vehicle activity. For the purpose of emission calculation in this study, the emission factor implemented in the COPERT: Street Level were used, and they can be seen in the Figures 6, 7, 8 and 9. Vehicle activity was recorded on multiple sites throughout the City of Zagreb as shown in Figure 2.

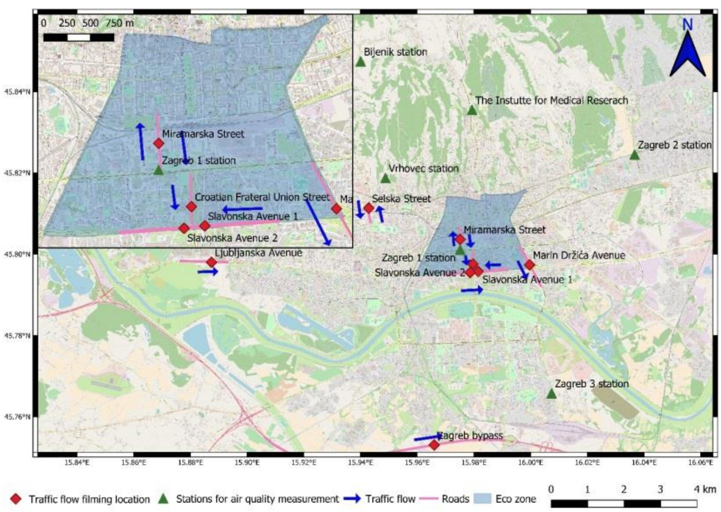


Figure 2. Main steps in ELV recycling process, according to EC Directive 2005/64/EC

2.1 Traffic Flow

Traffic flow is a simultaneous movement of a number of vehicles on a certain road segment in some ordered way. To describe traffic flow, it is necessary to define the basic traffic flow parameters. For the determination of these parameters, traffic was recorded using a GoPro Hero camera which has the ability to capture 50 frames per second at 2704x1520p (2.7k) resolution. Purpose of this camera was to accurately determine the exact moment when a vehicle passing across the detection line, as it is shown in Figure 3. Traffic flow recording locations are marked with red squares in Figure 2.

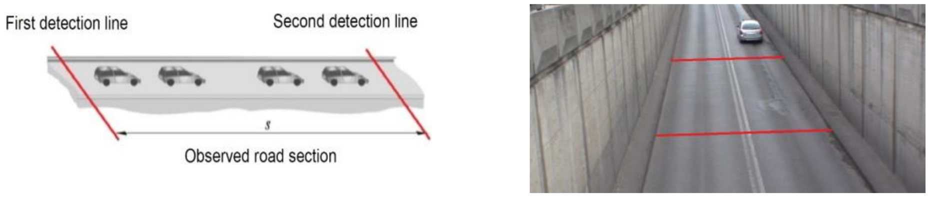


Figure 1. Example of observed road segment with detection lines (left - scheme, right - real situation) [11]

Basic traffic flow parameters are:

- Traffic flow –number of vehicles passing through the observed cross-section of the road in the unit of time, q_{veh} [veh/h];
- Traffic flow density – number of vehicles in the observed traffic lane per length unit, g [veh/km];
- Traffic flow speed – median value of speed from all vehicles involved in the traffic flow, v_{tf} [km/h];
- Vehicle passing interval – time between the passing of two consecutive vehicles through the observed cross-section on the road, t_h [s].

$$\Delta t_{h,x} = \frac{f_{L2} - f_{L1}}{50} \tag{1}$$

Where:

$\Delta t_{h,x}$ - vehicle x passing time, s

f_{L1} - frame number of front axle passing over the first detection line

f_{L2} - frame number of front axle passing over the second detection line.

After calculation of vehicle passing time, it was possible to determine vehicle speed according to equation 2.

$$v_x = \frac{\Delta s}{\Delta t_{h,x}} \tag{2}$$

Where:

v_x - vehicle x speed, m/s

$\Delta t_{h,x}$ - vehicle x passing time, s

Δs - distance between detection lines (17 m).

