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Analysis and Strategies for Urban Freight Logistics in A Low Emission Zone

Sandra Milena Alvarez-Gallo[1*], Jacobo Hernan Echavarria-Cuervo[1], Julien Maheut[2]

[1]*Institución Universitaria Pascual Bravo (Colombia)*

[2]*ROGLE-Department of Business Administration, Universitat Politècnica de València (Spain)*

**Corresponding author: sandra.alvarezga@pascualbravo.edu.co*
jacobo.echavarria@pascualbravo.edu.co, juma2@upv.es

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Abstract:

Purpose: This paper aims to identify complementary strategies for urban freight logistics in a low emission zone (LEZ) that can be implemented in downtown Medellin, Colombia. The strategies will be executed by identifying the characteristics and problems of the business establishments in the area and the entrepreneurs' opinions.

Design/methodology/approach: First, a literature review is performed to identify global and complementary strategies for the future LEZ, which is the study subject. Then, a "pilot" zone (a main corridor) of downtown Medellín is selected, and the business establishments of the area are identified to spot problems and evaluate possible strategies for the future LEZ. This identification and evaluation phase is conducted by interviewing logistics managers in 105 establishments selected in the corridor for analysis.

Findings: One of the outstanding findings concerns the specificity of the logistics and mobility problems in downtown Medellin, located in Colombia, a developing country. The main issues are traffic congestion, lack of regulation and control in loading and unloading areas, as well as inadequate infrastructure for these operations. These obstacles significantly impact business activities and air quality in the area. The proposed solutions to complement the LEZ strategy for freight transport focus on improving regulation, establishing specific loading and unloading areas, exploring sustainable transportation options such as the cargo bike, and supporting small and medium-sized businesses. This emphasizes the situation's complexity and the need for a comprehensive approach to address these logistical and environmental challenges.

Originality/value: This study analyses urban freight logistics strategies that complement the traffic flow restriction policies imposed by low-emission zones. Unlike other studies that address these two issues independently, this paper specifically examines how to improve a LEZ as a comprehensive strategy to reduce the environmental impact of freight transport. In addition, it is noted that most publications tend to focus on passenger mobility strategies, which highlights the potential for research in the freight logistics field.

Keywords: low emission zone, urban freight logistics, LEZ, logistics strategies, public policies, sustainable logistics

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1. Introduction

By 2050, 68% of the population is expected to live in urban areas (UN-Habitat, 2022). This rapid urbanization process, especially in developing countries, has increased vehicle use, causing growing congestion and more city pollution (Rajé, Tight & Pope, 2018). Thus, authorities have had to consider restrictive public policies to minimize the impact generated (Qin, Liang, Yang, Fu, Chao, Liu et al., 2023). Low emission zones (LEZs) are one of the effective regulatory strategies that has been set in place to control increasing environmental pollution (Lurkin, Hambuckers & van Woensel, 2021; Simic, Gokasar, Deveci & Svadlenka, 2022).

LEZs are areas within cities that regulate or limit the operation of polluting vehicles or have a non-compliance fee in place (de Borger & Proost, 2013; Oltra, Sala, López-Asensio, Germán & Boso, 2021). These traffic restrictions are based on vehicle age and type (Cruz & Montenon, 2016). In the late 1990s, Sweden became a pioneer by establishing the first LEZs in the world (Zhai & Wolff, 2021). Since then, many European cities have introduced LEZs, and there are currently more than 250 in Europe. Different types of LEZs with various levels of vehicle access restriction in the designated area have been established (Salas, Perez-Villadoniga, Prieto-Rodriguez & Russo, 2021). In some European countries, these areas have even evolved into zero-emission zones, where only vehicles that do not produce exhaust gases, such as electric cars, are allowed to circulate (Quarmby, Santos & Mathias, 2019).

