Classification of medium and small cities for the implementation of Low Emission Zones

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Abstract

Growing mobility within cities has led to an unacceptable increase in the negative externalities of transport. In order to reduce this negative impact, Low Emission Zones (LEZs) are being implemented; among other actions and objectives, they include some type of circulating restriction for vehicles to improve air quality. Given the differences among cities, and the great variety of measures that a LEZ may include, it is necessary to develop aids for choosing the most appropriate type of LEZ to be implemented. This study identifies groups of cities having similar geophysical and socioeconomic characteristics, as well as other traits related with the generation of negative impacts by transport. Our classification may be used to propose common policy guidelines —and in some cases even specific proposals— for planning an adequate LEZ in each city group, or for other municipalities that could identify with a particular group.
The study case is Spain. A total of 61 cities were considered, described by means of 11 variables. Cluster analysis was used to define the groups of cities, giving eight clusters; in view of their most relevant characteristics, different policy guidelines and actions could be put forth for the design of a particular LEZ for each group.

Keywords: Low Emission Zones; vehicle access regulations; impacts of transport in cities; cluster analysis.

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1. Introduction

Globally, populations continue to concentrate in urban areas. In 2021, 75% of European citizens lived in cities, and the figure is expected to reach 90% by 2050. This growth is accompanied by a rise in urban economic activity (85% of EU gross domestic product is generated in cities) and increased mobility (Eurostat, 2022, and European Commission, 2017). In turn, the negative effects of transport —air and noise pollution, congestion, occupation of urban space, accidents, etc.— are accentuated as public transport systems strive to adapt to the increasing demand.

In this context, to improve the "livability" of cities, Low Emission Zones (LEZs) are being implemented. Basically, a LEZ is understood an urban zone where there is some type of restriction for vehicle access, circulation, and parking, depending on the level of emissions. The objective is to improve air quality for health-related reasons. There are several ways to classify vehicles to limit their access to cities, mainly based on Euro standards, but lately also considering zero or low-emission vehicles (electric, gas, hybrid). Restrictions might also be applied by zones or corridors, varying according to the level of pollution or congestion, and they could even involve access tolls.

In line with the previous definition, the study for the European Commission by Ricci et al. (2017), on vehicle access regulations, underlines the reduction of pollution in cities as the main objective of LEZs. Air pollution causes an estimated 310,000 premature deaths in Europe per year (European Commission, 2021a). Moreover, in urban areas transportation is the source of 40% of CO_2 emissions and 70% of other air pollutants, thus contributing to global warming; the cost of traffic congestion in cities is around 100 billion euros per year (1% of the gross domestic product of the EU) (European Commission, 2020a and 2021b); and 22,800 fatalities take place each year in traffic accidents within cities (European Commission, 2020b). For these reasons, from a broader standpoint of sustainable transport, other objectives are usually considered when adopting urban access regulations in general and LEZs in particular (Ricci et al., 2017):

- Modal shift toward more sustainable modes of transport

- Transition to less contaminating vehicles
- Reduced congestion
- Improved accessibility
- Generation of income to improve mobility.

Along with these, Spanish legislation specifies additional priorities (Ministerio para la Transición Ecológica y el reto Demográfico, 2021a; Ministerio de la presidencia, relaciones con las cortes y memoria democrática, 2022):

- Prohibitions or restrictions for the access, circulation and parking of vehicles, depending on their potential for contamination
- Decreasing noise pollution
- Promoting public transport
- Prioritizing active mobility
- Achieving a balance in urban space, between motorized and non-motorized mobility, by reducing the area dedicated to vehicles, including parking space
- Guaranteeing the accessibility and mobility of vulnerable groups of inhabitants
- Promotion of alternative mobility for workers
- Supporting the use of zero-emissions vehicles in the urban transport of merchandise
- Promotion of electric mobility and shared mobility.

Summing up, a wide variety of actions can be considered when devising a LEZ. A full set of measures may be structured around two blocks: the restrictions of the LEZ itself, and the complementary measures to guarantee mobility (related to public transport reinforcement, shared and active mobility promotion, public space reorganization, etc.).

According to the European Commission (Ricci et al., 2017), due to the great diversity among cities (in terms of population, socioeconomic characteristics, pollution and other transport-related problems, as well as physical and meteorological conditions), the actions involved in implementing a LEZ cannot be the same for all. Indeed, within vast cities, transportation-related problems may vary from one zone to another, meaning the actions to be considered will differ; for instance, different restrictions may be implemented based on concentric rings, land use, etc., as stated in the document "Guidelines for the creation of low emission zones" (Ministerio para la Transición Ecológica y el reto Demográfico, 2021a).

The present study therefore seeks to identify groups of cities with common characteristics, making it possible to then propose similar guidelines for planning the implementation of an LEZ.

The paper is organized in the following sections: study objectives, literature review, description of the case study, the database compilation, and the methodology applied; and finally, a discussion of the results along with the most relevant conclusions.

2. Objective of study

Taking the above into account, the objective of this study is to identify groups of cities in similar situations regarding the implementation of LEZs. To that end, two main aspects will be considered:

- Air pollution and other transport-related problems. The main variables bearing a negative impact of transport in cities will be selected.
- City characteristics that may condition the type of LEZ to be implemented, such as city size, population, age of the population, level of economic activity, etc.

The common characteristics of the cities in each group will allow for the proposal of similar guidelines and specific actions for the type of LEZ to be implemented. These guidelines and actions may be useful as well for other cities that identify with one particular group.

3. State of the art

The cities will be grouped according to their similar situations regarding problems that the LEZs aim to solve. This section gathers the variables upon which the main negative externalities of transport in cities depend.

In relation to urban air pollution, emissions from transport, of residential origin (heating, kitchens), and from activities such as construction, industry, or the generation of electric energy, all contribute to atmospheric contamination. As far as transport is concerned, increased mobility requirements for inhabitants and merchandise have contributed largely to higher levels of contaminants in the air. The main ones deriving from traffic are carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and fine particulate matter (PM) (Ministerio para la Transición Ecológica y el Reto Demográfico, 2021a).

Yet air pollution depends on further factors, such as meteorology. Yin et al. (2016) analyzed the relationship between the concentrations of PM and meteorological conditions including temperature, humidity, wind velocity, atmospheric pressure, precipitation, and hours of sunlight in Beijing (China). The authors concluded that a relationship in the form of a “U” exists between the maximum daily wind speed and the concentrations of PM. Li et al. (2019) analyzed data from multiple cities in China to study the spatial and temporal variations of air pollutants, finding significant differences in the level of air pollution across seasons, the most decisive factors being temperature, sunshine duration, precipitation, relative humidity, and wind speed. In turn, Yang et al. (2020) studied the relationships among the same meteorological factors as the previous studies cited and the levels of contamination in 284 cities in China during the period 2015-2018, observing non-linear relations between the meteorological conditions and the levels of O_3 and PM. Finally, Tan et al. (2023), likewise found that atmospheric contamination was directly related with the temperature and hours of sunlight, and indirectly with humidity and precipitation.

