Low Emissions Zone: An approach to reduce carbon emissions in sensitive and congested urban areas

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Abstract.

The paper develops a detail study on how to reduce carbon emissions in sensitive and congested urban areas where people are especially affected by GHG pollution. The study focuses on the analysis of traffic restrictions to private and public vehicles which does not fulfil specific conditions for entering the so called “Low Emissions Zone” (LEZ). The article uses a simulation to reproduce current driving in modern cities and how the use of electric vehicles contribute to maintain air quality and environmental preservation. The simulation runs on the analysis of dynamic equations of vehicle driving, evaluating the reduction of the various GHG types and their influence on people health. Energy consumption and vehicle performance represent key parameters to determine the absolute reduction of carbon emissions and lowering the GHG impact factor. The article also deals with the detection way of carbon emission by vehicles in LEZ and the actions to block the access. Artificial Intelligence is also applied to the traffic management to avoid contaminating cars entering the LEZ or to modify the driving pattern so the GHG emissions from circulating vehicles vanishes. The paper proposes an innovative methodology to measure GHG emissions at the LEZ entrance, commanded by an intelligent control system that blocks or detours vehicles with GHG emissions above set up threshold. The results of the simulations show the proposed method is feasible and achieve near 100% reduction of carbon emissions at optimum operating conditions and above 90% reduction, on average.

Keywords: Low Emissions Zones. Carbon emissions reduction. Urban congested areas. Simulation. GHG measurement. Traffic regulation and restrictions.

INTRODUCTION

Traffic congestion represents one of the most relevant factors contributing to urban pollution and carbon emissions [1-3]. The vehicle fleet in large cities, both public and private, is made up mostly of cars with internal combustion engines, diesel, and gasoline [4-6], which contribute significantly to greenhouse gas emissions [7-9]. The reduction of GHG emissions has become one of the main worries of politicians, car manufacturers, environmental preservation organizations, and concerned people about pollution effects on human health [10-13]. In the past decades, national and supranational political decisions have aimed at promoting the use of electric vehicles to reduce pollution in many large cities due to road traffic [14-17]. People's resistance to change from internal combustion engine cars (ICE) to electric vehicles (EVs) avoids the implementation of political decisions unless authorities adopt coercive actions [18-23].

The promotion of vehicle fleet electrification in large cities adopts two opposite ways: incentive and coercion; the primary wish of local and national authorities is a gentle transition from ICE cars to EVs based on subsidizing or aiding through zero-interest financing the electric vehicle buying [24-31], the alternative is the coercion, which is adopted when incentive actions fail [32-35]. Combining the two methods is the most frequent EV promotion policy in countries where the vehicle fleet electrification is controversial.

Among the coercive actions is the road traffic ban for ICE cars in large cities and urban areas; this policy, however, is so drastic that local authorities tend to soften their decisions by implementing this measure in areas specially selected due to their high level of pollution, the especial sensitivity of the area due to the type of activity or existing population, or simply for reasons of political convenience [36-38].

Today, traffic policymakers have implemented the so-called Low Emissions Zone in many countries and cities, a specific urban area where traffic restrictions apply to ICE cars [39-42]. The progressive implementation of LEZ [43] deserves a detailed study on how this policy effectively affects environment preservation, reducing carbon emissions and encouraging drivers to buy electric vehicles.

A low emissions zone (LEZ) is a permanent urban area where vehicle circulation is regulated or limited for different types of vehicles according to the polluting emissions they produce [44]. On the other hand, atmospheric pollution that occurs mainly in urban environments impacts the health of citizens. Inhalation of this type of pollutants leads to an increase in the development of cardio-respiratory diseases and lung cancers that reduce the quality and quantity of people's lives. To this end, the World Health Organization (WHO) [45] establishes standards for air quality and the presence of pollutants in the air. Furthermore, the European Commission established legal limits for these contaminants; however, 96% of European citizens suffer from high pollution levels, which results in high economic and human life losses [46]. Table 1 shows the impact of GHG emissions on human lives.

Table 1 Early deaths and life expectancy reduction due to GHG emissions [46]

Contaminant	Issue	European Union
$PM_{2,5}$	Early deaths	238000
	Life expectancy reduction	544
NO_2	Early deaths	49000
	Life expectancy reduction	109
O_3	Early deaths	24000
	Life expectancy reduction	56

NOTE: Data for life expectancy reduction are per 100 thousand of inhabitants.

Low Emissions Zones intend to reduce GHG emissions due to road traffic, which is responsible for 30% of the greenhouse, nitrox oxides, Sulphur dioxides, small particles, and ozone emissions, among others [47-48]. An additional advantage of LEZ is the acoustic level reduction since electric motors are silent.

