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RESEARCH ARTICLE
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Analysis of Factors Driving the Acceptability of a Low Emission Zone

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Abstract:

Background: In many cities worldwide, a Low Emission Zone has been introduced with the aim to improve livability of urban areas and foster sustainable mobility habits. However, a limited or absent public support has proven to hinder the implementation of such intervention or negatively impact its effectiveness.

Objective: This paper aims to understand factors prompting and hindering acceptability of a Low Emission Zone in a medium-sized city.

Methods: The study area was the city of Padova (Italy), where a potential future shift from the current limited traffic zone toward a Low Emission Zone was investigated. A mobility questionnaire administered to stakeholders of the intervention area. Data collected were used as input of an integrated set of statistical models. A factor analysis was implemented to highlight the underlying structure of respondents' opinion about the Low Emission Zone. A cluster analysis was used to define stakeholders' profiles, and an ordinal logit model was developed to identify factors affecting the support of the new regulation.

Results: Results pointed out profiles of both supporters and opposers to the measure. To effectively improve public support, potential benefits of the current Limited Traffic Zone and how the Low Emission Zone aims to enhance them could be highlighted. As expected, the highest opposition could stem from car users, who should be targeted with specific strategies to increase their acceptability level.

Conclusions: The analysis highlighted how policy makers and local authorities can foster the widest support of the new Low Emission Zone and thus broadening its potential benefits.

Keywords: Urban vehicle access regulations, Sustainable mobility, Pollutant emissions, Low emission zone, Transportation system externalities, Stakeholder engagement, Smart mobility.

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1. INTRODUCTION

Transportation systems can cause several negative externalities with severe social, economic, and environmental impacts [1]. One of these externalities is the production of pollutant emissions from vehicles, which contributes to worsen air quality. Recently, although a decrease in pollutant concentrations was observed in 2020 during COVID-19 lockdowns [2], the European Environment Agency reported that air pollution remains a major concern in many European countries [3]. The most severe problems are registered in urban areas, where many people live. For example, in 2021, in Europe, about 96% of the urban population was exposed to levels of particulate matter above the health-based threshold defined by the World Health Organization [3, 4]. Furthermore, all reporting countries registered both daily and annual nitrogen dioxide above the limits set by the World Health Organization [3].

To reduce pollutant concentrations in urban areas, many local authorities have proposed and applied several interventions and policies [5]. These measures aim to change the travel habits of users of a transportation system and are called Transportation Demand Management policies [6]. These can be grouped as coercive and supportive measures [5]. The former ones are those enforced to limit or avoid specific mobility behaviors [7], and the latter ones are interventions implemented to encourage some practices [8]. Coercive policies include congestion/emission charging [9, 10, 11, 12]: drivers are charged where and when the system is congested or a certain level of pollutants is reached [13]. This policy relies on the assumption that pricing negative externalities generated by vehicles could prompt travelers to purchase less polluting vehicles, adopt alternative travel modes, or use their vehicles less [14]. Other coercive measures are license plate restrictions, which limit the circulation of vehicles on specific days depending on plate numbers [15], and carbon taxation, which is an additional tax applied to fuels [16]. On the other hand, examples of supportive policies are public transportation improvement and the creation of cyclist and pedestrian infrastructures and areas [5].

Some of the interventions mentioned above were clustered as Urban Vehicle Access Regulations (UVAR), referring to measures regulating the access of vehicles to urban infrastructures [17]. The creation of a Low Emission Zone (LEZ) is one of the main UVARs. Following this policy, only vehicles that meet specific pollution standards are allowed to enter an area during predefined periods, with the aim of limiting the number of emission sources [8]. Low Emission Zones were first introduced in Sweden in the 1990s [18], and, nowadays, are widespread in many European cities [19], such as London [20], Berlin [21], Lisbon [22], Paris [23] and Madrid [24]. This measure is a coercive Transportation Demand Management policy, which differs from other interventions for two main reasons [8]. First, the main target of a LEZ is to reduce local concentrations of pollutants in a specific zone, rather than improving transportation system operation; however, this policy can improve the livability of urban areas, by providing citizens with healthy spaces, thus broadening the consequent potential benefits of the local measure. Second, it addresses the complexity of the air quality problem by applying restrictions depending on the vehicle emission levels, rather than to specific vehicle classes. A common regulatory framework has not been defined at the European level [25]. In particular, regulations are site-dependent, and they can vary depending on what restrictions are applied to (*e.g.* types of fuels, emission characteristics of vehicles), the size of the operating area (*e.g.* the whole city or a specific zone), the enforcement period (*e.g.* entire day, working hours) [26]. Previous authors highlighted that a LEZ can provide several benefits for society, citizens and the environment [27]. These positive effects include the reduction of traffic congestion and noise, the improvement of air quality, and the diffusion of sustainable travel habits [24, 28, 29].

Although several Transportation Demand Management policies often require limited investments, their effective implementation could be hindered by a lack of public support, in addition to technological and legal issues [15]. Indeed, in many cases [8, 18, 30], a very limited public acceptability has severely and negatively impacted the effectiveness of the measure, forced changes in it, or even prevented its application. Therefore, understanding the acceptability and acceptance of a Travel Demand Management strategy is of paramount importance to ensure that the measure can reach the targeted goals. Acceptability refers to opinions before the measure implementation, *i.e.* when travelers have not yet experienced the new intervention, and acceptance is related to the reactions after the measure implementation [15, 16].

In recent years, many authors have identified several factors that could affect both acceptability and acceptance of Transportation Demand Management policies [9]. In addition to traditional variables, such as travel behavior and socio-economic characteristics of users [30], these factors include socio-psychological factors such as perceived effectiveness of the measure [31], the balance between costs and benefits [15, 32], potential future negative impacts [13], perceived equity [7, 9], prior attitudes [18], value orientations [5], problem awareness [8, 16], political motives, and trust in the government [11].

In this paper, acceptability, as already said, is used to define the attitude or support toward the implementation of a policy [15], thus referring to the judgments before the measure enforcement. In particular, this research work is focused on Low Emission Zones. With the notable exceptions of Morton *et al*. [8] and Oltra *et al*. [18], the acceptability of this measure has not been addressed. In particular, the former authors [8] implemented a Structural Equation Model to investigate the psychological constructs that could influence LEZ acceptability in Scotland. The latter authors [18] used path analysis to understand factors determining the acceptability of the measure in Barcelona (Spain). Moreover, few works were focused on the relationship between acceptability and potential mobility behavioral changes. For instance, in a previous work, Ceccato *et al*. [33], the authors of the present work, carried out an ex-ante assessment of the potential effects of a new Low Emission Zone on mobility behaviors, and thus vehicle pollutant emissions, of stakeholders entering the regulated area; however, they did not analyze the factors that could drive these changes. Lastly, although factors affecting public support of a LEZ are site-specific [18], only interventions on large cities were previously considered.