There are also certain physical traits specific to each city that may bear an impact on the level of contamination. Cárdenas et al. (2016) investigated 249 European cities in terms of the relationship between air pollution and: altitude, road density, urban structure, population density, and temperature. Their results indicate that air pollution (concentration of NO_2, PM_{10}, and SO_2) is related to population density, urban fragmentation, economic characteristics, and meteorological conditions; the most densely populated and most fragmented cities suffered from greater concentrations of contaminants. Authors Li et al. (2017) analyzed the relationship between atmospheric contamination (concentrations of PM, NO_x and SO_2) and 15 indicators associated with wealth, employment, energy consumption, motorization index, vegetal cover, transport infrastructures, and activity in the sector of construction in Beijing (China). Their results attest to a strong correlation between air pollution and the indicators linked to employment, energy consumption, vegetal cover, construction activity, per capital income, and transport infrastructures. Again, in the context of China, Qiu et al. (2019) explored the impacts of transport facilities, urban construction, and economic factors in several cities through an air quality index. Regarding the transportation impacts, factors such as the number of buses and taxis and annual passenger trips showed the most negative influence on urban air quality, while among the economic and construction-related factors, urbanized area and annual gross value of industrial output were most influential in a negative sense. As for the influence of vegetal cover on the concentrations of contaminants, Krupnova et al. (2020) found, in a study carried out in Chelyabinsk (Russia), that green areas help decrease the level of urban pollution.

With regard to noise pollution, Bilaşco et al. (2017) conducted a study to identify the locations with a high level of noise in cities using a GIS spatial analysis model. The GIS model was developed based on variables such as noise measurements, buildings (intensity of edification), land use, transport infrastructure, wind direction and speed, time of day, and traffic flows, from which noise maps were obtained. Faulkner and Murphy (2022) applied a noise calculation method to calculate population exposure to traffic noise in Dublin (Ireland) by considering variables such as wind speed, temperature, atmospheric pressure, air humidity, traffic flow, average speed, and inhabitants per building. Forouhid et al. (2023) measured the spatial and temporal distribution of noise levels in urban areas; they found that land use, traffic volume, slope, and road width had significant effects on noise pollution.

With a focus on traffic crashes in urban areas, Theofilatos et al. (2012) examined their severity in urban areas in Greece, finding that the main variables that bore an impact on the severity of crashes were location and time of the crash, driver age, type of collision and, as for the type of vehicle, bicycles and motorcycles. In addition, Potoglou et al. (2018) determined several factors that contributed to traffic crashes on urban roads in Palermo (Italy) —the ones most significantly associated included the season of the year, weather conditions, speeding, and the age of the driver. Xian et al. (2022) confirmed the risk factors having the most significant impact on crashes in Jinan (China): road conditions, vehicle characteristics, traffic volume, speeding, season, and time of day.

Finally, with regard to traffic congestion in cities, He et al. (2016) affirm that the primary underlying causes are travel demand, road capacity, traffic volume, and intersection design. The study conducted by Zhang et al. (2017) concluded that variables such as road type, ramps, number of bus stops, parking lots, schools, distance to hospitals, and proportion (in area) of transportation infrastructure were associated with higher traffic congestion. Bao et al. (2022) investigated the relationship between land use and the level of traffic congestion in Xining (China), arriving at a significant correlation between residential and educational land uses and traffic congestion. Dasgupta et al. (2022) studied the impact of congestion on travel time, contamination, and public health in Dhaka (Bangladesh). Regarding contamination, their results revealed a significant association between congestion and the concentration of atmospheric contaminants, especially $PM_{2.5}$.

4. Case of study

The present case of study is Spain, where the Law on Climate Change and Energy Transition establishes that municipalities having more than 50,000 inhabitants (containing about 53.2% of Spain´s population overall) must establish LEZs. More specifically, and in line with the classification by Monzón et al. (2021), the study´s scope comprises medium-sized cities (between half a million and one million inhabitants) and small ones (between 50,000 inhabitants and half a million), which gives a total of 151 cities and 20,230,745 inhabitants (INE, 2021).

Aside from the above legal imperative, the European Environmental Agency estimates there are over 20,000 premature deaths per year in Spain due to poor air quality, attributable to unhealthy levels of nitrogen oxides (NO_x), ozone (O_3) and PM smaller than 2.5 µm ($PM_{2.5}$). In fact, nearly all the provincial capitals of Spain present air quality data that do not meet the values established in the WHO (World Health Organization) guideline Directives for air quality (Ministerio de la Presidencia, Relaciones con las Cortes y Memoria Democrática, 2022).

5. Database

This section describes the process behind selecting variables that illustrate the situation of the cities studied in regard to implementing LEZs, as well as constructing the database associated with those variables. The period of study considered spans the years 2018, 2019, 2021 and 2022. The reason for not considering 2020 is the noteworthy drop in mobility as a result of measures to combat COVID-19 (Monzón et al., 2021), although an increase in the level of mobility was registered the following year (Monzón et al., 2022).

Initially, in view of the literature, 28 variables were considered. These variables were related to: meteorology (atmospheric pressure, temperature, humidity, wind and precipitation), the physical characteristics of the city (altitude, surface area, land uses, fragmentation of residential areas), mobility (modal share between public and private transport, congestion), socioeconomic traits (population, population over 65 years of age, mean age, unemployment rate, motorization index, antiquity of the vehicle park, number of drivers) and data regarding contamination (atmospheric and acoustic). Then, as database elaboration proceeded, due to the limited availability of data on the selected variables for the period of study and/or for the cities analyzed, and the high correlation existing between some variables, a database including 11 variables for 61 cities was derived. This procedure is described below.

Specifically, the consideration of atmospheric contamination indicators PM_{10} and NO_2 (initially O_3, SO_2, and $PM_{2,5}$ were also taken into account) is justified not only by the availability of data —limited for other indicators and certain cities— but also by the fact that road transport generates in Spain 7.3% of emissions in PM, and 30.6% of NO_x emissions, percentages that rise substantially in urban zones. For example, in the Zone of Special Protection of the 40 municipalities of greater Barcelona, road traffic causes 52% of total emissions of NO_x and of PM_{10} particles (Ministerio para la Transición Ecológica y el Reto Demográfico, 2021b).

Concerning meteorological variables, we considered wind and precipitation. Aside from being included in studies of reference (temperature in Tan et al., 2023 and Cárdenas, 2016; wind in Li et al., 2019), they were the least correlated of their type. For similar reasons we included altitude, which is considered in the studies by Cárdenas et al. (2016) and de Barrera et al. (2018).

As for the socioeconomic traits of the cities, we included population, with the understanding made manifest in the report by Ricci et al. (2017) for the European Commission: the measures to be included in a LEZ may vary in function of the characteristics of each city. Thus, the population of every city may constitute a basic characteristic for the selection of actions to be included in a LEZ, depending on the number of inhabitants. At the same time, the impact of atmospheric contamination increases as the population settles in places of substantial emissions (Cárdenas et al., 2016; Han et al., 2018; Qiu et al., 2019), so that the population density could reflect this phenomenon. The proportion of elderly people was taken into account for two reasons. Firstly, because it may influence mobility within the city, hence the generation of traffic-related contaminants. For instance, Cubells et al. (2020) found that in the metropolitan area of Barcelona, the use of a private vehicle was much lesser among persons over 65. Secondly, the elderly conform one of the collectives most affected by atmospheric pollution in terms of its impact on health. A main health problem stemming from air pollution is the incidence of cardiac disease, particularly in persons over 65 years of age (Margayan, 2021). Moreover, when contemplating the implementation of a LEZ in a given city, the proportion of elderly inhabitants should be taken into account when designing actions that will affect the mobility of the population; it is clearly necessary to guarantee access for this vulnerable collective. The unemployment rate was likewise held to be relevant for this study, being an important indicator of economic activity. Further, a greater unemployment rate has been related with lower levels of mobility (Hadam et al. 2023), in turn closely linked to the level of contamination.