Low emissions zones should meet specific requirements to reduce polluting emissions impact. The first is that it has to be implemented in an urban area to improve the air quality of a city or part of it. In addition, the LEZ implementation area must have a high concentration of contaminants. Two regulations may apply to know if an area has poor air quality: the WHO Global Guidelines on Air Quality or the air quality directive of the European Union, which has a legal impact on the territory of the European Union [49].

Currently, there is no European Union unified regulation on the criteria and requirements for the LEZ implementation. Each member state imposes its regulations. For instance, in Spain, the law on climate change and energy transition [50] establishes the guideline on low-emission zones. Specifically, the law enforces all municipalities with more than 50,000 inhabitants and island territories to implement measures to stop climate change before 2023, among which is the implementation of low-emission zones.

In this work, we study, in detail, the situation of LEZ related to the effective reduction of carbon emissions, with a specific analysis of the various electric vehicle types. We also analyze the impact on the nearby environment, how violations of traffic restrictions to polluting cars are detected, and the actions addressed to avoid repetitive violations. Besides, the work deals with innovative detection systems of possible traffic restriction violators and the proposed way how Artificial Intelligence may act to prevent this situation.

LOW EMISSIONS ZONE IMPLEMENTATION PROTOCOL

The Low Emissions Zone implementation should follow the next protocol:

1. **Atmospheric contaminant agents study**. Evaluation of the type and concentration of atmospheric contaminant agents.

2. **Urban road traffic**. Analysis of road traffic density, distribution, vehicle type, and congested zones.

3. **Pollution analysis data**. Comparative analysis of current contaminant agents' concentration with reference values.

4. **Environmental impact**. Study of LEZ implementation impact on the nearby environment and contaminant agents' reduction.

5. **Violation detection and coercive measurements for violators**. Study on the detection systems for violations and the coercive measurements like drivers or car owners fines in case of LEZ protocol violation.

6. **Sociological policy**. Promotion and dissemination of sociological policy to mitigate LEZ implementation impact on the society.

7. **Air quality control tracking**. Periodically measurement of contaminant agents' concentration and evaluation of the concentration evolution.

ROAD TRAFFIC RESTRICTIONS

Low Emissions Zone should restrict the traffic to contaminant vehicles like the internal combustion engine car. Nevertheless, some types of electric vehicles, like the hybrid electric vehicles (HEV), plug-in electric vehicles (PHEV), range-extended electric vehicles (REXEV), or the new mild hybrid electric vehicles (MHEV), should be submitted to traffic restrictions if they operate under combustion engine basis since in this mode they contribute to environmental pollution.

Traffic restrictions may apply to ICE cars differently depending on the combustion engine type: diesel, gasoline, or gas. Additionally, the vehicle age is another factor in imposing road traffic restrictions.

Road traffic restrictions can be of the economic type, like fines to LEZ protocol violators, tolls for circulating in LEZ neighborhoods for high contaminant vehicles, or taxes for getting access to the LEZ area.

DETECTION METHODS

The fulfilment of LEZ protocol by car drivers require detection methods to warranty that contaminant vehicles cannot enter or they are warned they are violating traffic restrictions no matter if the violation is voluntary or casual.

The simplest method for LEZ survey is the video surveillance cameras, which identify the car entering the zone. This method, however, suffers from the disadvantage of restricting car access to vehicles only as a function of the engine type, which the control system identifies from a database containing the characteristics of the vehicle model associated with the traffic plate [51-59].

Blocking car access through video surveillance cameras requires a blocking system like a physical barrier, which does not open unless the vehicle identification is positive for an access permit. The engine type identification, however, does not warrant that only non-contaminant vehicles are granted for entering the LEZ since mixed electric vehicles or ICE cars with low emissions certificates may generate high emissions levels if the engine is not well maintained; therefore, we propose an online detection method of vehicle emissions based on ultrasound technology.

Ultrasounds are mechanical waves that transmit depending on the transmission medium density (Equation 1) [60].

$$c = \sqrt{\frac{\kappa}{\rho}} \tag{1}$$

κ and ρ are the stiffness coefficient and density of the transmission medium, currently air.

If air contamination increases, the density does; therefore, the ultrasound transmission velocity decreases, and the system detects the pollution level increase from the air density increase.

Because the ultrasound waves move in the air at the same velocity that sounds (330 m/s) [60] and the distance between the ultrasound emitter and vehicle is low, currently a few meters, the detection time is in the order of milliseconds, which permits a blocking system quick reaction to avoid car entering.

Figures 1 and 2 show the side and overhead mount ultrasound detection system for GHG emissions from vehicle exhaust pipe.