This work can be considered as a next step of the research work performed by the authors in [33], where acceptability was one of the exogenous variables included in the developed forecasting models. In particular, the previous work highlighted the need for a specific and detailed analysis of the causes of acceptability of the considered Low Emission Zone among stakeholders. In addition, the current analysis was developed in line with the purposes of the ReVeAL project (Regulating Vehicle Access for Improved Liveability), which aimed at analyzing and promoting the adoption of sustainable interventions in urban areas to improve the liveability of cities [34]. Therefore, the case study is the same of [33], nevertheless, the objective of this research work is to understand factors that prompt and hinder the acceptability of a LEZ in a medium-sized city. Specifically, this paper contributes to enrich the study of public support toward LEZ. This step is of paramount importance for two reasons: (1) assessing the ex-ante effectiveness of such a Vehicle Urban Access Regulation; and (2) properly designing an effective public engagement strategy with activities tailored on the characteristics and habits of involved stakeholders, in order to gain their support. For these reasons, the paper contributes to understanding the gap between the desired objectives of a LEZ that local authorities seek to reach, and the effectiveness of the measure. Specifically, the developed analysis can shed light on the drivers toward LEZ acceptance, which is considered as the first and essential step to ensure the achievement of its goals.

The paper is organized as follows. First, a description of the case study area and the new potential regulations (LEZ) is presented (Section 2.1). After that, the structure of the mobility survey used as input data for subsequent models is reported, as well as the characteristics of the targeted population (Section 2.2). In Section 2.3, the methodological approach is explained; in particular, the section includes a detailed description of the adopted methods and related input data. In the next section (Section 3), descriptive statistics of the survey respondents and the results of the applied models are presented. After that (Section 4), the previously reported findings are summarized, discussed, and compared with those obtained by other works on the topic. Lastly (Section 5), conclusions, future works, and limitations of the adopted approach are presented.

2. MATERIALS AND METHODS

2.1. Case Study

The study area is the one considered in a previous work of the same authors [33], *i.e.* the city of Padova, a medium-sized and high-density city located in north-eastern Italy.

Specific details about the current and future regulations for entering the central part of the city can be found in [33] and a brief description is reported hereinafter. Since 1989, a Limited Traffic Zone (LTZ) has been introduced in the historic city center [35], as shown in Fig. (**1**). Currently, access is allowed to specific types of vehicles and users, and during defined hours and days. Restrictions vary depending on the subzones where they are applied. Vehicles can enter the area by purchasing a permit, which can be permanent or temporary. Only specific user categories are entitled to the former type of access authorization; these include people living in the area, those owning a private parking lot, shopkeepers, people working in medical clinics and public administrative offices, those owning a hotel, journalists, and people with reduced mobility. Temporary permits can be requested for specific purposes (*e.g.*, loading/unloading of specific goods, escorting children in nursery and primary schools). In addition, specific restrictions are applied to freight vehicles, depending on their weight and fueling, during fixed time periods. Lastly, access is always allowed to vehicles of emergency departments, public transportation services, taxis, motorbikes and scooters, and shared and electric vehicles. Entries are monitored through automatic control gates installed on roads accessing the area, recording the license plate number of vehicles. The speed limit in the area is 30 km/h. From a traffic survey carried out in May 2021, about 1,460 motorbikes, 3,800 cars, 1,100 light, and medium duty vehicles, 10 heavy vehicles, and 1300 buses entering the area in a working day from 7:30 am to 7:30 pm were recorded.

A new Low Emission Zone could be implemented in the central part of the current Limited Traffic Zone, as depicted in Fig. (**1**). Unlike the current scheme, the new measure could regulate the access of vehicles depending on the fuel type and the emission standard of vehicles. Entry could be allowed to people living in the area, those with reduced mobility, and those working for emergency services. However, the access of other types of users could be authorized only if they travel on electric, CNG, LPG Bifuel, CNG Bifuel, Petrol Hybrid, or Diesel vehicles (only for freight vehicles) considering specific levels of EURO emission standard. Restrictions could be permanently applied, and both entries and exits could be monitored by an automatic number plate recognition system. Further details about the access regulation and enforcement measures are reported in [33].

2.2. Data Collection

In order to achieve the described objectives, a travel survey was administered to potential stakeholders of the new Low Emission Zone in the city. Details about the questions included in the questionnaire are reported in [33], however, a description of its structure is synthesized in this sub-section. In particular, the questionnaire consisted of three parts. In the first section, questions about opinions and travel habits related to the current situation were posed. The second part aimed to collect information on the future implementation of the Low Emission Zone, including the level of acceptability of the measure and opinions about its potential positive and negative impacts. The design of this section of the survey was based on an analysis of previous literature on the topic [5, 14, 18, 31, 36]. Lastly, a few questions related to the socio-economic characteristics of respondents were posed (*e.g.*, gender, age, car availability).

Fig. (1). Padova city center. Perimeter of the current Limited Traffic Zone (LTZ) and area of the potential future Low Emission Zone (LEZ).

The survey was administered online, sending individual invitation letters to potential stakeholders. To guarantee that the targeted people were actually those impacted by the new LEZ, potential participants living and/or working in the area were identified by the Municipality of Padova, who sent the survey link. In particular, 27 stakeholders representing people living in the area, and several social and economic activities were identified. Recipients were invited to share the reported link with their colleagues/employees to complete the survey. This approach aimed to reach the widest range of people that could be affected by the potential implementation of the new regulatory measure, thus contributing to create a sound input for the subsequent analysis. The questionnaire could be filled out from March to June 2022.

2.3. Adopted Methodological Framework

In order to obtain a comprehensive analysis of the factors that affect the acceptability of the new Low Emission Zone, an integrated analysis procedure based on three combined methods was developed and applied using data from the survey. The methodological framework is depicted in Fig. (**2**). Specifically, three statistical techniques were applied to achieve the following sub-targets, that contribute to reaching the global objective of the work. In particular, first, a factor analysis was implemented to identify potential correlation patterns among a subset of questions, thus highlighting a potential underlying structure of attitudes and opinions about the new LEZ [37, 38, 39]. Then, a cluster analysis was used to define profiles of stakeholders, considering their attitude toward the new measure [39, 40]. After that, due to the ordinal nature of answers related to the acceptability level of the LEZ, an ordinal logit model was developed to understand factors affecting the possible support of the new regulation [41, 42, 30]. In particular, the three methods were selected for the following reasons. The factor analysis could allow to create significant and synthesized latent factors describing perceived positive and negative impacts of the new LEZ. The clustering approach could lead to the identification and characterization of LEZ supporters and opposers. The ordinal logit model could highlight the causal relationship among the characteristics and opinions of stakeholders and their acceptability level toward the measure. The combined application of the three methods can provide an in-depth analysis of the drivers of LEZ acceptability, to understand how the measure can receive effective support from stakeholders.

2.3.1. Exploratory Factor Analysis

A factor analysis was applied with two main aims: to remove the potential multicollinearity issue among answers and to identify correlation patterns among variables. In this way, variables strongly correlated with each other can be grouped, thus allowing to define a smaller number of factors representing the latent constructs behind the original items [38, 43]. Factor analysis is a multivariate statistical technique that underlines the structure among the variables. The approach is defined as an interdependence technique, that uses the correlation matrix to create new composite measures representing related variables [38]. In this work, answers to questions reported in Table **1** were considered [33]. These include opinions about the current Limited Traffic Zone, as well as judgments about the characteristics and potential impacts of the new Low Emission Zone.