Traffic flows were recorded in February and March 2017 at eight locations on working days. Most of the city roads have similar peak hour interval as shown in Figure 4, so data was analysed for the period from 16:15 to 17:15. Figure 4 shows hourly traffic flow during the whole week at the intersection of Ljubljanska Avenue and Puljska Street and afternoon peak hour can be clearly seen.

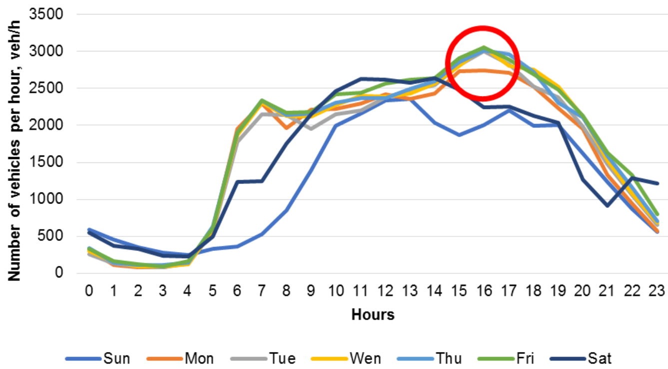


Figure 2. Example of weekly traffic flow

As it is earlier stated, for emission calculation it is important to define the traffic flow speed. After calculating the speed for all vehicles, the median value was used. The median value represents value separating higher and lower half of all calculated speeds. The median value is used instead of the arithmetic mean value because it is less sensitive to extreme value oscillations. Figure 5 shows an example of the median value of speed at Slavonska Avenue 1.

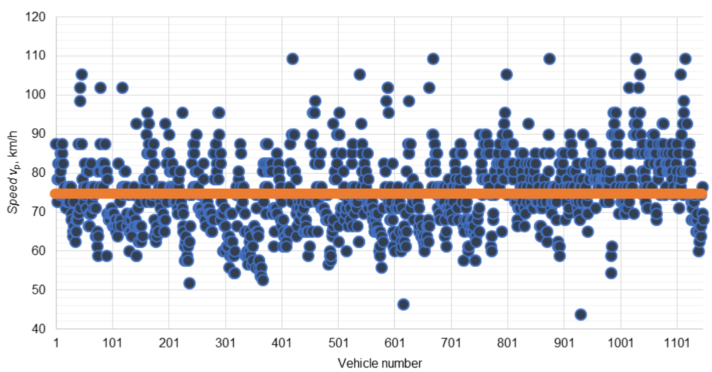


Figure 3. Example of the median value of speed at Slavonska Avenue 1

2.2 Vehicle fleet

For the purpose of calculating emission of harmful substances, it is necessary to determine vehicle fleet on the observed roads. One of the ways would be to record every vehicle registration plate and verify vehicle characteristics through the database of the Ministry of Interior, which is very slow and time-consuming process. For that type of vehicle fleet recognition, it would be better to use the specialised camera for number plate's recognition.

Other way, used for the purpose of this research, is to use predefined vehicle fleet composed of all the vehicles that had an active periodic technical inspection (PTI) in the City of Zagreb on the date of January 1st 2018. This way vehicle fleet definition was much easier and quicker, while still precise enough for the calculation of roadside emission. By using this method, the majority of the vehicles registered in the City of Zagreb that are not used in the city are left out and vice versa. Fleet is structured from all the vehicles from M1 and N1 category as they represent more than 90% of all vehicles entering the city. In addition, all the vehicles of M1 and N1 category which use compressed natural gas (CNG) or liquefied petroleum gas (LPG) are not included in the fleet mostly because they represent a small fraction, but also because it was not possible to precisely define their emission factor.