In addition, we accounted for the vehicle park. Vehicles of internal combustion are known to generate most contaminating emissions, and in Spain, 97.6% are vehicles of this type (DGT, 2023). The vehicle park also contributes to significant problems in cities such as congestion, the occupation of public space, and accidents. Between 2013 and 2021, the number of accidents with victims in Spanish cities reportedly rose 11% (Monzón et al., 2022).

Table 1 offers the main statistics of the available variables, for their subsequent analysis.

	min	**max**	**mean**	**median**	**sd**	**Source**
Altitude (m)	0.0	865.0	248.4	130.0	274.05	INE (2022)
Density of population (inhab./km²)	3,649	28,638	12,393	12,470	5,367.73	INE (2022)
Index of motorization (veh. /1,000 inhab.)	0.475	0.867	0.676	0.685	0.077	DGT (2023)
Accidents (per 1,000 inhab.)	0.044	4.58	1.477	1.284	1.001	DGT (2023)
Population (inhab.)	51,291	792,175	193,686	142,994	158,366.2	INE (2023)
Population over age 65 (%)	11.15	28.53	20.48	19.86	3.759	INE (2023)
Rate of unemployment (%)	6.01	25.67	15.38	14.12	4.526	INE (2023)
PM_{10} (µg/m³, annual mean)	12.50	33.75	21.15	20.88	4.894	Informe de Calidad del Aire (2022)
NO_2 (µg/m³, annual mean)	6.50	34.50	19.70	20.00	7.478	Informe de Calidad del Aire (2022)
Wind (km/h, annual mean)	12.11	23.06	18.10	18.22	2.253	NASA (2023)
Precipitation (mm, anual total)	132.0	1385.5	622.3	512.5	325.716	NASA (2023)

Table 1: Statistics of the selected variables.

6. Methodology

The study is developed in four stages:

1) According to literature, the variables related to the negative impacts of transport in cities were selected, to identify the factors that may influence the initial situation of the cities where it is intended to implement a LEZ (descriptive variables related to pollution, accidents, geophysical and meteorological characteristics, etc.).

2) Selection of further variables that reflect other characteristics of the city to be taken into account when implementing a LEZ (demographic, socioeconomic, etc.).

3) Database development for the selected variables (data were gathered for 11 variables and 61 cities).

4) Identification of groups of cities with similar characteristics according to the selected variables, through cluster analysis. Below this aspect of the methodology is explained in more detail.

To carry out the analysis, free software R was used. First, a database was generated for each year of study, with all the variables and cities. For data processing, the mean of the four years for each variable and municipality was taken.

With the selected variables, groups of cities having similar characteristics were constructed. To this end, the algorithm CLARA (Kaufman and Rousseeuw, 1990) was used. It is an extension of PAM (Partitioning Around Medoids), a means of dealing with data sets of great dimensions. By partitioning around the medoids —instead of the centroids, as is habitually done in the k-means method— one is sure to obtain, for each group, a "central" representative city. Moreover, using the medians instead of the means is adequate for asymmetric variables (like those of the datasets), most of which have a positive asymmetry. In order to determine the number of groups to be retained, the silhouette coefficient is calculated. This coefficient measures the cohesion that exists among the members of each group (the closer to 1, the more appropriate the grouping made).

Finally, the list of cities pertaining to each group is obtained, and the variables that best characterize a group in terms of the medians for each are identified. In addition, to more clearly see how the variables influence the definition of each group, boxplots are represented (by groups) for every variable. This underscores the median of each group, how the data are distributed by groups and variables, the isolated points presented, and which variables are more significant for describing each group.

7. Discussion of results

This section offers a description of the groups of cities, highlighting their most representative and differential characteristics. Bearing them in mind, some general guidelines for initial planning of the LEZs for each group will be proposed.

After calculating the silhouette coefficient, it is found that the highest one corresponds to k=8 (Figure 1), meaning that 8 groups of cities will be considered, their medoids (most representative cities of each group) being Huelva, Manresa, Valencia, Oviedo, Mérida, Leganés, Palencia and Santiago de Compostela.

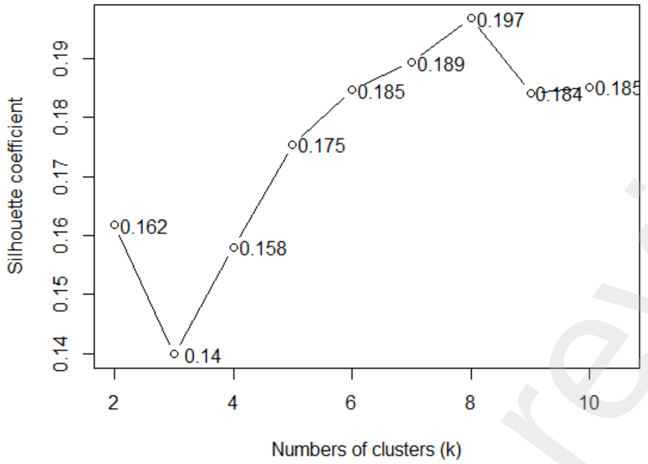

Figure 1: Silhouette coefficient according to the number of clusters.

Then, the lists of cities pertaining to each one of the groups are obtained, as well as the euclidean distance of each city to the medoid of the group. The distance is indicated in parentheses, and indicates the similarity of each city to the representative city of each group (the further away, the less similarity):

- Group 1: Huelva (0); Alcalá de Guadaira (1.704); Telde (1.96); Cartagena (2.232); Elx (2.282); Alicante (2.434); Córdoba (2.471); Almería (2.613); Las Palmas de Gran Canaria (3.005); Arrecife (3.029); Cádiz (3.224).
- Group 2: Manresa (0); Lleida (1.753); Granollers (1.915); Logroño (1.931); Sabadell (2.106); Terrassa (2.409); Rubí (2.651); Mataró (2.68); Sant Cugat del Valles (2.924); Girona (3.725); Granada (3.824).
- Group 3: Valencia (0); Zaragoza (3.232); Málaga (3.263); Sevilla (3.462); Palma (4.16).
- Group 4: Oviedo (0); Santander (1.971); Avilés (2.63); Gijón (2.679); Barakaldo (2.8); Santa Coloma De Gramenet (2.893); L'Hospitalet de Llobregat (3.199); Torrelavega (3.757).
- Group 5: Mérida (0); Cáceres (1.492); Gandía (2.049); Torrevieja (2.307); Sta Cruz de Tenerife (2.778); Castellón (3.036).
- Group 6: Leganés (0); Getafe (1.092); Coslada (1.95); Alcalá de Henares (2.003); Valladolid (2.533); León (2.543).
- Group 7: Palencia (0); Zamora (1.31); Burgos (1.902); Alcoi (2.069); Salamanca (2.213).
- Group 8: Santiago de Compostela (0); Pontevedra (1.349); Lugo (2.212); Pamplona (2.47); Ourense (2.564); Vigo (2.714); Vitoria-Gasteiz (2.719); Ferrol (2.749).