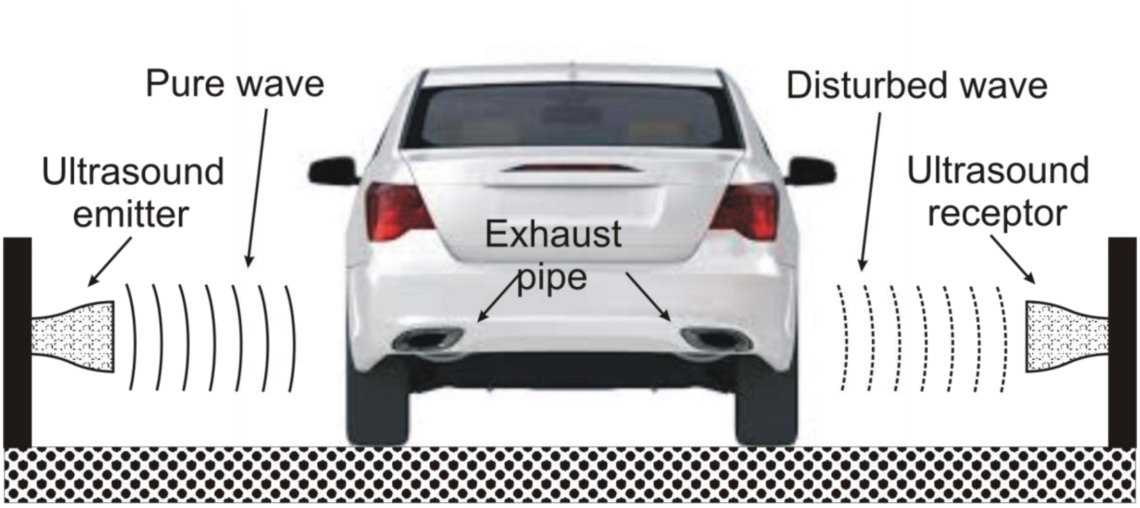

Figure 1 Schematic view of the ultrasound detection system (side mount)