To verify whether factor analysis can be adopted, a partial correlation matrix, Bartlett's test of sphericity, and the Measure of Sampling Adequacy were applied [38]. The factor number was set considering eigenvalues, the results of a screen test, and the cumulative percentage of total variance extracted by the indicators. Factor loadings were estimated by testing both orthogonal and oblique rotation methods. In order to replace the initial set of variables with a new reduced set, summated scales were used. Among many alternative approaches estimating factor scores [44], the summated scale approach was adopted to facilitate factor interpretation and use in subsequent analysis. In particular, for each scale, the items with the highest loadings from the factor analysis were averaged, thus ensuring complete control over the calculation and providing easy replication across studies [38]. Furthermore, Cronbach's alpha was used to verify scale consistencies.

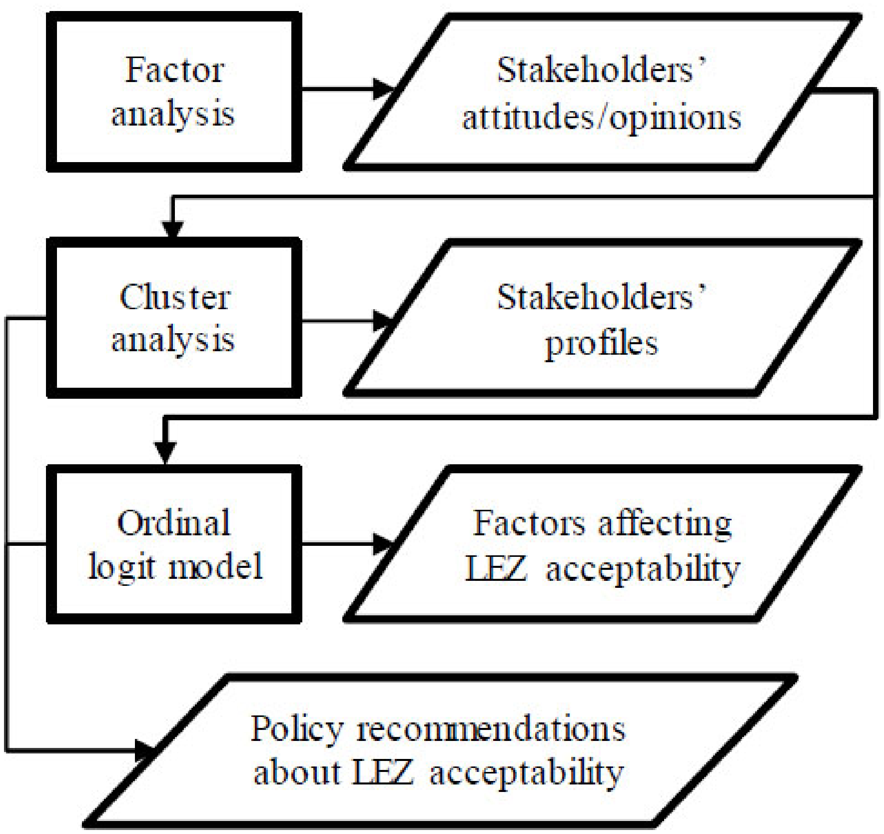

Fig. (2). Percentage distribution of access purpose for the adopted travel modes.

Table 1. Questions and related scales adopted in the factor analysis [33].

Question	Statement
Q1	*To what extent do you consider that the current Limited Traffic Zone can address the following needs? [From 1 = "Very ineffective" to 5 = "Very effective"]*
Q1_01	Air quality improvement
Q1_02	Reduction of circulating vehicles (independently of emitted pollutants)
Q1_03	Reduction of circulating vehicles (first considering the most pollutants vehicles)
Q1_04	Reduction of parked vehicles on streets
Q1_05	Extending pedestrian areas
Q2	*Considering the area of intervention, to what extend do you agree with the following statements? [From 1 = "Strongly disagree" to 5 = "Strongly agree"]*
Q2_01	Currently, travelling by car/motorbike in the area is easy
Q2_02	Currently, walking in the area is safe and pleasant
Q2_03	Currently, riding a bike in the area is safe and pleasant
Q2_04	The area of intervention is easily accessible by people with reduced mobility
Q2_05	There are many alternative travel modes to access the area beyond private car/motorbike
Q12	*To what extent do you agree with the following statements regarding the potential new regulation (new Low Emission Zone) in the area? [From 1 = "Strongly disagree" to 5 = "Strongly agree"]*
Q12_01	The implementation of the new regulation could impact my travel habits
Q12_04	The implementation of the new regulation could improve the quality of my life
Q12_05	The implementation of the new regulation could improve citizens' quality of life
Q12_06	The new regulation can effectively reduce air pollutants
Q12_07	The implementation of the new regulation could have a negative impact on the economic activities in the area
Q12_08	The implementation of the new regulation could increase traffic flows on the surrounding streets
Q12_09	The new measure is equitable
Q12_10	The new measure could support many people and disadvantage few others
Q12_11	The new measure could make the area more accessible by walking/bike
Q12_12	The new measure could make the area more accessible by car
Q12_13	The new measure could improve road safety of walking and bike trips in the area

2.3.2. Cluster Analysis

In order to identify the potential group of respondents sharing similar attributes in terms of individual characteristics, attitudes, and opinions toward the new Low Emission Zone, a cluster analysis was implemented. Among the available clustering approaches, agglomerative hierarchical cluster analysis was implemented [45]. The method iteratively applies a clustering algorithm that estimates the dissimilarities between clusters with multiple items, to create multiple clustering alternatives. The result of the technique is a dendrogram representing the combination of clusters for the full range of cluster solutions. The dendrogram highlights the obtained distances between elements so that different clustering solutions can be directly compared [38]. This method has been widely adopted in many previous research works [46].

The set of variables considered for the cluster analysis includes factors derived from the factor analysis and additional variables related to the characteristics of the respondents, as well as their opinions about the intervention and potential changes after the implementation of the measure. The set of these additional variables is reported in Table **2**. The variables were used to describe the characteristics of stakeholders' profiles identified by the cluster analysis. Significant statistical differences among attributes of individuals in the clusters were assessed by applying Chi-square tests and Mann-Whitney tests.

Table 2. Additional variables used in cluster analysis [33].