Table 1. Number of vehicles that had an active periodic technical inspection (PTI) in the City of Zagreb on the date of January 1st 2018 according to the emission standard

Category	Fuel type	EURO 0&1	EURO 2	EURO 3	EURO 4	EURO 5	EURO 6
M1	PETROL	9,390	25,856	28,840	44,518	20,730	13,872
	CNG (total)	13					
	DIESEL	6,526	12,293	34010	44,680	43,445	28,316
	LPG (total)	11,908					
M1 (total)	/	27,897	38,149	62850	89,198	64,175	42,188
N1	PETROL	41	57	128	171	239	120
	CNG (total)	32					
	DIESEL	778	1,716	3,895	6,716	8,893	2,939
	LPG (total)	224					
N1 (total)	/	1,115	1,773	4,023	6,887	9,132	3,059

As it is shown in Table 1, there are 324,457 vehicles of M1 category in everyday traffic across the City of Zagreb. It can be clearly seen that diesel vehicles are most represented type with 52.17%, gasoline vehicles are following with 44.14%, vehicles powered by LPG are present with 3.67% while CNG vehicle holds a neglect able share of the M1 fleet.

Following the M1 category, there is N1 category with 25,989 vehicles operating across the City of Zagreb. Again, diesel vehicles are the most represented type with 95.95% followed by gasoline vehicles with only 2.91%. Vehicles of N1 category powered by liquefied petroleum gas and compressed natural gas hold 1.14% combined. Overall, it can be assumed that there are around 350,446 vehicles involved in everyday traffic across the City of Zagreb. Average vehicle age of these vehicles is over 10 years. Disregarding vehicle powered by LPG and CNG and looking by emission standard it can be seen that Euro 0, Euro 1 and Euro 2 represent high 16.75% and if we add up Euro 3 vehicles, number crosses over one-third of entire vehicle fleet with 36.52%, which is extremely high.

2.3 Emission Calculation

After traffic flow calculation and vehicle fleet description, the last step in emission calculation is the definition of emission factors. Emission factors need to be from reliable source, e.g. internal combustion engine manufacturer, environmental agency etc. Emission factors used for this research are compiled from emission factors from COPERT: Street Level, a commercial software package used for calculation of emission on street level [12]. Emission factor represents a functional link between vehicle fleet characteristics, vehicle activity and emission. Emission factors of particulate matter and nitrogen oxides can be seen in Figure 6, 7, 8 and 9.

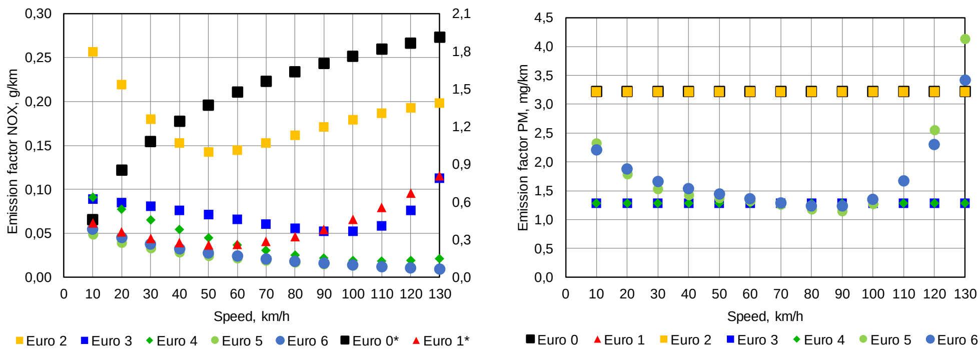


Figure 6. Emission factors for NOX (left) and PM (right) for M1 vehicle category (petrol) - * secondary axis

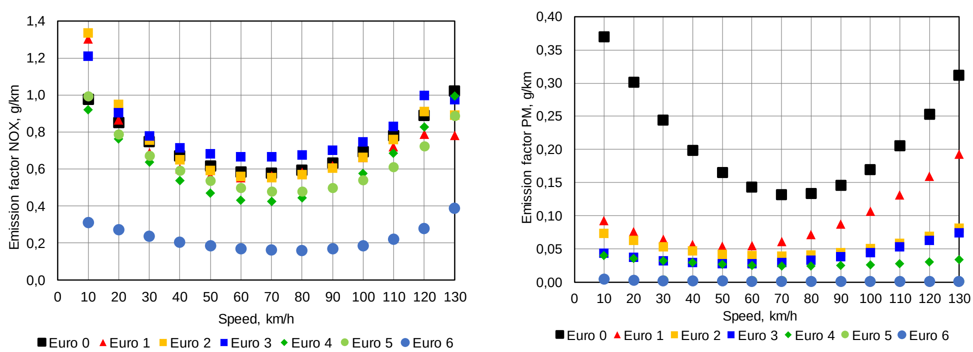


Figure 7. Emission factors for NOX (left) and PM (right) for M1 vehicle category (diesel)