Then, the boxplots corresponding to each variable were depicted. These diagrams illustrate how the data of each variable in each group behave. Accordingly, one sees which variables best identify a grouping or make it stand out from the rest, which serves to characterize each city group in terms of its transport-related problems and particular traits. Because 11 diagrams were made (one for each variable), they are included as an Annex. For illustrative purposes, however, one boxplot—corresponding to the variable precipitation— is shown in Figure 2. Group 8 is noteworthy in that it attains much higher values for precipitation than the rest, while Group 4 reaches higher values than the other groups (excepting Group 8). Therefore, Groups 4 and 8 are characterized by a high precipitation index (very high in the case of Group 8). Meanwhile, Group 1 shows lower values than the remainder, meaning this group comprises cities with a dry climate. Finally, Groups 2, 3, 5, 6, and 7 contain intermediate precipitation values (except isolated values), meaning this variable does not allow one to identify them according to this variable.

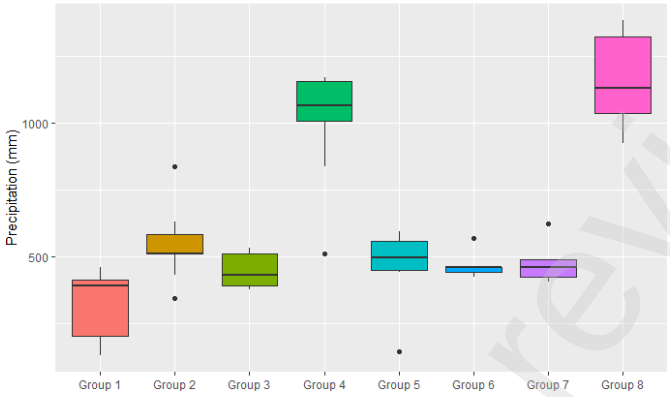

Figure 2: Boxplot for the variable precipitation.

Aiming to concisely present the results obtained in the boxplots, and facilitate the extraction of conclusions, in Table 2 '(++)' is used to indicate the groups whose interquartile values are higher than those of the other groups for a given variable. In the event that another group attains higher interquartile values than the rest –but lower than the group marked '(++)', the symbol '(+)' is used. The opposite situations (that is, groups with lower values) are indicated by (-) and (--).

In this way, when we state that a group attains higher interquartile values, it implies that the individual values within that group for that particular variable are higher than in the other groups (excepting atypical values). Likewise, when we say that a group harvests lower interquartile values, it means that the individual values within that group for that variable are lesser than in the other groups (with the exception of atypical values). For example, in Figure 2, Group 8 is represented by the sign (++), Group 4 by (+) and Group 1 by (--).

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
Altitude						+	++	
Density of population			++		--			
Index of motorization				--	++			
Accidents			++					
Population			++					
Population over age 65	--			+	-		++	
Rate of unemployment	++				+			--
PM_{10}	++				--		-	
NO_2					-	++	--	
Wind				++			+	--
Precipitation	--			+				++

Note: (++) indicates groups with interquartile values higher than the rest for a given variable. (+) indicates a group with high interquartile values, but lesser than those of the group marked (++). Likewise for (--) and (-), but with lower values.

Table 2: Groups description through the selected variables.

In light of the results displayed in Table 2, the main characteristics of each group can be summed up:

- Group 1: it adopts much higher values than the other groups for: unemployment rate and fine particulate matter; whereas the values are much lower for: percentage of population over 65 and precipitation.
- Group 2: does not stand out for any variable (neither above or below the other groups).
- Group 3: it exhibits the highest values for accidents, population density, and population.
- Group 4: contains much higher values than the others for the variable wind, higher values for population over 65 and precipitation, and much lower values than the rest for the index of motorization.
- Group 5: has much higher values for the index of motorization, and higher values for unemployment rate. At the same time, it has much lower values for the variables population density and particle contamination. Its values for population over 65 and nitrogen dioxide contamination are lower than for the rest of the groups.
- Group 6: shows much higher values than the rest for nitrogen dioxide, and higher ones for altitude.
- Group 7: has much higher values than the other groups for altitude and population over 65, while the values are higher regarding wind. In turn, the values are much lower for nitrogen dioxide, and somewhat lower for particles.
- Group 8: it is characterized by adopting the highest values in precipitations and the lowest values in unemployment and wind.

Bearing in mind the results expounded in Table 2, and the objectives mentioned in section 1, a series of prioritary directives may be traced, factors to be accounted for when planning a LEZ for the cities in each group:

- Group 1: this group is clearly identified by its socioeconomic characteristics (very high unemployment and very low percentage of elderly inhabitants) and contamination (very high in PM, made worse by the scarce precipitation). Therefore, regarding measures to be taken into consideration for the LEZ of the cities in this group we may underline:
  a) While it is not an intrinsic objective of the LEZ, some basic actions often included have demonstrated a positive effect on the economic activity, and might therefore

help mitigate unemployment. The study Clean Cities (2021), regarding the impact of LEZs on the retail sector in several European cities, concludes that measures promoting public transport and active mobility (i.e. reallocate public space for walking and cycling projects) can favor retail sales and reduce retail vacancy (the number of empty shops). Thus, concrete measures such as pedestrian streets, wider sidewalks, and urban bike lanes might contribute to this goal and should be considered for this group of cities.

  b) Development of actions aimed especially toward the younger population, since it is a vulnerable segment of the population in Spain: the highest unemployment rate (27.6% of the unemployed are between 16 and 29 years old, INE, 2023). For example, positive discrimination in public transport (cheaper fare for youth).
  c) Emphasis on the modal shift toward more sustainable transport modes (improving public transport and promoting active mobility, electric mobility and shared mobility).
  d) Implementation of severe restrictions to access for highly contaminating vehicles. Such restrictions should be particularly sharp for diesel vehicles, being the ones that emit most PM. In turn, policy-makers might consider the possibility of implanting measures to facilitate the transition to less contaminating vehicles (subventions for the purchase of vehicles or for the installation of particle filters, fiscal incentives, etc.). Bearing in mind the high level of unemployment and the contamination by PM in this group of cities, the latter action should be designed to renovate the vehicle park involved in the urban transport of merchandise —made up mainly of diesel vehicles— without negatively affecting the economic activity, generating more unemployment.