Name	Description	Type	Scale
Acceptability	Extent of acceptability of the new Low Emission Zone	Ordinal	From 1 = "Strongly disagree" to 5 = "Strongly agree"
Age	Age of the respondent	Metric	Years
Frequency	Frequency of access the area	Metric	Times per week
Gender	Gender of the respondent	Categorical	Female, Male
Purpose	Purpose to access the area	Categorical	Work, Shopping, Leisure
Travel mode	Travel mode most frequently adopted to reach the area	Categorical	Private car, Motorbike, Public transportation, Private bike, Walking

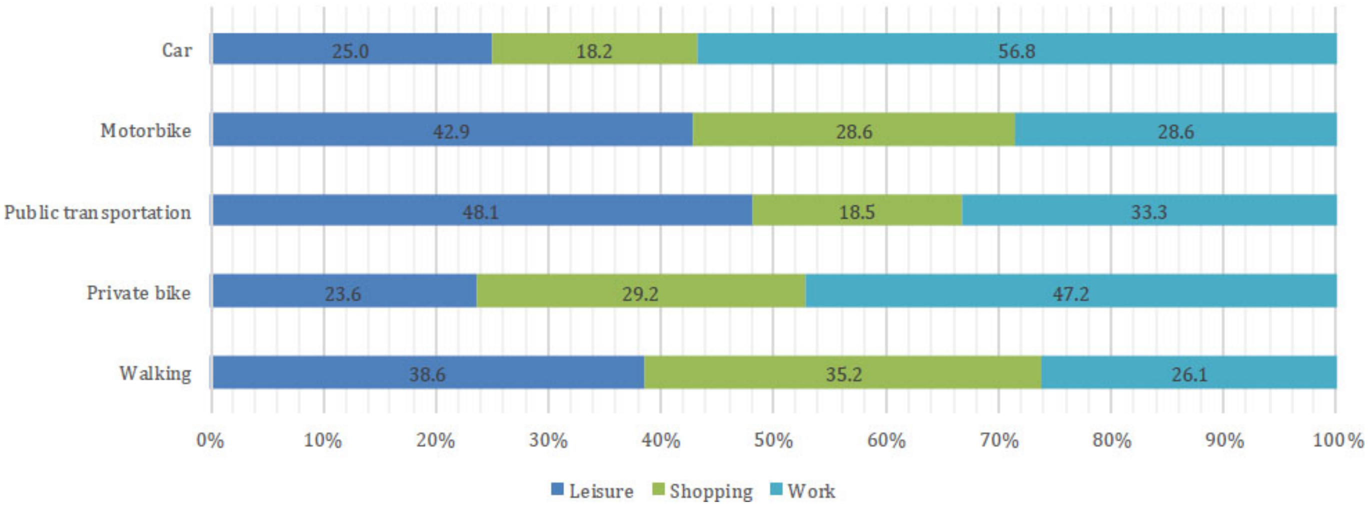

Fig. (3). Percentage distribution of gender of respondents.

2.3.3. Ordinal Logit Model

An ordinal logit model was implemented to understand factors affecting the acceptability level of the new Low Emission Zone. This approach explicitly takes into account the ordered nature of response variables. In particular, in order to predict the probability of the selection of each alternative, the model uses a logistic distribution of ordered choice options. Moreover, the approach assumes that the respondent's answer is based on the magnitude of the utility associated with the object of the question [47]. Unlike cluster analysis, which allowed the identification of significant profiles of stakeholders, the developed model aimed to analyze the causes of the level of acceptability, which measures the attitude of a stakeholder toward the new regulation. Answers to the question "To what extent do you accept the new Low Emission Zone" expressed using a 5-point Likert scale ranging from "Strongly disagree" to "Strongly agree" were considered as dependent variables. The indicators resulting from the factor analysis and the variables reported in Table **2** were included as explanatory variables Since the answers are ordered by definition, an ordinal logit model was adopted. A Brant test was used to assess the proportional odds assumption of the technique [48].

3. RESULTS

3.1. Descriptive Statistics of the Sample

In total, 509 people accessed the provided link, however, 245 participants completed the whole survey. The number of collected responses was similar to those adopted in previous works investigating the acceptability of LEZs and other UVARs [5, 7, 30, 49]. In addition, based on the data provided by the Municipality of Padova [50] and the Italian National Institute of Statistics [51], the universe of potential stakeholders of the new LEZ was estimated to be about 7,500 persons. Details about the estimation procedure are reported in [33]. The obtained sample size can be used for the subsequent analysis, considering a margin of error of 10% at a 90% confidence level [52].

The descriptive statistics of the sample of respondents are summarized in Figs. (**3**-**7**) and further details can be found in [33]. By observing the figures one can note that female participants represent about 60% of the total sample (Fig. **3**), and about 80% of the individuals are aged 40 to 64 years (Fig. **4**). Although this range is mainly related to working people, registered purposes to access the area are equally distributed, highlighting that the survey effectively targeted a wide range of stakeholders (Fig. **5**). With respect to the frequency of entering the area (Fig. **6**), different values were observed; moreover, the figure confirms that stakeholders actually affected by the LEZ were targeted, since the number of people reporting they never access the area is null. As regards the cross-relationship between travel modes to enter the area and access purposes, Fig. (**5**) shows that private car and bike are mainly adopted for work purposes. Concerning attitude toward the potential Low Emission Zone and its impacts (Fig. **7**), about 68% of respondents stated that they are willing to accept the new regulation, suggesting that the measure could be supported by many persons.

3.2. Exploratory Factor Analysis

A factor analysis was applied to highlight the underlying structure among the selected questions and to define synthetic indicators to reduce their original number. In order to evaluate the appropriateness of the model application, specific analyses and tests were carried out. In particular, the correlation matrix showed several cell values greater than 0.70; moreover, Bartlett's test was found to be significant (χ^2 = 2,159, *p*-value < 0.001) and the Measure of Sampling Adequacy (MSA) was greater than 0.7, thus highlighting that the method could generate representative factors [53]. The number of factors was set at 5, by analyzing eigenvalues, the results of the screen test, and the cumulative percentage of total variance extracted by factors. Table 3 reports factor loadings estimated by applying a cluster rotation method for which a cut-off value of 0.4 was considered [38]. For the sake of readiness, in the table, the questions were sorted and grouped depending on their loading and their assigned factor.

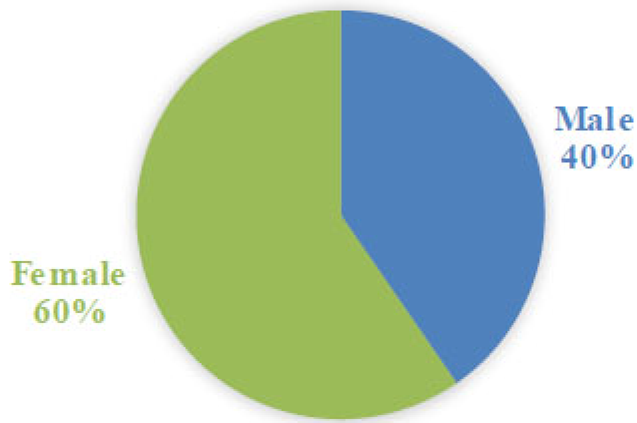

Fig. (4). Percentage distribution of age of respondents.