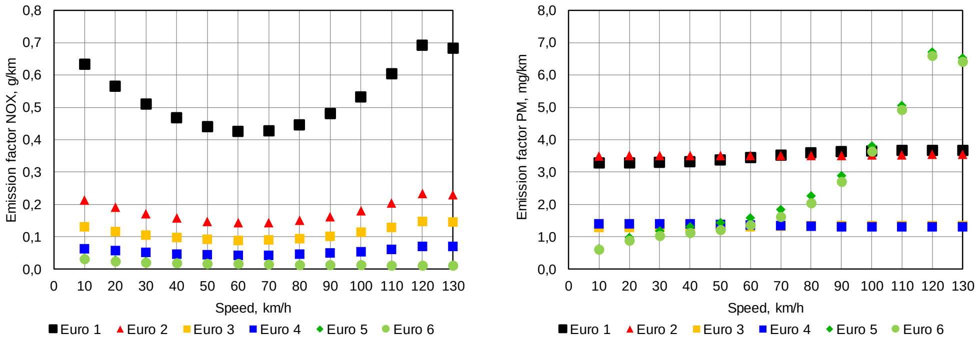


Figure 4. Emission factors for NO_X (left) and PM (right) for N1 vehicle category (petrol)

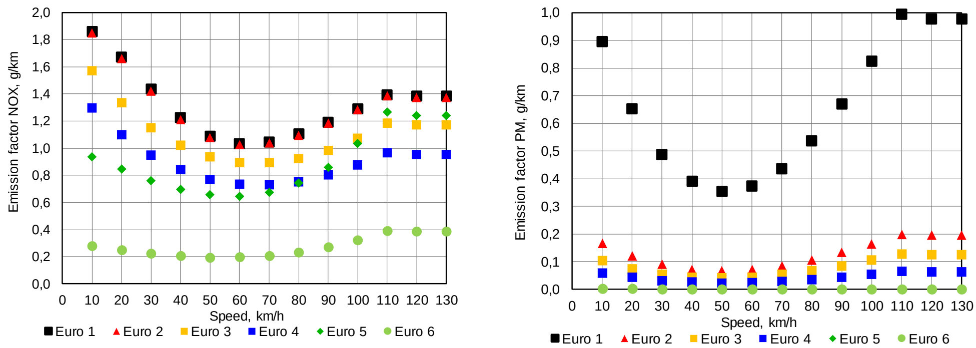


Figure 5. Emission factors for NO_X (left) and PM (right) for N1 vehicle category (diesel)

Vehicle activity is represented through vehicle fleet characteristics, traffic flow, length of a road segment and vehicle speed. The basic equation for calculation of roadside emission is:

$$Emission = Vehicle\ activity(speed, type, number, ...)\ x\ Emission\ factor \quad (3)$$

By implementing this method, it is possible to calculate roadside emission from traffic in the specific time period on the observed road segment. In this research, the emission is calculated for eight observed road segments. For emission calculation, according to this method, it was necessary to define overall vehicle number and divide them according to fleet characteristics, add travelled distance and median speeds to all vehicles and allocate them their unique emission factor as shown in Equation 4.

$$E_p[g] = \sum_{FUEL} \sum_{EURO} \sum_{j=1}^{n} EF_p(EURO, v) \left[\frac{g}{km}\right] \text{x}\ s\ [km] \quad (4)$$

Where:

E_p -Overall emission of a specific pollutant

$FUEL$ -Fuel type (petrol or diesel)

EURO -Emission standard
N -Vehicle number
EF_p -Emission factor of specific pollutant as a function of emission standard and vehicle speed
p -Specific pollutant (NO_X or PM)
v -Vehicle speed
s -Travelled distance.