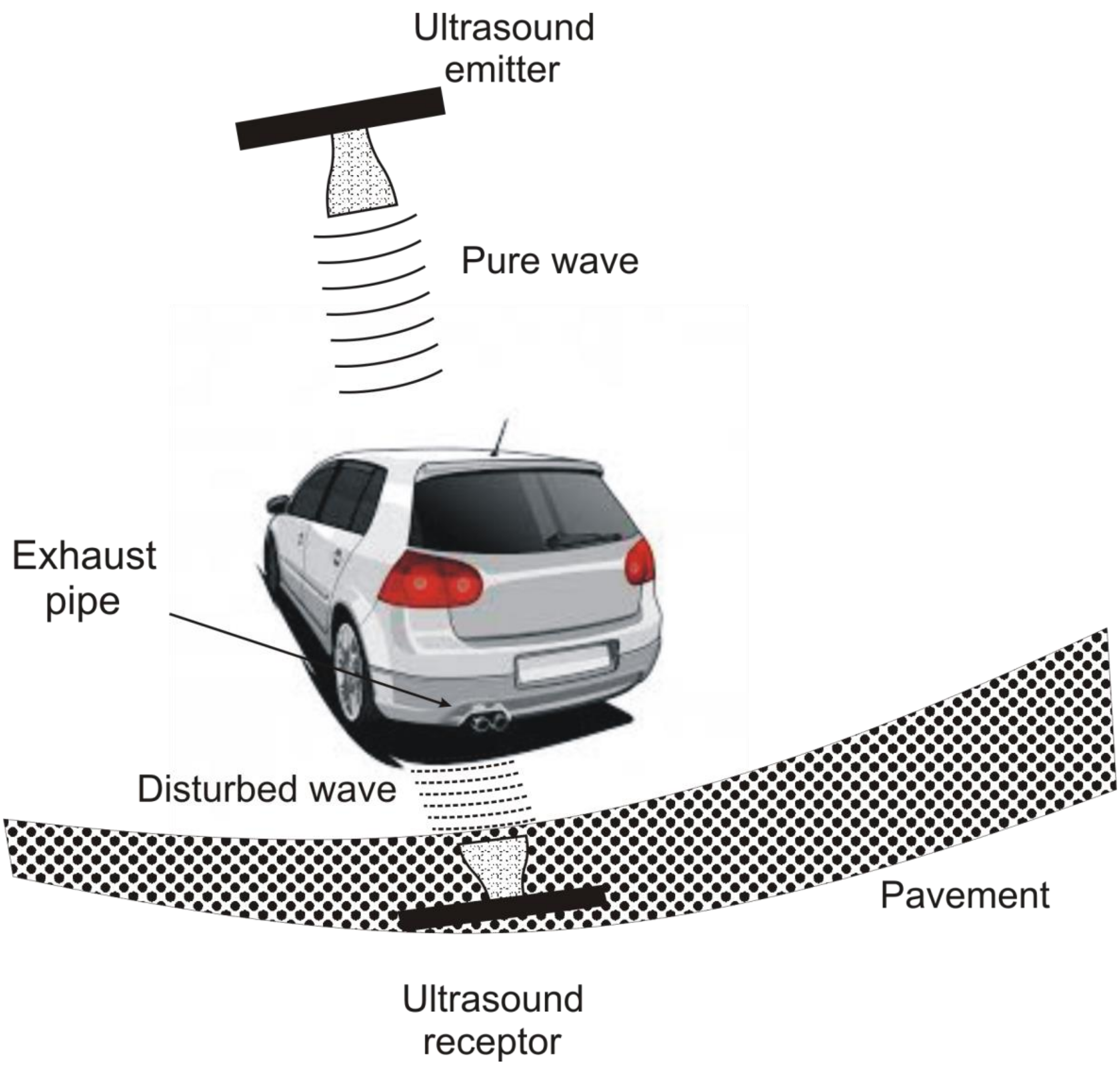

Figure 2 Schematic view of the ultrasound detection system (overhead mount)

Traffic sign vertical poles are suitable for side mount while overhead traffic panels, tunnel inner top side, or hanging traffic lights can accommodate overhead mount. Side mount is recommended for lane road, while for two or more lanes of road, we suggest the overhead mount. For the overhead mount, the ultrasound emitter should cover the entire width of the road to detect any pollutant car independently of the lane the vehicle is circulating by. Traffic sign vertical poles are suitable for side mount while overhead traffic panels, tunnel inner top side, or hanging traffic lights can accommodate overhead mount. Side mount is recommended for lane road, while for two or more lanes of road, we suggest the overhead mount. For the overhead mount, the ultrasound emitter should cover the entire road width to detect any pollutant car independently of the lane the vehicle is circulating by or the relative position of the exhaust pipe at the vehicle's rear side.

Considering standard dimensions for one or more lanes road width and overhead traffic panels, we obtain an ultrasound wave emission angle of 6.5º for side mount and 38º for overhead mount. For these values the emitter and receptor in side mount should be placed at 40 cm high, and for the overhead mount the emitter is located at 5 m high and the receptor buried in the pavement.

CARBON EMISSIONS

The main goal of a LEZ is the carbon emissions reduction through traffic restrictions to contaminant vehicles; therefore, to evaluate the environmental impact of a LEZ implementation, we must determine the carbon emissions before and after implementing the LEZ.

Carbon emissions for vehicles depend on the fuel consumption rate since the combustion of diesel, gasoline, or gas produces a specific emission of GHG per liter of used fuel. Battery electric vehicles do not generate carbon emissions since they operate on electricity at all times; however, hybrid and plug-in hybrid electric cars produce carbon emissions when they run on the ICE: obviously, internal combustion engine cars generate carbon emissions at all times.

Fuel consumption

We use reference values from car manufacturers to determine the fuel consumption. The study applies to ICE, HEV, and PHEV cars. Retrieving data from the literature, we have (Table 2):

Table 2 Fuel consumption rate for ICE, HEV and PHEV cars [61-64]

Engine type	Driving pattern	Consumption	Unit
ICE (gasoline)	Sport	7.8	L/100 km
	Normal	5.6	
	ECO	4.7	
ICE (diesel)	Sport	6.1	
	Normal	4.6	
	ECO	3.5	
EV	Sport	20.8	kWh/100 km
	Normal	17.5	
	ECO	15.7	

Since hybrid and plug-in hybrid electric vehicles do not operate on internal combustion engines at all times, we define a time factor, β_f, that shows how long the car runs on an ICE basis. On the other hand, we must consider the extra weight due to the battery in hybrid electric vehicles, HEV and PHEV. A coefficient, αm, accounts for the contribution of the additional weight to the fuel consumption rate. We determine this coefficient by applying the second Newton's law to the vehicle motion:

$$F = ma + kv^2 + \mu mg + mg\sin\theta \tag{2}$$

m, a, and *v* are the mass, acceleration, and vehicle velocity, *k* and μ are the drag and rolling coefficient, and θ is the road slope.

Considering the vehicle moves on a flat terrain, we divide the motion into two steps, acceleration and constant speed, defined by the motion factor, γ. For acceleration and constant speed, $\gamma=\gamma_a$ and $\gamma=\gamma_c$.

We define the coefficient αm as a function of γ_a as follows

$$\alpha_m = \gamma_a \frac{\mu mg}{kv^2 + \mu mg} + \gamma_c \frac{ma + \mu mg}{ma + kv^2 + \mu mg} \tag{3}$$

Applying data for a specific vehicle (Table 3), α_m=0.76.