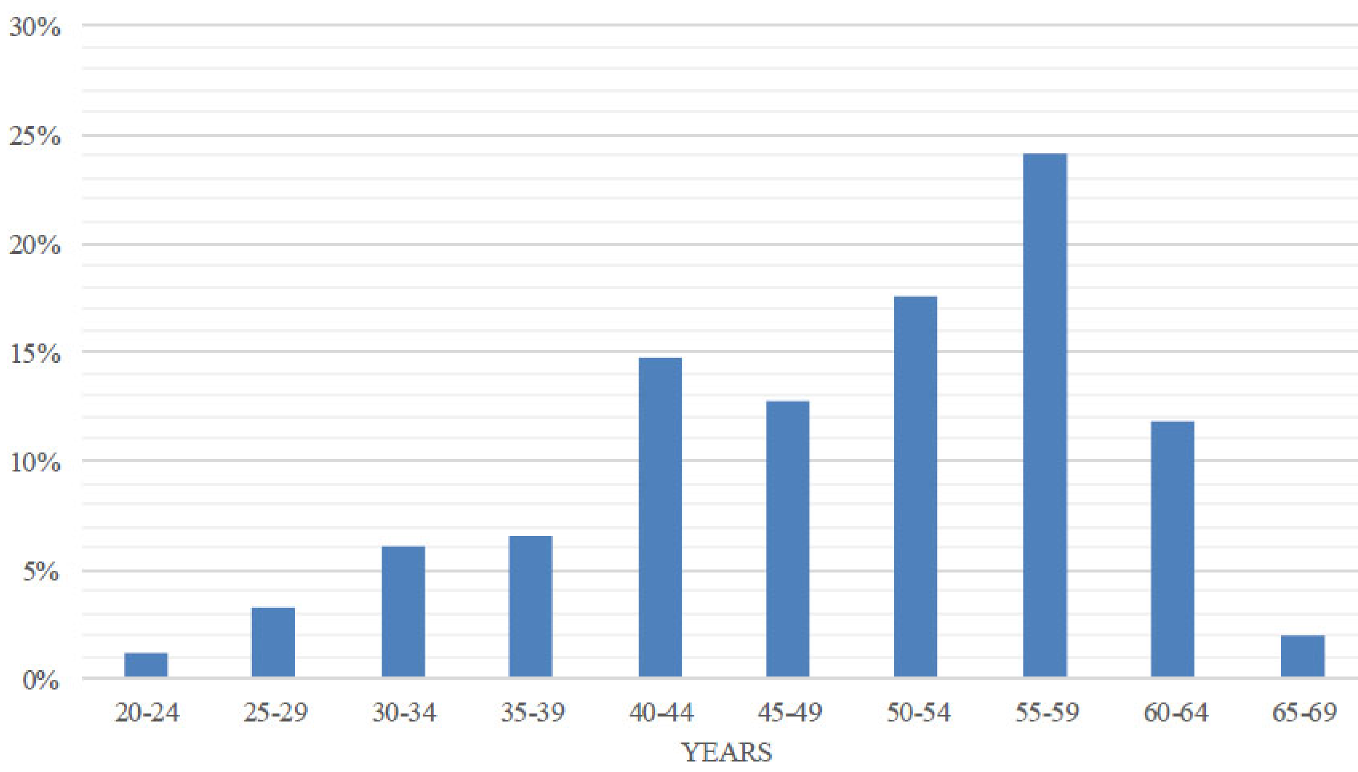

Fig. (5). Percentage distribution of access purpose for the adopted travel modes.

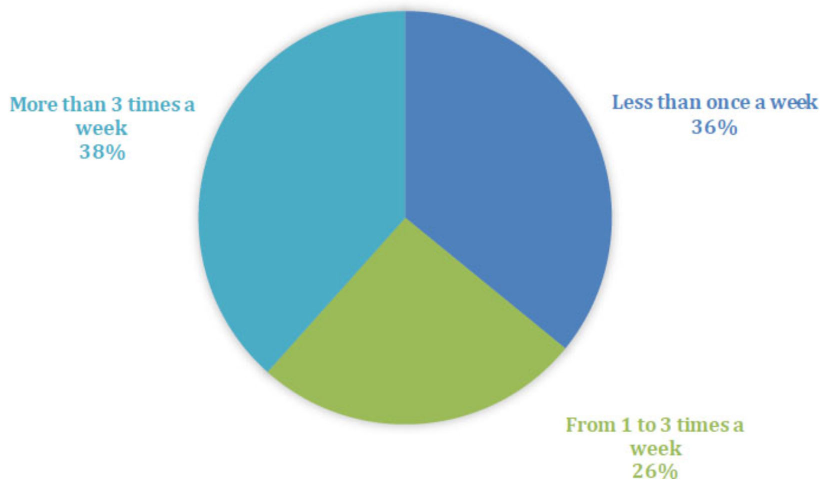

Fig. (6). Percentage distribution of frequency of access the regulated area.

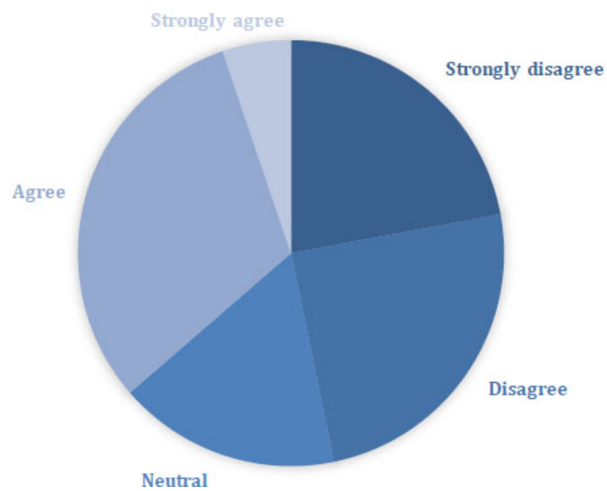

Fig. (7). Percentage distribution of answers related to acceptability of LEZ.

By observing the table one can note that 62% of the variance is cumulatively explained. The analysis of factor loadings allowed to group the questions and associate them to a specific factor. The results indicate that the first factor accounts for 20% of the total variance; it includes questions in which respondents were asked to consider the positive impacts of the measure, such as an improvement of personal and citizens' quality of life, reduction of air pollutants, equity of the regulation, and increase in accessibility and safety for walking and bike trips in the area. All the questions regarding the participants' opinions about the current Limited Traffic Zone can be associated with the second factor, which accounts for 14% of the total variance; specifically, the indicator considers the main aspects related to the effectiveness of the current regulation in improving air quality, reducing circulating and parked vehicles, and extending pedestrian areas. The third factor accounts for 11% of the total variance, and it groups questions about accessibility and the ease of currently moving in the area by travel modes different from private cars. Factor loadings of variables related to the fourth factor (10% of the total variance) show that people tend to equally consider changes in personal travel habits and potential negative impacts of the new regulation, such as an increase in traffic flows on the streets surrounding the area and a negative effect on economic activities. In addition, it is worth noting that a relationship between questions related to private cars regarding both the current and the potential future regulation was highlighted by the factor analysis; these two questions were associated with the fifth factor accounting for 7% of the total variance.

Table 3. Results of factor analysis.