2.4 Scenarios

Before the development of different scenarios, the base case (Scenario 0) was calculated and analysed for before mentioned composition of the vehicle fleet. After the base case was established, several other scenarios were developed. Scenario 1 represents LEZ with the ban of all Euro 2 or lower emission standard vehicles with petrol engines and all Euro 3 or lower emission standard vehicles with diesel engines and the same goes for Scenario 2. The difference is that Scenario 1 represents a condition in which total traffic flow vehicle number is lowered for the share of banned vehicles which in return represents starting state of LEZ implementation. In other hand, Scenario 2 represents a state where the number of all vehicles banned by LEZ implementation is returned to the normal state by other vehicles which in return shows long-term effect.

Table 2. Vehicles permitted to enter LEZ by emission standard and category

Scenario	Fuel type	Euro 0	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6	Vehicle category	
									M1	N1
Scenario 1 & 2	Petrol	✗	✗	✗	✓	✓	✓	✓	✓	✓
	Diesel	✗	✗	✗	✗	✓	✓	✓	✓	✓
Scenario 3	Petrol	✓	✓	✓	✓	✓	✓	✓	✓	✗
	Diesel	✓	✓	✓	✓	✓	✓	✓	✓	✗

3. RESULTS

The busiest street during the peak hour with 2296 vehicles is Hrvatske Bratske Zajednice Street and is closely followed by Selska Street and Slavonska and Ljubljanska Avenue. Miramarska Street has least vehicle passages during the peak hour which is slightly under 1600 vehicles. On the other hand, Zagreb bypass has the fastest moving traffic with a median speed of 93 km/h, while the slowest traffic can be observed on Slavonska Avenue if a traffic jam occurs. If there is no traffic congestion, Miramarska Street traffic becomes the slowest moving with the median speed of 37 km/h and Slavonska Avenue traffic becomes one of the fastest with median speed over 70 km/h. Largest observed road section is Zagreb bypass with well over 4 kilometres, while the length of Ljubljanska Avenue observed road section is only 380 meters.

Table 3. Road measurement data and specific road emissions with possible reductions to the base scenario

Location	Traffic flow, veh/h	Vehicle speed, km/h	Observed road section, km	Harmful emission	Scenario 0 (Base case), g/km	Scenario 1		Scenario 2		Scenario 3	
						g/km	%	g/km	%	g/km	%
Slavonska Avenue (regular traffic)	2059	72	1.65	NO_X	552	296	46%	313	43%	518	6%
				PM	40	24	80%	8	79%	39	3%
Slavonska Avenue (traffic jam)	1616	15	1.65	NO_X	1536	527	66%	962	37%	779	49%
				PM	64	12	81%	35	46%	24	62%
Hrvatske bratske zajednice Street	2296	50	0.55	NO_X	740	429	42%	440	41%	622	16%
				PM	47	11	77%	11	77%	44	8%
Marin Držić Avenue	1721	57	1.17	NO_X	532	303	43%	312	41%	446	16%
				PM	35	8	78%	8	78%	32	7%
Ljubljanska Avenue	2166	78	0.38	NO_X	666	371	44%	379	43%	550	17%
				PM	47	11	78%	11	78%	42	11%
Selska Street	2123	40	0.52	NO_X	750	442	41%	456	39%	633	16%
				PM	46	12	75%	12	75%	44	4%
Miramarska Street	1596	37	0.58	NO_X	634	397	38%	417	34%	543	14%
				PM	36	9	76%	9	76%	34	5%
Zagreb bypass	1759	93	4.24	NO_X	596	335	44%	344	42%	489	18%
				PM	43	8	81%	8	80%	38	12%

Emission calculation for the base case (Scenario 0) shows that despite the small number of 1,616 vehicles per hour, congestion on Slavonska Avenue causes greatest specific emission of NOX (1,536 g/km) and PM (64 g/km). The reason behind that is a very small median traffic speed of just 15 km/h. According to the emission factor in Figures 6, 7, 8, 9 and 10 low vehicle speed can cause a significant increase in harmful emission. If only roads with regular traffic were observed, greatest specific emission of NOx would be on Selska Street with 750 g/km, while for particulate matter it would be on Ljubljanska Avenue and Hrvatske Bratske Zajednice Street with 47 g/km.