Table 3 Technical data for the selected testing vehicle [65-66]

Issue	Symbol	Value	Unit
Average speed	v	50	km/h
Average acceleration	a	1	m/s^2
Mass	m	1415	kg
Front area	A_f	2.59	m^2
Aerodynamic coefficient	C_x	0.27	---
Air density	ρ	1.113	kg/m^3
Drag coefficient	k	0.39	---
Rolling coefficient	μ	0.015	---
Acceleration time fraction	γ_a	0.1	---
Constant speed time fraction	γ_c	0.9	

The fuel consumption rate derives from the equation:

$$C_{xfz} = \alpha_m \beta_f \frac{m_x}{m_{ref}} C_{ref,z} + \left(1-\alpha_m\right)\beta_f C_{ref,z} \tag{4}$$

Sub-indexes *x, f, z,* and *ref* account for engine type, fuel type, driving pattern, and reference.

For fuel consumption in hybrid and plug-in hybrid electric vehicles, we use the reference value for gasoline since hybrid electric vehicles with gasoline engines represent 87% of the market for HEV and 93% for the PHEV.

Table 4 shows the results of the fuel consumption rate calculation.

Table 4 Fuel consumption rate

Engine type	Driving pattern	C_{xfz} (L/100 km)	C_{xez} (kWh/100 km)
ICE diesel	Sport	5.30	---
	Normal	4.62	
	ECO	3.90	
ICE gasoline	Sport	6.55	
	Normal	5.86	
	ECO	4.95	
HEV	Sport	5.84	4.2
	Normal	4.74	5.3
	ECO	3.80	5.5
PHEV	Sport	5.15	7.3
	Normal	4.11	7.9
	ECO	3.26	7.9
BEV	Sport	---	20.8
	Normal	---	17.5
	ECO	---	15.7

Now, converting the energy consumption rate to a normalized unit (MJ/100 km) through the fuel combustion power of diesel and gasoline:

$$\xi_{xfz} = Q_x \rho_x C_{xfz} \tag{5}$$

ξ represents the normalized energy consumption, Q is the fuel combustion power, and ρ is the fuel density.

For diesel and gasoline, we have (Table 5):

Table 5 Fuel combustion power and density [67-68]

Fuel type	Combustion power (MJ/kg)	Density (kg/m^3)
Diesel	43.1	0.832
Gasoline	43.2	0.743

Applying values from Table 5 and using Equation 5, we obtain the normalized value for the energy consumption rate (Table 6).

Table 6 Normalized fuel consumption rate

Engine type	Driving pattern	C_{xfz} (L/100 km)	C_{xez} (kWh/100 km)
ICE diesel	Sport	190.1	---
	Normal	165.7	
	ECO	139.9	
ICE gasoline	Sport	210.2	
	Normal	188.1	
	ECO	158.9	
HEV	Sport	187.3	15.0
	Normal	152.2	18.9
	ECO	122.0	19.8

PHEV	Sport	165.3	26.2
	Normal	132.0	28.4
	ECO	104.7	28.3
BEV	Sport	---	74.9
	Normal	---	63.0
	ECO	---	56.5

CARBON EMISSIONS BALANCE

The conversion of energy consumption into carbon emissions requires the GHG emissions rate for the two fuel types, diesel and gasoline. Retrieving data from the literature (Table 7):

Table 7 GHG emissions rate for diesel and gasoline [69-71]

	GHG			
Fuel type	NO_x (g/km)	SO_2 (mg/km)	$PM_{2.5}$ (mg/km)	CO (g/km)
Diesel	0.531	1.45	1.0	0.073
Gasoline	0.054	2.23	0.4	0.799

We calculate the vehicle GHG emissions, *P*, using the ratio between the fuel consumption for the specific driving pattern and vehicle type and the reference value from Table 4. Mathematically:

$$P_{xyz} = \frac{C_{xfz}}{C_{ref}} P_{ref} \tag{6}$$

Considering the vehicle does not produce GHG emissions when running in electric mode, we obtain (Table 8):

Table 8 Vehicle GHG emissions per kilometer for various driving patterns

Engine type	Driving pattern	NO_x (g/km)	SO_2 (mg/km)	$PM_{2.5}$ (mg/km)	CO (g/km)
ICE diesel	Sport	0.6092	1.66	1.147	0.084
	Normal	0.5310	1.45	1.000	0.073
	ECO	0.4482	1.22	0.844	0.062
ICE gasoline	Sport	0.0604	2.49	0.447	0.893
	Normal	0.0540	2.23	0.400	0.799
	ECO	0.0456	1.88	0.338	0.675
HEV	Sport	0.0538	2.22	0.398	0.796
	Normal	0.0437	1.80	0.324	0.646
	ECO	0.0350	1.45	0.259	0.518
PHEV	Sport	0.0475	1.96	0.352	0.702
	Normal	0.0379	1.56	0.281	0.561
	ECO	0.0301	1.24	0.223	0.445
BEV	Sport Normal ECO	0	0	0	0

We realize the diesel engine is responsible for the highest nitrox oxide emissions level, more than ten times higher than any other engine type. The gasoline engine produces more emissions regarding Sulphur dioxides, although the ratio is not as high as for the diesel engine nitrox oxides. A diesel engine generates more particle emissions than other engines but emits less carbon monoxide. Concerning the hybrid electric vehicles, HEV and PHEV, GHG emissions are lower than for the gasoline engine, for all pollutant gases, but emit more Sulphur dioxide and carbon monoxide than diesel. If we compare emissions from the two types of hybrid electric vehicles, plug-in technology is friendlier with the environment as it generates lower GHG emissions in all cases.