Question	Positive Impacts	Effectiveness of Current LTZ	Accessibility	Negative Impacts	Car related Effects
Q12_13	0.87	-	-	-	-
Q12_11	0.85	-	-	-	-
Q12_05	0.79	-	-	-	-
Q12_06	0.76	-	-	-	-
Q12_04	0.67	-	-	-	-
Q12_09	0.62	-	-	-	-
Q12_10	0.60	-	-	-	-
Q1_03	-	0.89	-	-	-
Q1_02	-	0.83	-	-	-
Q1_01	-	0.68	-	-	-
Q1_04	-	0.67	-	-	-
Q1_05	-	0.65	-	-	-
Q2_04	-	-	0.84	-	-
Q2_03	-	-	0.72	-	-
Q2_02	-	-	0.72	-	-
Q2_05	-	-	0.58	-	-
Q12_01	-	-	-	0.79	-
Q12_07	-	-	-	0.71	-
Q12_08	-	-	-	0.68	-
Q12_12	-	-	-	-	0.83
Q2_01	-	-	-	-	0.50
SS loadings	4.12	2.99	2.33	2.10	1.49
Proportion Var	0.20	0.14	0.11	0.10	0.07
Cumulative Var	0.20	0.34	0.45	0.55	0.62
Cronbach’s alpha	0.87	0.68	0.72	0.70	0.69

Based on the presented association among questions and factors, the latter were respectively named “Positive impacts”, “Effectiveness of current LTZ”, “Accessibility”, “Negative impacts” and “Car-related effects”. To obtain a straightforward interpretation of estimated coefficients in the ordinal logit model [38, 44], summated scales were created by averaging answers to questions associated with each factor. The consistency of generated scales was assessed by calculating Cronbach’s alpha, which ranges from 0.7 to 0.9, indicating good reliability coefficients [38]. It is worth mentioning that the same technique was applied in a previous work on the topic [33], but with the aim to highlight and analyze the relationships between indicators and latent variables, as one of the integrated and sequential steps of the developed Integrated Choice and Latent Variable model that predicts the behavioral changes after a LEZ implementation; in particular, since factor analysis in [33] was part of a wider and more comprehensive modeling system, the results of the approach are different than those obtained in the present work.

3.3. Stakeholder Profiles

From the application of the hierarchical cluster analysis, five clusters of individuals were identified by considering changes in heterogeneity measure (*i.e*. the distance between observations within clusters) when dissimilar clusters are merged [38]. The emerged clusters respectively group 20, 33, 85, 59, and 49 survey participants. The size of the clusters, both in absolute and relative terms, was found to be in line with those obtained by other authors who analyzed behavioral profiles from similar mobility surveys [39, 54, 55]. The results are reported in Table **4**, showing the mean, standard deviation, and distribution of the variables useful for the purposes of the study.

The first cluster (8% of the respondents) groups individuals showing low acceptability of the new measure. Most of them are male, with the lowest mean age if compared with other clusters – even if statistically significant difference was found only for cluster 5 (Mann-Whitney W = 295, p-value < 0.05). They exhibit multiple purposes in entering the area. Moreover, these respondents access the area less than twice a week, with travel means that ca ould be impacted by the new regulation (45% by private car or motorbike); indeed, unlike other clusters, they consider that the measure could affect car trips (cluster 1 *vs* 2-3-4-5: Mann-Whitney W = 593-1442, p-values < 0.001). In addition, like cluster 5 and unlike other clusters, they judge the effectiveness of the current Limited Traffic Zone as low (cluster 1 *vs* 5: Mann-Whitney W = 379, p-value = 0.16; cluster 1 *vs* 2-3-4: Mann-Whitney W = 213-404, p-values < 0.05) and, if compared with individuals in other clusters, they consider that the new regulation could not generate positive impacts (cluster 1 *vs* 2-3-4-5: Mann-Whitney W = 38-103, p-values < 0.001).

Table 4. Mean, standard deviation, and distribution of clustering variables among clusters (from C1 to C5).

Clustering Variable	C1 (N=20; 8%)	C2 (N=33; 13%)	C3 (N=85; 35%)	C4 (N=59; 24%)	C5 (N=48; 20%)
Acceptability of the measure - Mean (Std Dev)	1.80 (0.7)	3.88 (0.89)	4.09 (0.89)	3.69 (1.13)	3.83 (1.14)
Accessibility - Mean (Std Dev)	2.7 (1.03)	3.21 (0.82)	3.51 (0.8)	3.15 (0.85)	2.83 (0.93)
Car related - Mean (Std Dev)	4.15 (0.49)	2.88 (0.78)	2.98 (0.94)	3.42 (0.91)	3.31 (0.9)
Effectiveness current LTZ - Mean (Std Dev)	2.55 (0.94)	3.09 (0.68)	3.38 (0.67)	3.12 (0.79)	2.88 (0.94)
Negative impacts - Mean (Std Dev)	1.60 (0.5)	2.21 (0.6)	2.29 (0.75)	2.29 (0.74)	2.1 (0.88)
Positive impacts - Mean (Std Dev)	2.00 (0.56)	3.67 (0.82)	3.64 (0.75)	3.47 (0.82)	3.58 (0.77)
Frequency of accessing the area - Mean (Std Dev)	1.88 (1.29)	1.14 (1.11)	2.04 (1.48)	3.59 (1.01)	1.79 (1.33)
Age	46.75 (8.66)	48.97 (10.6)	48.59 (10.61)	48.27 (9.76)	52.63 (9.76)
Gender: Female (%)	30	100	5	97	96
Gender: Male (%)	70	0	95	3	4
Travel mode: Car (%)	25	0	21	24	15
Travel mode: Motorbike (%)	20	0	12	0	0
Travel mode: Private bike (%)	35	21	28	39	23
Travel mode: Public transportation (%)	0	15	15	8	8
Travel mode: Walking (%)	20	64	24	29	54
Purpose: Leisure (%)	50	100	45	0	0
Purpose: Shopping (%)	10	0	22	0	100
Purpose: Work (%)	40	0	33	100	0

Cluster 2, 3, 4, and 5 group individuals with a high similar level of acceptability of the measure (clusters 2-3-4-5 *vs* 2-3-4-5: Mann-Whitney W = 772-3612, *p*-values > 0.10) and considering that the new regulation could generate positive impacts (clusters 2-3-4-5 *vs* 2-3-4-5: Mann-Whitney W = 816-1543, *p*-values > 0.10). However, cluster 2 (13% of the respondents) is associated with female respondents, entering the area for few times a week (cluster 2 *vs* 1-3-4-5: Mann-Whitney W = 209-445, *p*-values < 0.05) and for leisure purposes; furthermore, they do not use travel modes that could be affected by the measure, and they do not show concerns about impacts on car travel habits (cluster 2 *vs* 1-4-5: Mann-Whitney W = 68-574, *p*-values < 0.05).

Cluster 3 (35% of the respondents) mainly includes men (95%) who, like cluster 1, reported a similar frequency of access (Mann-Whitney W = 819, *p*-value = 0.79) and equal distribution of travel modes (χ^2 = 10, *p*-value = 0.24) and purposes (χ^2 = 6, *p*-value = 0.20); however, unlike cluster 1, they show a high opinion about the effectiveness of the current regulation (Mann-Whitney W = 1296, *p*-value < 0.001) and they consider that the area is currently easily accessible (Mann-Whitney W = 456, *p*-value < 0.001).

Cluster 4 (24% of the respondents) considers individuals who reported a support toward the measure, although they could be mainly affected by its implementation. In particular, they frequently access the area (cluster 4 *vs* 1-2-3-5: Mann-Whitney W = 1754-3873, *p*-values < 0.001) for work purposes and 24% of them adopt private cars.