Scenario 1 shows large reduction in specific emission for all observed roads. Emission of NOX can be reduced in the range of 38% to 66% while particulate matter shows an even greater reduction in the range of 75% to 81%. For nitrogen oxides, the greatest reduction would be achieved during the congestion on Slavonska Avenue while on the other roads reduction would be around 40%. Once again, it is necessary to mention that this scenario shows a reduction that would occur right after Low Emission Zone implementation and mainly as a result of vehicle number reduction. After the introduction of LEZ, it takes time for vehicle number to increase to its regular value.

Scenario 2 shows specific emission values after banned vehicles are replaced with newer ones. It can be seen that after the vehicle fleet stabilisation reduction from 34% to 43% can be achieved for NOx and 46% to 80% for particulate matter. The minimum reduction is achieved on Miramarska Street because of a small number of vehicles, while the greatest reduction is on Slavonska and Ljubljanska Avenue. In the case of particulate matter, the majority of streets could achieve a reduction up to 80%, while congested Slavonska Avenue could achieve minimal but still significant reduction of 46%.

Scenario 3 in which ban of all N category vehicles is being simulated represents a solution for incensement of traffic speed. Vehicles of this category are often responsible for slowing down traffic. With this kind of restriction, it is possible to reduce NOx and particulate matter emission by less than 20%. A significant difference can be seen during traffic jam where 49% of NOx emission reduction is achieved and 62% particulate matter emission reduction. This fact shows how vehicles of this category contribute to roadside emission during the traffic jam. If some type of congestion regulation was implemented, it would have a two-sided effect. Firstly, it would greatly reduce emission and secondly it would increase traffic speed which in return would have an even further reduction in emissions.

Despite the highest number of vehicles on Hrvatske bratske zajednice Street does not stand out in specific emission nor in emission reduction. Reason for this lies in the traffic speed. Emission factor shows that traffic speed of around 60 km/h has the advantage of low emission of harmful substances. The same thing goes for Marin Držić Avenue where the lowest specific emission is achieved for both particulate matter (35 g/km) and nitrogen oxides (532 g/km) because of its median speed of 57 km/h.

4. DISCUSSION

The most of Low Emission Zones already introduced in cities of Europe have less restrictive emission standard than one proposed in this research. Reason for the proposal of such a high standard lies in the fact that every major LEZ was introduced 10+ years ago and have set higher goals for the future. Implementation of LEZ in Zagreb takes time, and by the time it would be introduced, LEZ with lower standards will have the same or stricter standards than those proposed in this research. For example, authorities in London have set a goal for Euro 4 petrol vehicles and Euro 6 diesel by 2020 which is a lot higher standard than proposed. Similarly, Brussels plans to introduce Euro 2 petrol and Euro 4 diesel by 2020 and Euro 3 petrol and Euro 6 diesel by 2025 [13]. Traffic was analysed on distinctive road segments across City of Zagreb for the purpose of traffic modelling [11]. As it is evident, each and every observed road segment is specific and different from others, but the result of emissions reduction are still very similar and intuitive. This states that overall percentage emission reduction does not lie within the road segment type or traffic flow but in its speed and vehicle fleet composition. Vehicle fleet composition and emission factors showed that traffic speed has significant influence in the specific emission of harmful substances. When talking about traffic speed, there are two relevant facts that need to be considered. Firstly, because of the large variety of traffic speeds over the observed road segments, it can be considered that same results could be applied on roads across proposed LEZ according to their own traffic speeds, meaning that the same results would be achieved over roads with traffic speed similar to those observed. Secondly, traffic congestion has the largest specific emissions, and the reason for this is low vehicle median speed, despite small overall vehicle number. To ensure reduction of congestions specific emission, it is necessary to increase medial vehicle speed towards optimum of approx. 60 km/h. This could be achieved with better traffic organisation during daily traffic peak hours or by some sort of congestion charge.