Making a comparative analysis between engine types, we obtain the following average ratio (Table 9).

Table 9 GHG emissions ratio between engine technologies

GHG	Engine type	Diesel	Gasoline	HEV	PHEV
NO_x	Diesel		9.93	11.99	13.75
	Gasoline	0.10		1.21	1.39
	HEV	0.08	0.83		1.15
	PHEV	0.07	0.72	0.87	
SO_2	Diesel		0.65	0.79	0.91
	Gasoline	1.54		1.21	1.38
	HEV	1.27	0.83		1.14
	PHEV	1.10	0.72	0.88	
$PM_{2.5}$	Diesel		2.52	3.05	3.50
	Gasoline	0.40		1.21	1.39
	HEV	0.33	0.83		1.15
	PHEV	0.29	0.72	0.87	
CO	Diesel		0.09	0.11	0.13
	Gasoline	10.81		1.21	1.39
	HEV	8.95	0.83		1.15
	PHEV	7.79	0.72	0.87	

Results from Table 9 confirm that diesel engines for nitrox dioxide and gasoline for carbon monoxide emissions are the most pollutant car engines, with hybrid electric vehicles at an intermediate level for all GHG types.

Regarding carbon dioxide, the pollutant gas that most contributes to the greenhouse effect, the analysis of engine type follows a similar development, using the emissions rate for diesel and gasoline (Table 10).

Table 10 Carbon dioxide emissions rate for diesel and gasoline engine [72]

Fuel type	CO_2 emissions (kg/L)
Diesel	2.6949
Gasoline	2.3875

Carbon dioxide emissions, however, should add a carbon footprint due to electricity generation in non-renewable power plants. We use the electric energy generation mix database, which shows a carbon dioxide emissions rate of 120 kg/MWh [73]. Applying this value, we obtain (Table 11):

Table 11 Carbon dioxide emissions (kg/km)

Engine type	Driving pattern	Traffic	Electricity generation	Total
ICE diesel	Sport	0.143	0	0.1428
	Normal	0.125	0	0.1245
	ECO	0.105	0	0.1051
ICE gasoline	Sport	0.156	0	0.1564
	Normal	0.140	0	0.1399
	ECO	0.118	0	0.1182
HEV	Sport	0.139	0	0.1390
	Normal	0.113	0	0.1130
	ECO	0.091	0	0.0910
PHEV	Sport	0.123	0.0087	0.1317
	Normal	0.098	0.0095	0.1076
	ECO	0.078	0.0094	0.0873
BEV	Sport	0	0.0250	0.0250
	Normal	0	0.0210	0.0210
	ECO	0	0.0188	0.0188

Hybrid electric vehicles (HEVs) do not have a carbon footprint due to electricity generation in non-renewable power plants because they charge the battery using the ICE engine.

SIMULATION

In this section, we develop a simulation to evaluate the environmental impact reduction of Low Emissions Zone implementation. The simulation uses the global energy consumption and emissions due to traffic in the selected LEZ and the travelled distance inside the LEZ. The time interval used for the simulation is a day. The developed simulation applies to the Spain case but is valid for any country.

We obtain the vehicle fleet distribution by engine type, retrieving data from a specialized database [74] (Table 12).

Table 12 Engine type distribution for Spanish vehicle fleet

Engine type	Number of vehicles	Percentage
Diesel	14092093	54.4
Gasoline	10246934	39.6
HEV	1222643	4.7
PHEV	195451	0.8
BEV	143640	0.6

Additional conditions for the simulation are the driving pattern, the travelled distance and the number of circulating vehicles. In our case, we establish the following conditions:

- Normal driving pattern, since it is the most frequent driving mode
- A travelling distance equivalent to half the perimeter of a circle of radius R_{LEZ} that contours the Low Emissions Zone
- The average number of vehicles circulating inside the LEZ, provided by the municipality

If we apply these boundary conditions to the city of Madrid, it results (Table 13):

Table 13 Simulated boundary conditions for the city of Madrid (Spain)

Driving pattern	Travelling distance (km)	Average daily number of vehicles [75]
Normal	35.8	1511077

The simulated travelling distance matches the average distance for a daily journey [76] with 98.5% accuracy. The covered travelling factor within the LEZ is 0.8 regarding the average daily journey distance.

Figure 3 shows the simulation results for daily global energy consumption and GHG emissions.