Like cluster 2, cluster 5 (20% of the respondents) mainly consists of female individuals (96%) with a similar acceptability level of the measure (Mann-Whitney W = 772, *p*-value = 0.84) and modal share (χ^2 = 15, *p*-value = 0.24). However, they accessed the area for shopping purposes and they reported a slightly higher frequency of access (Mann-Whitney W = 563, *p*-value <0.05).

To sum up, cluster 1 considers individuals not accepting the new measure; they are mainly male subjects, entering the zone with travel modes that could be affected by the new regulation, and, therefore, with high concerns about the related impacts, even if they access the area less than twice a week; in addition, they do not consider that the current Limited Traffic Zone is effective and that the new regulation could generate positive impacts. On the contrary, other clusters allowed to define profiles of individuals reporting support for the new Low Emission Zone. Among them, cluster 2 groups of women who access the area infrequently, with sustainable modes and for leisure purposes. Cluster 3 includes men who have a positive opinion on the current regulation in terms of accessibility and effectiveness in achieving goals related to safety and sustainability. Cluster 4 considers stakeholders supporting the measure, even if they could be mainly impacted by the new regulation, since they frequently access the area for work purposes and even by car. Lastly, cluster 5 consists of women entering the area for shopping purposes less than twice a week. The results of the analysis suggest that further individual characteristics could be useful to explain the obtained clusters, highlighting the need for an additional future study, as discussed in Section 4.

3.4. Acceptability of the Low-Emission Zone

The results of the final version of the model that estimates the probability of accepting the potential Low Emission Zone are reported in Table **5**. The Brant test was applied to assess the proportional odds assumption of the ordinal logit model with a positive result (χ^2 = 1,102, *p*-value = 1).

Table 5. Estimation results of the acceptability of the low emission model.

Name	Value	Std. Error	t-value	*p*-value
Car related effects – Disagree [ref. Neutral]	0.873	0.365	2.39	0.017*
Effectiveness current LTZ – Agree [ref. Neutral]	0.792	0.287	2.76	0.006**
Frequency	-0.279	0.122	-2.29	0.022*
Frequency * Travel mode – Motorbike	0.789	0.254	3.11	0.002**
Frequency * Travel mode – Private bike	0.326	0.133	2.46	0.014*
Frequency * Travel mode – Public transportation	0.413	0.204	2.02	0.043*
Frequency * Travel mode – Walking	0.468	0.141	3.32	0.001**
Positive impacts – Strongly disagree [ref. Neutral]	-3.970	1.057	-3.76	<0.001***
Positive impacts – Disagree [ref. Neutral]	-2.916	0.461	-6.32	<0.001***
Positive impacts – Strongly agree [ref. Neutral]	3.216	0.776	4.15	<0.001***
Strongly disagree | Disagree	-4.184	0.507	-8.25	<0.001***
Disagree | Neutral	-1.605	0.294	-5.46	<0.001***
Neutral | Agree	-0.632	0.261	-2.42	0.015*
Agree | Strongly agree	1.726	0.294	5.88	<0.001***
Statistics:	-	-	-	-
Sample size	245	-	-	-
Null log likelihood	-343.3	-	-	-
Final log likelihood	-271.7	-	-	-
McFadden Rho-square	0.21	-	-	-
Nagelkerke Rho-square	0.51	-	-	-
AIC (Akaike criterion)	83.24	-	-	-
Bayesian Information Criterion	104.33	-	-	-

Note: Significance codes: *** *p*-value < 0.001; ** *p*-value < 0.01; * *p*-value < 0.05; † *p*-value < 0.10.

Table 6. Marginal effects for the Acceptability of the Low Emission model (*p*-value in parentheses).

Variable	L1	L2	L3	L4	L5
Frequency	0.000 (0.983)	-0.004 (0.504)	-0.004 (0.303)	-0.008 (0.023)	0.016 (0.214)
Travel mode – Motorbike	-0.047 (0.003)	-0.119 (0.001)	-0.075 (0.000)	-0.026 (0.651)	0.267 (0.004)
Travel mode – Private bike	-0.029 (0.038)	-0.063 (0.030)	-0.035 (0.017)	0.041 (0.097)	0.086 (0.013)
Travel mode – Public transportation	-0.034 (0.035)	-0.076 (0.041)	-0.044 (0.041)	0.038 (0.169)	0.116 (0.083)
Travel mode – Walking	-0.037 (0.010)	-0.083 (0.007)	-0.050 (0.001)	0.033 (0.221)	0.137 (0.001)
Car related effects – Disagree [ref. Neutral]	-0.028 (0.036)	-0.060 (0.028)	-0.039 (0.019)	0.002 (0.859)	0.125 (0.014)
Effectiveness current LTZ – Agree [ref. Neutral]	-0.025 (0.019)	-0.055 (0.012)	-0.036 (0.008)	0.002 (0.859)	0.113 (0.005)
Positive impacts – Strongly disagree [ref. Neutral]	0.126 (0.000)	0.275 (0.001)	0.179 (0.004)	-0.011 (0.857)	-0.569 (0.000)
Positive impacts – Disagree [ref. Neutral]	0.093 (0.000)	0.202 (0.000)	0.132 (0.000)	-0.008 (0.857)	-0.418 (0.000)
Positive impacts – Strongly agree [ref. Neutral]	-0.025 (0.019)	-0.055 (0.012)	-0.036 (0.008)	0.002 (0.859)	0.113 (0.005)

Note: L1: "Strongly disagree"; L2: "Disagree"; L3: "Neutral"; L4: "Agree"; L5: "Strongly agree".

By observing estimation results, one can note that considering that the new Low Emission Zone could have positive impacts (concerning quality of life, air quality, accessibility and safety of walking and bike trips) has a significant positive effect on the acceptability of the new regulation. This is an expected result, confirmed by the outcomes of the cluster analysis, that identified four groups of supporters of the new regulation that even consider positive impacts of the intervention. Additionally, people who positively assess the effectiveness of the current Limited Traffic Zone in meeting some sustainable goals (such as improving air quality, reducing vehicles, and increasing pedestrian areas) tend to support the new regulation. These two results suggest that the level of acceptability of the Low Emission Zone is strictly dependent on the perception of the effectiveness of this type of regulation in producing positive effects on society and the environment, and these impacts could be experienced in the current situation. This highlights that, in order to foster support of the LEZ, local authorities should first focus on reporting positive impacts related to the current LTZ and then present how this effect could be improved by the new regulation.

Moreover, variables related to the interaction between the frequency of access in the area and the adopted travel mode to reach the zone highlight that the frequent use of private car has a negative impact on stakeholders' acceptability; this negative effect is mitigated by the adoption of alternative travel modes. Furthermore, respondents less concerned about future car-related impacts of the regulation in the area are likely to support the measure. This indicates a low attitude toward the potential measure due to car adoption, as expected, because of the access restrictions that could be directly applied to this means.

Table **6** reports the marginal effects of the variable included in the final model version. The values in the table confirm the significance and direction of the impacts of factors shown in Table **5**. In addition, the marginal effects of the frequency of access in the area highlight the uneven role of the variable pointed out by the cluster analysis in Section 3.3.