The biggest concern lies in particulate matter (PM), especially PM2.5 because the general rule says that the smaller the PM, the more dangerous it is to human health. Also, it is quite difficult to define minimum value at which particulate matter is harmless to human health, so this represents the reason why it should be closely monitored and kept at its minimum level. As it is shown earlier, depending on the type of the street, particulate matter can be reduced from 46% to 80%. Studies have found that there is a 7% increase in mortality with every 5 micrograms per cubic metre increase in the particulate matter [14]. Therefore a huge accomplishment could be achieved if some type of LEZ is implemented in the City of Zagreb. Although particulate matter represents the biggest concern in cities, by implementing Low Emission Zone nitrogen oxides would also be affected. As it is earlier shown, by implementing some kind of restriction it is possible to reduce nitrogen oxides in the range of 34% all the way up to 43%. Nitrogen oxides are a big concern not only to human health but the environment as well [15]. Many European cities struggle with the balance of congestion, 'liveability', air pollution, noise levels, accessibility, damage to historic buildings and other pressures of urban life. As shown earlier, many cities have levels of pollution that adversely affect health. Also, congested, polluted, noisy cities are not attractive for businesses, residents or tourists. Congestion also has a significant impact on the economy, costing nearly €100 billion, or 1% of the EU's GDP [16]. The different types of traffic regulation zones can reduce traffic and congestion in a city, and ensure that those that need to travel with a vehicle can travel rather than sit in a traffic jam. In addition, noise contributes to at least 10,000 cases of premature mortality each year and almost 90% of the health impact caused by noise exposure is associated with road traffic noise [17]. According to the data gathered by Center for Vehicles of Croatia, average M1 category vehicle age stands at 12.95 years while for N1 category is slightly lower at 11.09 years. Older vehicles increase safety concerns in traffic. Research done by the Center for Vehicle of Croatia show that vehicle age has a high influence on vehicles technical validity and roadworthiness. By implementing the Low Emission Zone, it would help to reduce the high age of the fleet and ensure better traffic safety.

5. CONCLUSIONS

Conducted research has shown that the City of Zagreb deals with the problem of high emission of harmful substances derived from traffic. In order to deal with this problem, it is necessary to implement some sort of a Low Emission Zone which primary purpose would be to ensure greater air quality and cleaner environment for all of the city's residents. By conducting this research on various types of urban roads during peak hours of traffic, it is shown that it is possible to improve current condition regarding roadside air pollution by the introduction of LEZ. Measured traffic flow parameters, in terms of vehicle activity, were combined with vehicle fleet composition and appropriate emission factors. This made it possible to develop emission equations which were used for theoretical determination of roadside emission and possibilities for its reduction. Results showed that it is possible to achieve great emission reduction by changing vehicle fleet composition. Furthermore, it would also help reduce overall vehicle number which would increase road safety.

By conducting this method during the traffic peak hour, it is estimated that the introduction of LEZ would help achieve improvement in air quality in the City of Zagreb. By applying Scenario 1, it is possible to reduce NOx emissions by significant 66% and PM emissions all the way up to 81%. Once again, it is important to note that Scenario 1 represents a starting state of LEZ implementation with much lower traffic flow. Long-term achievement is accomplished with Scenario 2 which represents traffic flow stabilisation. By Scenario 2 it is possible to reduce around 40% of NOx emission and 80% PM emission. Scenario 3 showed that great reduction could be achieved by regulating light-duty vehicles during traffic congestions, while not much reduction is achieved during regular traffic.

In order to have a more detailed look into roadside emission and impact of LEZ introduction, further research should be directed towards including more road segments from inside the LEZ. Automatic counters, speed measuring tools and plates recognition software should be used in order to minimize field work and reduce measuring error possibilities. That kind of automated analysis would make it possible to develop software for gathering real-time emission estimation and combine it with air quality measuring stations in order to see their more detailed correlation.. If we want to avoid that scenario, we need to change our way of thinking, to educate young generations indicating the importance of environment protection and to act “green”

REFERENCES

[1] EEA. European Union emission inventory report 1990–2015 under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP). No 9/2017, https://www.eea.europa.eu/publications/annual-eu-emissions-inventory-report, 2017.