- Group 2: as the variables considered do not highlight any identifying characteristic, no prioritary directives for the design of LEZs in the cities of this group can be put forth.
- Group 3: it includes the larger cities of study (population over 400,000), which additionally show the greatest values in density of population and in accidents. Therefore, even though this group does not have the highest levels of contamination, fighting against it should be a priority when planning a LEZ among these cities (for example, through vehicle access restrictions, since the exposed population is very large and densely concentrated as well, compounding the impact of pollution). Meanwhile, the greater population density could heighten the potential for conflict between persons and vehicles over the use of public space. The reorganization of public space (to create pedestrian streets, wider sidewalks, etc.) should therefore be another priority to be contemplated for this group. The fact that this group contains the largest cities included in the study sample, implies greater complexity regarding the measures to be implemented (more advanced controlled access, discrimination in vehicle access depending on their levels of contamination, establishing different LEZs depending on the neighborhood or the ground use, etc.). Lastly, to reduce the high index of accidents occurring in these cities, the LEZ should include measures intended to help diminish the number of vehicles having access, plus measures of "traffic calming".
- Group 4: contains much higher values than the remaining groups for wind, and higher for the variables elderly population (over 65) and precipitation; the values are much lower, however, for the index of motorization. Because this group shows characteristics that help reduce the atmospheric pollution (strong winds, abundant rainfall, and a lower level of motorization), the measures intended to alleviate contamination could be somewhat slighter (for example, more lenient restrictions for vehicle access). Something to be taken into account when planning LEZs for the cities of Group 4 is the high proportion of elderly inhabitants. The measures proposed would have to guarantee the mobility of this vulnerable collective (pedestrian streets, wider sidewalks, traffic calming

measures, adaptation of public transport to their accessibility needs, reduced fares for public transport, etc.).

- Group 5: like Group 4, this group is remarkable insofar as the much lower potential impact of contamination (owing to the low levels of contamination, low level of exposure, and lesser percentage of elderly inhabitants). Planning the LEZ should take into account this favorable starting situation. In other aspects, this group resembles the profile of Group 1, though less pronounced: young population, and high unemployment. The corresponding LEZ would need to be planned accordingly, taking into account measures related with public transport, active mobility, and youth, as mentioned for Group 1. Yet because this group presents the highest index of motorization of all the realm of study (possibly implying problems of congestion and occupancy in the urban space), the measures most needed would have to aim toward diminishing the space dedicated to private vehicles, preferably granted to more sustainable modes of transport (bus lanes, more space for active mobility, etc.). Indeed, actions like the ones proposed for this group have proven to help discourage car ownership, thereby reducing the motorization index (González et al., 2021).
- Group 6: it has exceptionally high values for nitrogen dioxide, and high ones for city altitude. For this group, strong restrictions should be implanted to impede the access of highly contaminating vehicles, and gradually contemplate the establishment of transitional measures to welcome less contaminating vehicle (subventions and/or fiscal incentives for the purchase of vehicles, subventions for installing particle filters, etc.).
- Group 7: given the low levels of contamination observed for this group, any LEZ to be implemented would not be very restrictive; still, one key aspect in the design of the LEZ for this group is the guaranteed mobility of elderly persons.
- Group 8: showing the highest values for precipitation and the lowest ones for unemployment and wind speed, the results of this group (with reference to meteorological characteristics and low unemployment) do not point to any particular priority when designing LEZ for local implantation.

Table 3 displays, in summarized fashion, the characteristics of each group with the corresponding policy guidelines recommended.

GROUP	Characteristics	Priority guidelines for LEZ implementation
1	Unemployment (++) PM10 (++) Population over 65 (--) Precipitation (--)	Promote public transport. Promote active mobility. Reduce the public space for private vehicles. Promote modal change toward sustainable transport modes, above all in view of younger inhabitants. Strong vehicle access restrictions. Measures to facilitate the transition toward less contaminating vehicles, above all for merchandise vehicles.
2	*	*
3	Population (++) Population density (++) Traffic crashes (++)	Vehicle access restrictions. Reduce public space for private vehicles. More complex LEZ. Traffic calming.
4	Motorization index (--) Population over 65 (+) Wind (++) Precipitation (+)	LEZ planning that guarantees the mobility of the elderly. Reduce public space for private vehicles. Traffic calming.
5	Population density (--) Motorization index (++) Population over 65 (-) Unemployment (+) PM10 (--) NO_2 (-)	Promote public transport. Promote active mobility. Facilitate sustainable mobility of younger inhabitants. Reduce public space for private vehicles
6	Altitude (+) NO_2 (++)	Strong vehicle access restrictions. Measures to facilitate the transition toward less contaminating vehicles.
7	Altitude (++) Population over 65 (++) PM10 (-) NO_2 (--) Wind (+)	LEZ planned to ensure the mobility of the elderly.
8	Unemployment (--) Wind (--) Precipitation (++)	*

Note: (++) indicates groups with interquartile values for a given variable that are higher than for the rest. (+) indicates a group with high interquartile values, but lower than those of the group marked (++). The same goes for (--) and (-), but with lower values.

** indicates that the group does not stand out in terms of any variable and/or that, in view of the results obtained, no priority guidelines can be formulated.*

Table 3. Summary of the characteristics of the cities of each group, and of the prioritary recommendations for planning the LEZ.

8. Conclusions

In this study, certain variables that describe cities, along with others that might influence the negative impacts of transport in cities, were selected. Next, through cluster analysis, eight groups of similar cities within the scope of study (Spanish medium-sized and small cities) were defined. This classification was finally taken into account to propose common priority guidelines and specific measures and actions for LEZ implementation in the cities of each group. As practical implications, since a particular city may identify with one particular group, the results of this study can be considered, at an early stage of planning, as an aid for decision-making in cities that are in the process of implementing a LEZ, thus contributing to the achievement of more efficient LEZ initiatives.

In acknowledging the limitations of the present study, it is important to again stress that, in any case, when a LEZ is about to be implemented, it is necessary to analyze the given city in detail. The priorities recommended here are only an initial step to identify the specific measures to be implemented, in view of some basic or general characteristics.

In further research efforts, it would be necessary to explore in greater detail the cities (i.e. including more variables, performing a differential analysis in diverse zones of the city, etc.), in order to propose more concrete and adjusted actions when developing a LEZ suited for each. This would be particularly necessary for those city groups that did not stand out in terms of any specific variable, or whose distinctive variables were insufficient for orienting the design of a LEZ.