4. DISCUSSION

The implemented methodological framework allowed to carry out an in-depth analysis of the acceptability of a new Low Emission Zone, as one of the objectives of the ReVeAL project. In particular, the clustering technique was adopted to identify potential profiles of stakeholders supporting and opposing the measure; whereas, the ordinal logit model was used to highlight the factors that can affect acceptability level.

Specifically, from the application of the cluster analysis, five clusters of individuals emerged. The first one was associated with individuals not accepting the measure, who enter the zone with travel modes that could be affected by the new regulation, and with low frequency; in addition, they do not consider that the current Limited Traffic Zone is effective and that the new regulation could generate positive impacts. On the contrary, other clusters allowed to define profiles of individuals reporting a support for the new Low Emission Zone: the first one grouped women accessing the area infrequently, with sustainable modes and for leisure purposes, the second one included men exhibiting a positive opinion about the current regulation in terms of accessibility and effectiveness in achieving goals related to safety and sustainability, the third one considered stakeholders supporting the new measure, even if they could be mainly impacted by the new regulation since they frequently access the area for work purposes and even by car, and the fourth one consisted in female individuals entering the area for shopping purposes less than twice a week.

The ordinal logit model highlighted that the level of acceptability depends on the perception of the effectiveness of the current Limited Traffic Zone and the belief in positive impacts of the new regulation. This indicates that publicizing the social and environmental positive effects of the current regulation and demonstrating how the new measure could improve them could be a powerful policy to effectively improve public support. Furthermore, as expected, the model pointed out the low support from car drivers, underlying that people directly affected by the intervention should be specifically considered.

Some of the findings of the developed analysis are confirmed by previous works concerning the acceptability and acceptance of a LEZ, as well as other Urban Vehicle Access Regulations (UVARs). In particular, many authors highlighted that the perceived effectiveness of future measures could significantly affect their acceptability [5, 7, 30]. Following this perspective, the awareness of positive effects was found to play a non-negligible role in the support of the new regulation [11, 15, 56], especially considering environmental benefits [31]. On the other hand, great concern about the potential risks of the implementation of the measure, such as increasing travel times to bypass the LEZ and higher traffic flows on the surrounding streets, could negatively impact the acceptability [57]. Furthermore, several authors pointed out that car drivers tend to be against the implementation of LEZ and other UVARs [13, 18]. Awareness of current problems in the area was found to significantly affect the acceptability of such interventions by many authors [5, 7, 8, 15, 16]. Unlike these works, this paper studied a shift from an existing Limited Traffic Zone (LTZ) to a new LEZ, therefore, the perceived presence of potential current problems was not directly evaluated, but it was investigated as the effectiveness of the LTZ in addressing these issues.

CONCLUSION

In this paper, the acceptability level of a future Low Emission Zone (LEZ) in a medium-sized city is evaluated through an integrated procedure obtained from the combination of different statistical models, thus providing a comprehensive view of the topic. In particular, answers from a mobility survey administered to future stakeholders of a new LEZ in Padova (Italy) were used as input for three approaches.

First, a factor analysis was applied to highlight the underlying structure among selected questions and define synthetic indicators to reduce their original number. Then, a cluster analysis was implemented in order to identify potential groups of respondents sharing similar attributes in terms of individual characteristics, attitudes, and opinions toward the new Low Emission Zone (LEZ). After that, an ordinal logit model was calibrated, to understand factors affecting the possible support of the new regulation.

Descriptive statistics pointed out that the survey effectively targeted a wide range of stakeholders, and the measure could be supported by many people. Cluster analysis resulted in five clusters describing the emerged profiles of stakeholders accepting and opposing the intervention. In particular, opposers were found to be those highly impacted by the new regulations and considered the current Limited Traffic Zone (LTZ) as ineffective. Different profiles of LEZ supporters were observed, including women infrequently entering the area with sustainable modes, men exhibiting a positive attitude toward the existing LTZ, people frequently accessing the zone with a private car, and women infrequently going to the city center to have shopping. The ordinal logit model pointed out that making people aware of the sustainability and accessibility goals achieved by the current LTZ and how the new regulation could improve them, could effectively foster stakeholders' acceptability. Lastly, the model highlighted that a strong opposition to the new LEZ could come from car drivers.

Results can be helpful for both policy makers and local authorities in fostering the widest support of the new Low Emission Zone and thus broadening its potential benefits. In particular, the outcomes of the work were useful for the ReVeAL project, since the analysis contributed to identifying main factors significantly affecting LEZ acceptability; these factors can be considered to design tailored strategies for effective public engagement activities, with the aim to raise stakeholders' support toward the introduction of Urban Vehicle Access Regulations. In particular, the results could be used to formulate the following policy recommendations. First, local authorities should identify proper public engagement activities specifically planned for the various groups of stakeholders. Second, an effective strategy to create an effective transition from an LTZ to a LEZ could be to make people aware of the sustainability and accessibility targets reached by the current measure; in addition, how the new regulation could improve them should be emphasized. Lastly, attention should be paid to progressively implement such an intervention that can directly impact car drivers, since strong opposition could come from their side; this does not mean that new restrictions should not be enforced but highlights the importance of a proper strategy to gain their support. These suggested elements could contribute to defining a proper policy supporting LEZ introduction; in this way, citizens could effectively understand the measure, they could be prompted to accept the applied restrictions, and, therefore, the expected benefits of the LEZ can be maximized. To sum up, the results presented in this paper highlighted how local authorities could maximize the stakeholders' acceptability of a Low Emission Zone, thus contributing to pave the way toward a new sustainable urban mobility.

The presented research work has the following limitations. Although the designed questionnaire effectively targeted stakeholders of the new LEZ, the sample size could be expanded. Moreover, due to the imposed maximum response time and privacy issues, the number and types of questions included in the survey were limited. Future research steps can be performed to overcome the described limitations. Specifically, a more comprehensive survey could be designed and administered, allowing to highlight further factors, constructs, and attitudes impacting the acceptability of the new regulation. In particular, a proper analysis of additional socio-economic variables (like income and a number of household members), as well as attributes of the trip to reach the area (like travel distance, time, and cost) could be performed. This study could be helpful in identifying further stakeholders' characteristics to better understand the individual profiles from cluster analysis. Moreover, a new survey could be repeated after the implementation of the new LEZ, to evaluate its acceptance and potential effects on the new trips to reach the area. In addition, the work assumes a pre-defined causal relationship between attitudes/opinions about the new regulation and acceptability level; in the next step of the research, a specific analysis could be carried out to verify the hypothesized direction.

AUTHORS CONTRIBUTION

It is hereby acknowledged that all authors have accepted responsibility for the manuscript's content and consented to its submission. They have meticulously reviewed all results and unanimously approved the final version of the manuscript.

LIST OF ABBREVIATION

UVAR	=	Urban Vehicle Access Regulations
LEZ	=	Low Emission Zone
ReVeAL	=	Regulating Vehicle Access for Improved Liveability
MSA	=	Measure of Sampling Adequacy

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

The data and supportive information is available within the article.

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CONFLICT OF INTEREST

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