[2] Costa, L.G., Cole, T.B., Coburn, J., Chang, Y., Dao, K., Roqué, P.J.: "Neurotoxicity of traffic-related air pollution", Neuro Toxicology, Vol. 59, 2017, pp 133-139, doi. 10.1016/j.neuro.2015.11.008.

[3] Hendricks, J., Righi, M., Dahlmann, K., Gottschaldt, K., Grewe, V., Ponater, M., Sausen R., Heinrichs, D., Winkler, C., Wolfermann, A., Kampffmeyer, T., Friedrich, R., Klötzke, M., Kugler, U.: "Quantifying the climate impact of emissions from land-based transport in Germany", Transportation Research Part D: Transport and Environment, 2017 July, doi. 10.1016/j.trd.2017.06.003.

[4] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe, http://eur-lex.europa.eu/legal-content/HR/TXT/?uri=CELEX:32008L0050a.

[5] Božić, M., Vučetić, A., Sjerić, M., Kozarac, D., Lulić, Z.: "Experimental Study on Knock Sources in Spark Ignition Engine with Exhaust Gas Recirculation”, Energy conversion and management, 2018, Vol. 165, pp 35-44, doi. 10.1016/j.enconman.2018.03.053.

[6] Kurt, O.K., Zhang, J., Pinkerton, K.E.: "Pulmonary health effects of air pollution", Current Opinion in Pulmonary Medicine, pp 138–143, doi. 10.1097/MCP.0000000000000248.

[7] Poorfakhraei, A., Tayarani, M., Rowangould, G.: “Evaluating health outcomes from vehicle emissions exposure in the long range regional transportation planning process", Journal of Transport & Health, Vol. 6, 2017, pp 501-505, doi. 10.1016/j.jth.2017.05.177.

[8] Holman, C., Harrison, R., Querol, X.: "Review of the efficacy of low emission zones to improve urban air quality in European cities”, Atmospheric Environment, Vol. 111, 2015, pp 161-169, doi. 10.1016/j.atmosenv.2015.04.009.

[9] Urban Access Regulations In Europe, http://urbanaccessregulations.eu.

[10] Bonačić Bartolin, P., Bunjevac, M., Lulić, Z.: "Vehicle Emissions and Air Quality in the City of Zagreb", Digital proceedings of the 8th European Combustion Meeting, Dubrovnik, Croatia, 8-21.4. 2017.

[11] Horvat, R., Kos, G., Ševrović, M.: "Traffic Flow Modelling on the Road Network in the Cities", Technical Gazette, Vol. 22, No. 2, 2015, pp 475-486. doi. 10.17559/TV-20150127093334.

[12] Ntziachristos, L., Gkatzoflias, D., Kouridis, C., Samaras, Z.: "COPERT: A European Road Transport Emission Inventory Model", Information Technologies in Environmental Engineering, 2009, pp 491-504, doi. 10.1007/978-3-540-88351-7_37.

[13] Urban Access Regulations In Europe, Overview of Low Emission Zones, http://urbanaccessregulations.eu/ overview-of-lezs.

[14] Eeftens, M.: "Spatial variation of PM2,5, PM10, PM2,5 absorbance and PM coarse concentrations between and within 20 European study areas and the relationship with NO2 – Results of the ESCAPE project", Atmospheric Environment, Vol. 62, 2012, pp 303-317. doi. 10.1016/j.atmosenv.2012.08.038.

[15] Boningari, T., Smirniotis, P.G.: "Impact of nitrogen oxides on the environment and human health: Mn-based materials for the NOX abatement", Current Opinion in Chemical Engineering, Vol. 13, 2016, pp 133-141. doi. 10.1016/j.coche.2016.09.004.

[16] European Commission, Green Paper - Towards a new culture for urban mobility {SEC 1209}.https://eurlex.europa.eu/legalcontent/en/ALL/?uri=CELEX%3A52007DC0551, 2007.

[17] EEA, Noise in Europe 2014, EEA Report No 10/2014, https://www.eea.europa.eu/publications/noise-in-europe-2014.