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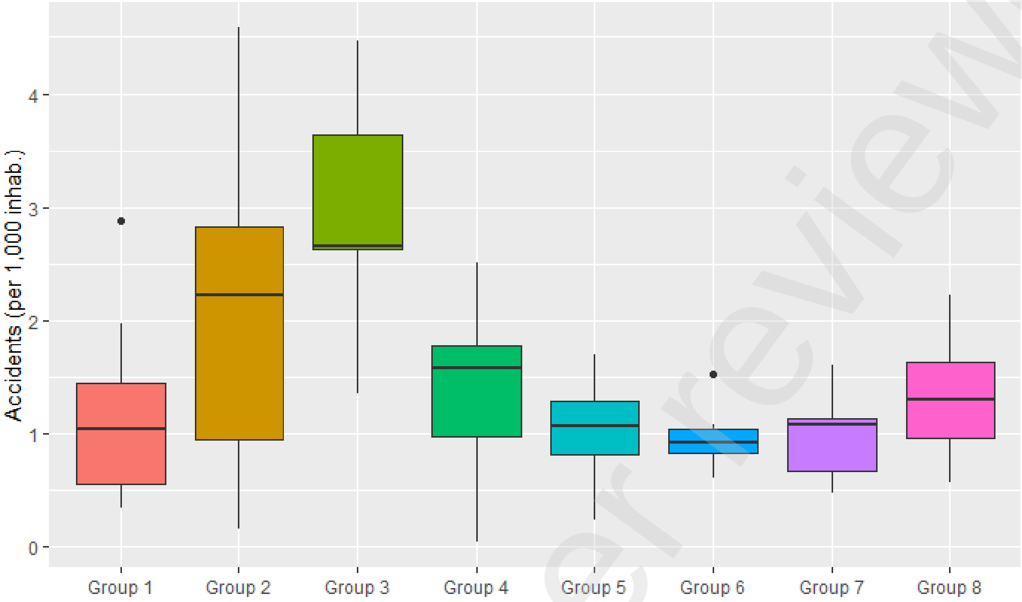
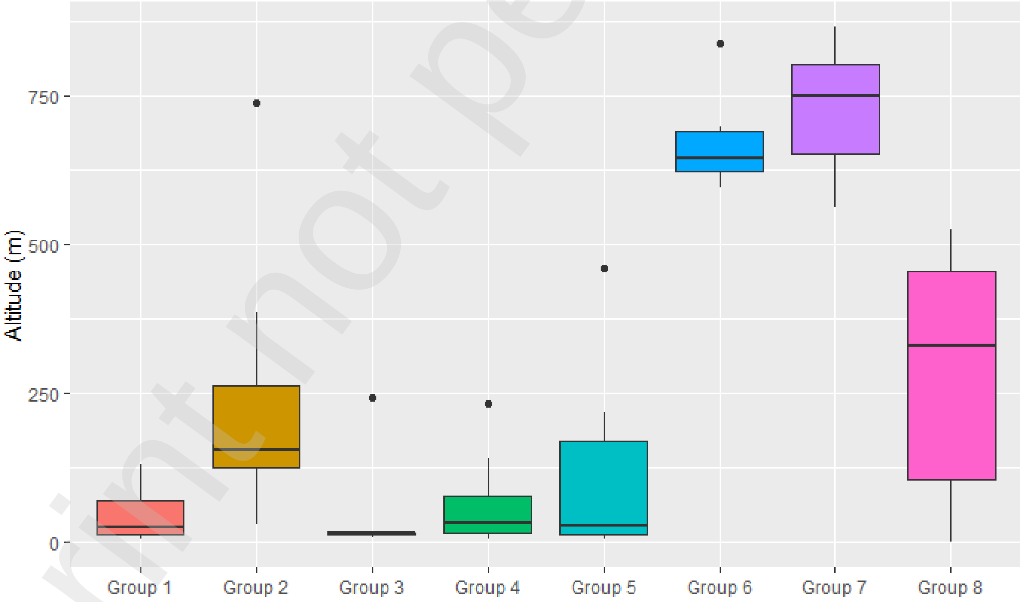
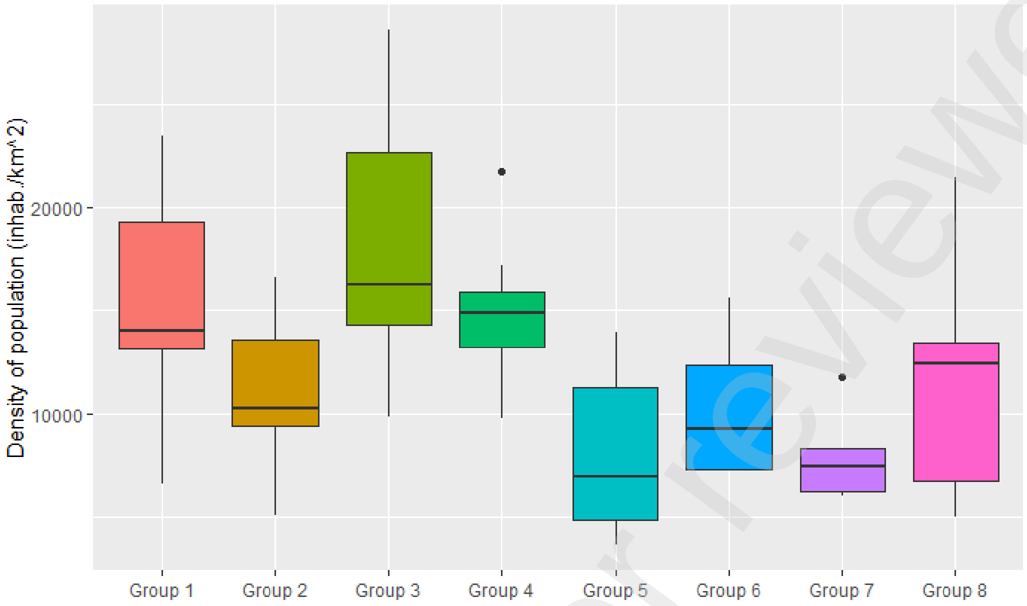
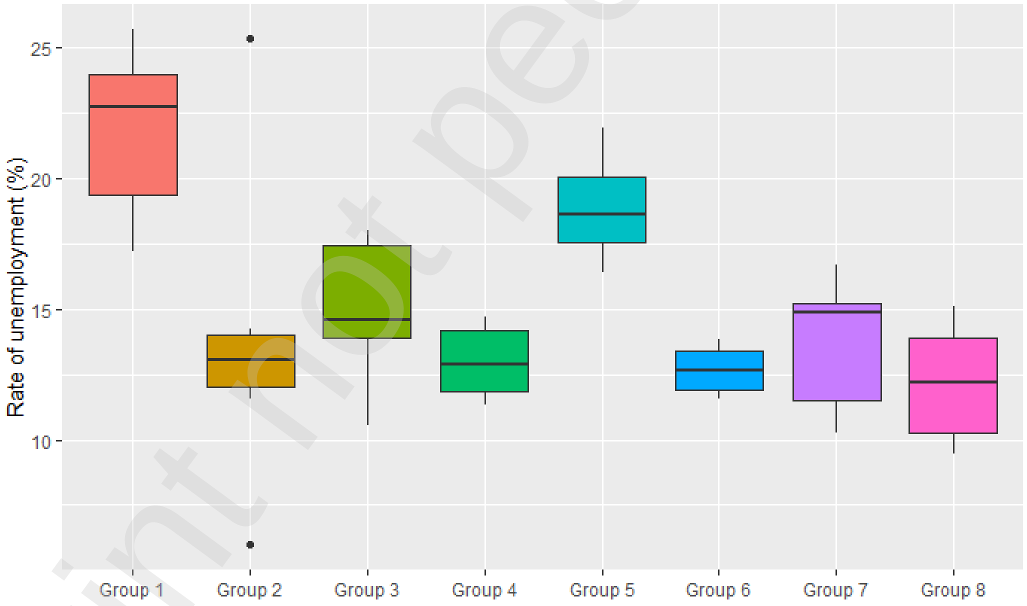
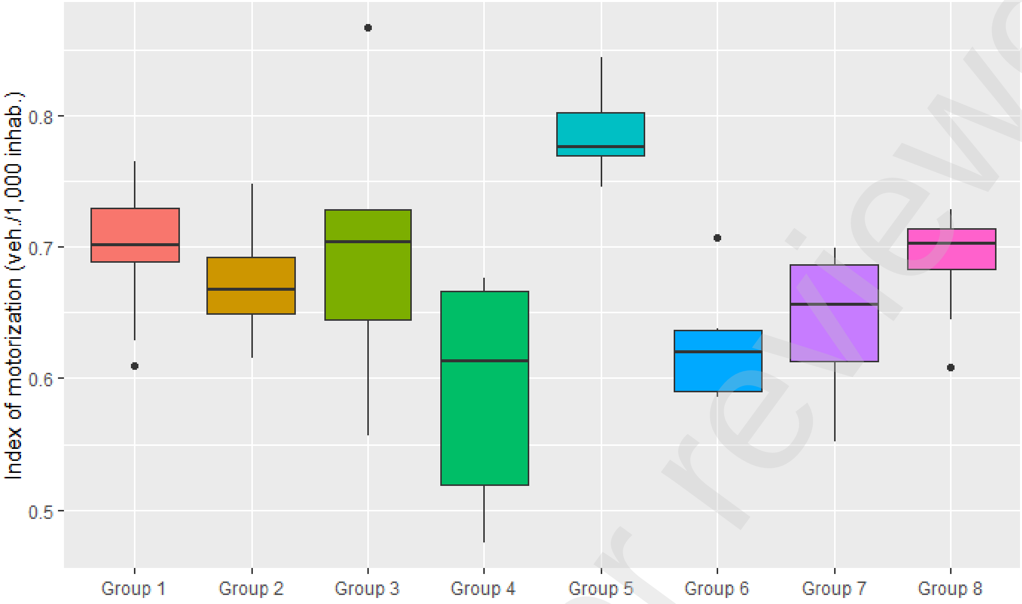
Annex