According to this configuration the global energy consumption is 42 TJ/day, equivalent to 1.32 million liters of gasoline; 52% of this consumption proceeds from diesel engines, 42% for the gasoline ICE, 4.1% from HEVs, 0.7% from PHEVs, and 0.2% from BEVs.

Global carbon dioxide emissions are of 3174.9 tons/day, from which 52.4% corresponds to diesel engines, 42.8% to gasoline ICE vehicles, 4.1% to HEVs, 0.6% to PHEVs, and 0.1% to BEVs.

Regarding nitrox oxides emissions, 7672.6 kg/day, the engine vehicle distribution is 92.4% for diesel engines, 6.8% for gasoline, 0.7% for HEVs, and 0.1% for PHEVs. BEVs do not contribute to NO_x emissions.

Diesel and gasoline engines are responsible for the highest fraction of Sulphur dioxides emissions, 44.6% and 49.9%, with only 1.1% for hybrid electric vehicles, HEV and PHEV. The global daily SO_2 emissions is 43.394 kg.

Diesel engines are also the principal contaminant agent for particle emissions, with 75.6% of a daily total of 17.664 kg, followed by the gasoline engines, with 22%, and 2.1% and 0.2% for HEVs and PHEVs.

Finally, monoxide carbon emissions, 9585.6 kg/day, are mainly generated by gasoline engines, 80.9%, while for diesel, HEVs and PHEVs the fraction is 10.2%, 7.8% and 1.1%, respectively.

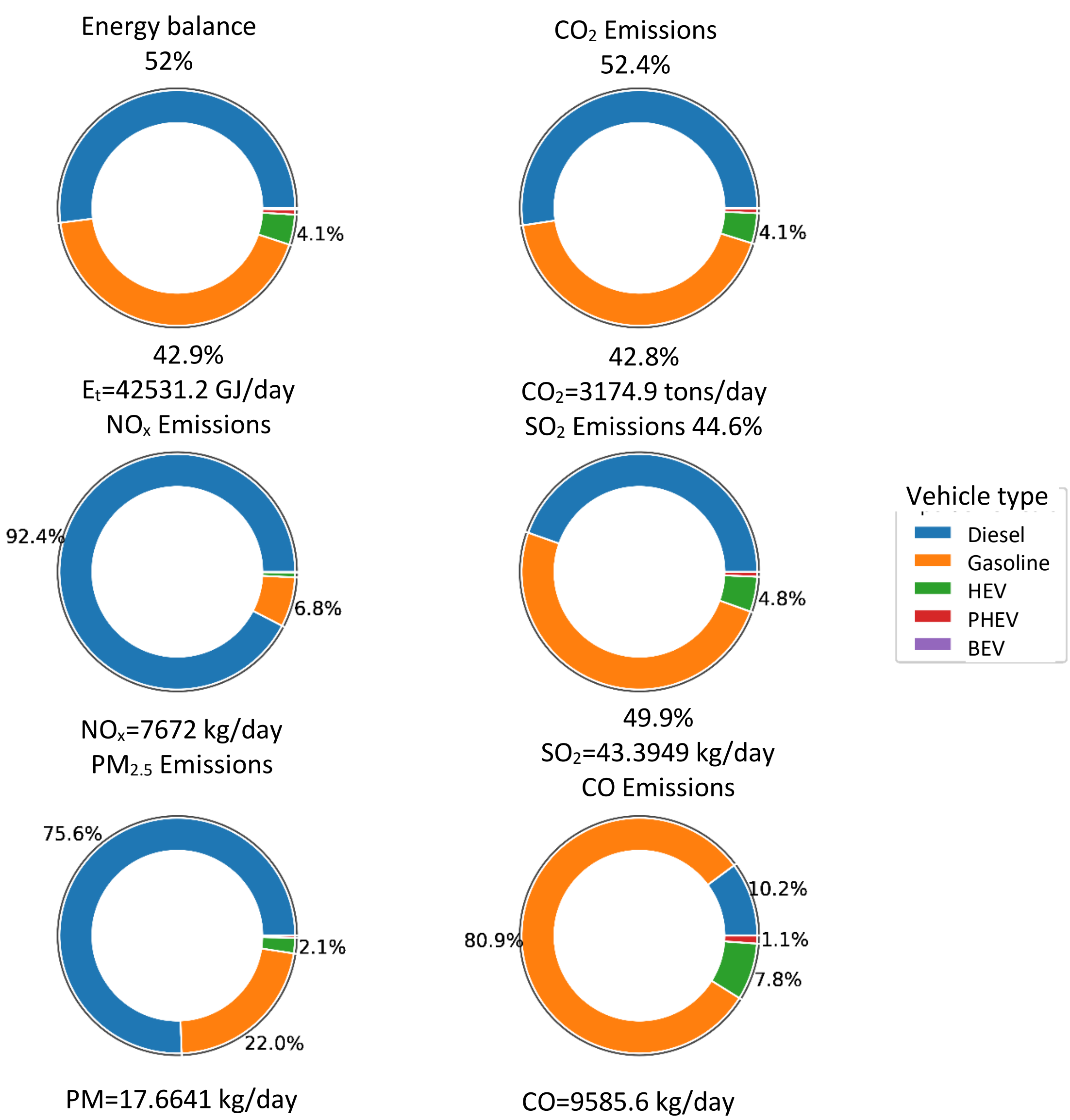

Figure 3 Daily global energy consumption and GHG emissions (simulation)

The simulation results show the impact of implementing Low Emissions Zones in congested or sensitive areas in cities where pollution represents a problem for human health and environmental preservation. Nevertheless, this situation is not realistic since people adapt to the traffic restrictions or coercive actions buying cars that can circulate inside the LEZ. Therefore, we propose various scenarios where the vehicle's number and type change, analyzing how every scenario influences the carbon emissions reduction and energy saving regarding the initial situation where no traffic restrictions apply.

The new study includes 4 scenarios:

1. Traffic restriction apply to diesel engine, which cannot circulate inside PEZ
2. Traffic restrictions avoid diesel and gasoline engine circulation

3. Only PHEV and BEV are allow entering LEZ
4. LEZ circulation is restricted to all vehicles except BEV

Additionally, the study considers a vehicle engine type distribution as shown in Table 14:

Table 14 Number of vehicles per engine type for every scenario

Engine type	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Diesel	0	0	0	0
Gasoline	993982	0	0	0
HEV	381007	976914	0	0
PHEV	75474	198765	573078	0
BEV	60802	161676	467933	1001637

Applying the protocol for the proposed simulation, we have (Table 15):

Table 15 Percentage of energy saving and GHG emissions

Parameter	Energy	CO_2	NO_x	SO_2	$PM_{2.5}$	CO
Scenario 1	0.38	2.0	84.5	-13.1	50.2	-83.5
Scenario 2	27.2	30.8	89.4	22.4	65.8	-25.9
Scenario 3	53.7	63.4	95.4	66.4	85.2	45.6
Scenario 4	75.9	89.2	100	100	100	100

Values in Table 15 show the energy saving and GHG lowering. Negative values indicate an increase in the emissions level percentage for the corresponding gas. We realize that two cases show a deterioration of air quality for specific gas emissions: Sulphur dioxide for scenario 1 (diesel engine vehicles ban) and carbon monoxide for scenarios 1 and 2 (diesel and diesel plus gasoline engine vehicles submitted to traffic restrictions). This situation is due to the high influence that diesel and gasoline engines have on the emissions of these two gasses.

The new simulation results are consistent with the current scenario, where avoiding access to vehicles with fossil fuel engine vehicles reduces GHG emissions and saves energy. Besides, the energy saving in electric cars increases, and GHG emissions lower with the dependence on ICE.

CONCLUSIONS

The Low Emissions Zones implementation in congested or highly polluted urban areas reduces GHG emissions, improving air quality and preserving environmental conditions and human health.

We propose in this work a protocol to apply in Low Emissions Zones to make more effective GHG reduction; this protocol bases on early detection of pollutant vehicles when entering the Low Emissions Zone (LEZ), blocking the access to the LEZ or persuading drivers to move to a less polluting driving pattern.

This work shows an innovative detection system for pollutant vehicles, valid for single or multiple-lane roads. The detection system uses ultrasound waves to detect GHG emissions from car exhaust pipes.

A simulation run for standard driving conditions in a big city shows that the Low Emissions Zone implementation in a circular urban area of a 5.7 km radius with an average of 1.5 million circulating vehicles reduces the carbon dioxide daily emissions by 3174.9 tons.

The simulation also predicts reduction of GHG reduction like in nitrox oxides, Sulphur dioxides, and carbon monoxide in 7672 kg, 43.4 kg, and 9.59 tons per day. The particle emissions saving due to LEZ implementation is 17.7 kg per day.

The protocol applied for the simulation is valid for any city or town independent of the size and number of circulating vehicles. We can apply traffic restrictions for pollutant cars to various scenarios depending on the permitted engine type that equips the vehicle, ICE, or hybrid electric vehicles, with improving results as the internal combustion engine dependence lowers.

Lowering carbon dioxide emissions ranges from 2% to 89.2% when the scenario moves from traffic restrictions to diesel engines to only battery electric vehicles allowed. For other GHGs, the lowering in emissions percentage is less significant but also relevant.

The simulation for various engine type traffic restrictions may produce negative results in lowering GHG emissions percentage as in the case of Sulphur dioxide for diesel engine restriction only or carbon monoxide for diesel and gasoline engine restriction. These apparent contradictory effects are due to the higher influence that diesel and gasoline engines have on the emissions of these two gases.

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