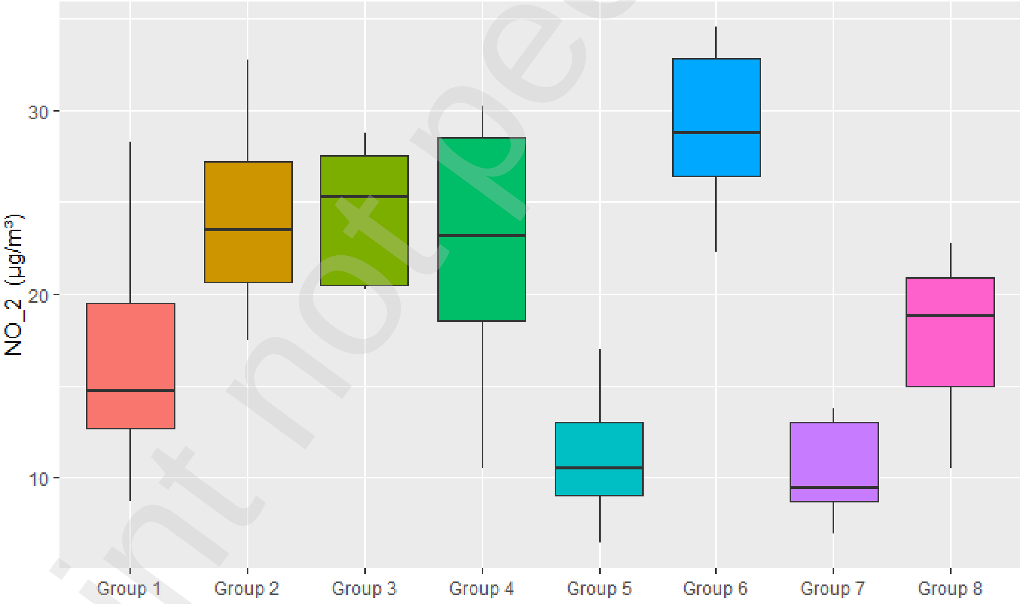

Accidents (per 1,000 inhab.)
0
1
2
3
4
Group 1
Group 2
Group 3
Group 4
Group 5
Group 6
Group 7
Group 8

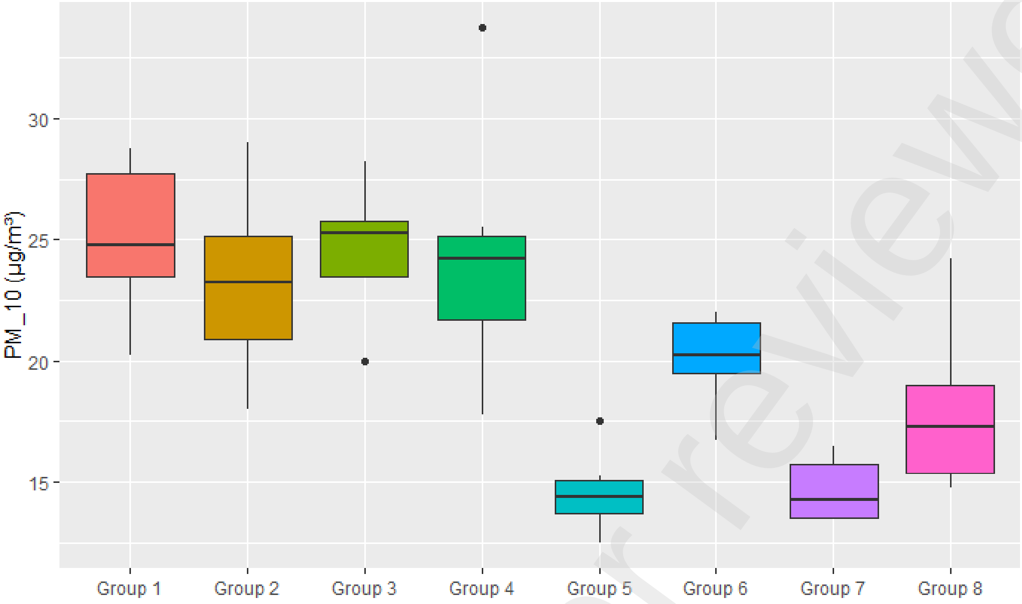

Altitude (m)
0
250
500
750
Group 1
Group 2
Group 3
Group 4
Group 5
Group 6
Group 7
Group 8

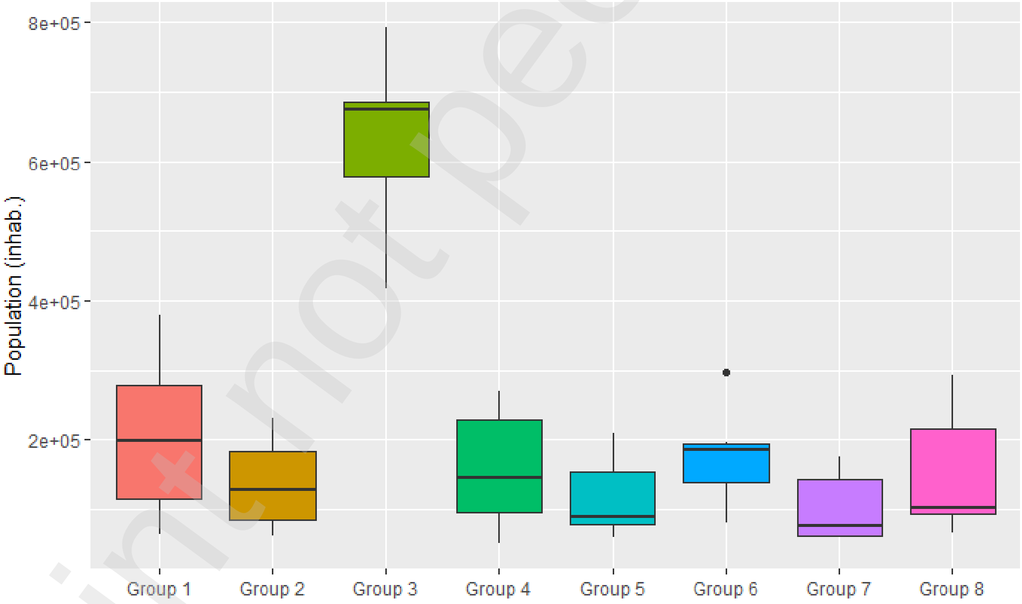

Density of population (inhab./km^2)
20000
10000
Group 1
Group 2
Group 3
Group 4
Group 5
Group 6
Group 7
Group 8

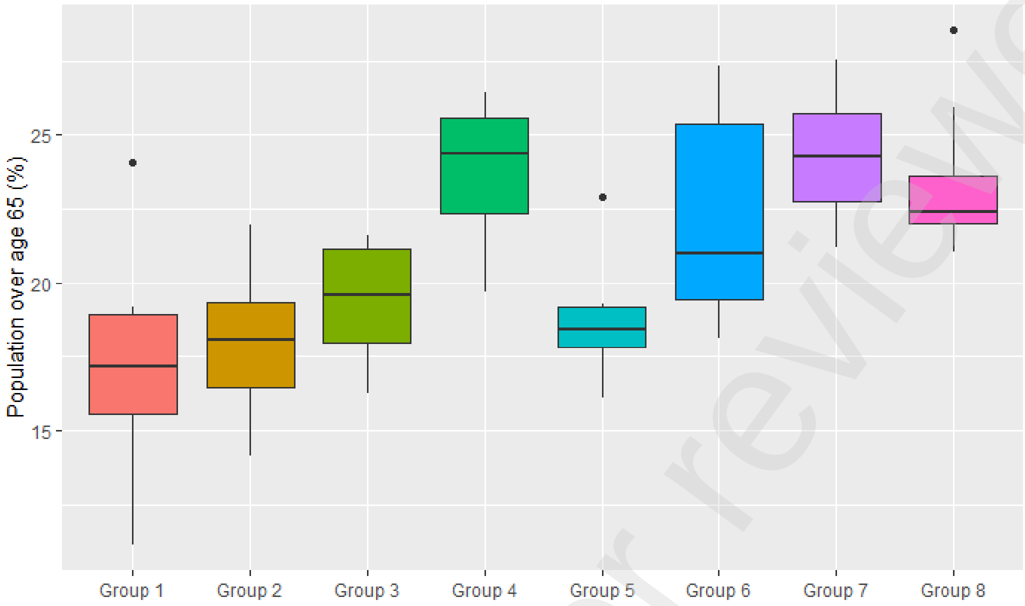

Rate of unemployment (%)
25
20
15
10
Group 1
Group 2
Group 3
Group 4
Group 5
Group 6
Group 7
Group 8

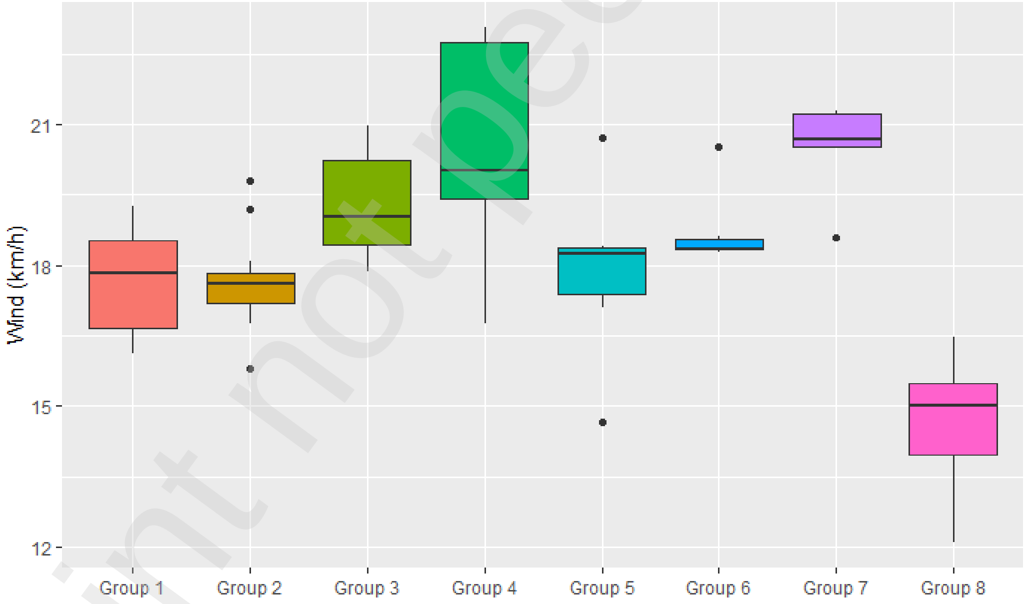

Index of motorization (veh./1,000 inhab.)
0.8
0.7
0.6
0.5
Group 1
Group 2
Group 3
Group 4
Group 5
Group 6
Group 7
Group 8


NO_2 (µg/m³)
30
20
10
Group 1
Group 2
Group 3
Group 4
Group 5
Group 6
Group 7
Group 8


PM_10 (µg/m³)
30
25
20
15
Group 1
Group 2
Group 3
Group 4
Group 5
Group 6
Group 7
Group 8


Population (inhab.)
8e+05
6e+05
4e+05
2e+05
Group 1
Group 2
Group 3
Group 4
Group 5
Group 6
Group 7
Group 8


Population over age 65 (%)
25
20
15
Group 1
Group 2
Group 3
Group 4
Group 5
Group 6
Group 7
Group 8


Wind (km/h)
21
18
15
12
Group 1
Group 2
Group 3
Group 4
Group 5
Group 6
Group 7
Group 8

CLASSIFICATION OF MEDIUM AND SMALL CITIES FOR THE IMPLEMENTATION OF LOW EMISSION ZONES

Francisco Calvo-Poyo

Corresponding author. TRYSE Research Group. Department of Civil Engineering, University of Granada, E.T.S.I. Caminos, Canales y Puertos, c/ Severo Ochoa, s/n, 18071. Granada (Spain), Phone: +34 958 24 94 52, fjcalvo@ugr.es

Pilar Astorga-Ramos

TRYSE Research Group. Department of Civil Engineering, University of Granada, E.T.S.I. Caminos, Canales y Puertos, c/ Severo Ochoa, s/n, 18071. Granada (Spain), pilarastorga@ugr.es

Juan de Oña

TRYSE Research Group. Department of Civil Engineering, University of Granada, E.T.S.I. Caminos, Canales y Puertos, c/ Severo Ochoa, s/n, 18071. Granada (Spain), jdona@ugr.es

Ramón Ferri-García

Department of Statistic and Operational Research, University of Granada, Faculty of Sciences, Avenida de la Fuente Nueva, s/n, 18071. Granada (Spain), rferri@ugr.es