In addition to the traffic flow restriction measures put in place on the (LEZs), there are complementary actions that can improve its effectiveness in reducing air pollution, both in terms of passenger mobility and freight transport. Viable passenger transport strategies include promoting the adoption of electric vehicles and encouraging active commuting such as walking and cycling. In addition, public transport vehicles can be adapted to meet environmental standards (Rashid, Chong, Islam, Bryant & McEachan, 2021). Likewise, carsharing is also a relevant strategy (Roblek, Meško & Podbregar, 2021). There are additional alternatives for freight transport in urban areas that may vary according to the regional context. These initiatives may include implementing consolidation centers and limiting the flow of heavy vehicles at certain hours (Rashid et al., 2021). Among other measures, implementing cargo bikes in the business logistics operation is also being taken into consideration (Ceccato & Gastaldi, 2023).

The implementation of LEZs poses a challenge for local authorities around the world. These areas are intended to reduce vehicular traffic's social and environmental impacts. However, at the same time, the defined policies may affect the transportation management of companies operating in such areas (Wolff, 2014). Therefore, before implementing LEZs, it is critical to characterize the freight logistics operations by identifying their main challenges and considering possible suggestions from business logistics managers regarding viable alternative measures. This would make it possible to comply with the restrictions imposed by the LEZ without impairing the operation of these companies.

In emerging economies, such LEZs initiatives are only now beginning to be implemented. In the specific case of Colombia, as of 2021, awareness has been raised to implement the country's first LEZ –also called Urban Protected Air Zone– in downtown Medellin. This decision is based on the fact that, according to monitoring stations, this area regularly exceeds the permissible emissions limits. This fact categorizes the area as a high source of pollution (Secretaría de Movilidad, 2023). Unlike many LEZs in Europe, the predominant approach of this zone is not tourism but commerce. As a result, it is common to find street vendors occupying public space, which hinders both pedestrian and vehicular traffic.

One of the main obstacles for effective strategic decisions regarding LEZ implementation in Medellin is the lack of information on businesses' freight logistics. Hence, this study aims to examine the logistics practices and issues affecting the operation of a group of establishments located in the designated LEZ downtown. In order to perform this analysis, a pilot corridor has been chosen to illustrate the general behavior of the LEZ, due to its complexity and its representativeness of the commercial activity of the zone. Interviews were conducted in all the establishments in this corridor to understand the zone behavior, excluding only residential buildings and chapels. These interviews were specifically conducted with the freight logistics staff at these establishments. The analysis of the gathered information allows us to propose strategies that align with LEZ policies implementation in downtown Medellin.

This paper is structured as follows: Section 2 conducts a literature review that aims to identify LEZ impact, stakeholders' perception and complementary business and public strategies to be deployed in LEZ, with a particular focus on identifying publications related to urban freight logistics. Section 3 examines downtown Medellín (Colombia) as a study area and explores LEZ as a solution to congestion and pollution, focusing particularly on the need for adaptation of business logistics. Section 4 details the research methodology and explains the instruments and variables used in the interviews. Section 5 analyzes the results obtained, addressing the characterization of LEZ in Medellín, the problems identified, and the complementary strategies proposed for its implementation. Finally, Section 6 presents the conclusions derived from the performed research.

2. Literature Review

Publications that focus on LEZs research were reviewed. Then, the addressed topics are identified, especially those related to urban freight logistics. For this purpose, an exhaustive literature review was conducted in the Web of Science database (WoS) and Scopus, using terms related to LEZs or clean air zones (the term used in the United Kingdom to refer to these areas). The following search equation was used:

Database	Search equation
WoS	(TS=("Low Emission Zone*" OR "Zero Emission Zone*" OR "Clean air zone*" OR "LEZs" OR "Emission-Free Zone*" OR "LOW-EMISSION ZONE*")) AND (DT=("ARTICLE" OR "PROCEEDINGS PAPER" OR "REVIEW" OR "EARLY ACCESS") NOT DT=("BOOK CHAPTER" OR "correction")) AND PY=(1985-2023)
Scopus	(TITLE-ABS-KEY ("Low Emission Zone*" OR "Zero Emission Zone*" OR "Clean air zone*" OR "LEZs" OR "Emission-Free Zone*" OR "LOW-EMISSION ZONE*") AND TITLE-ABS-KEY ("ARTICLE" OR "PROCEEDINGS PAPER" OR "REVIEW" OR "EARLY ACCESS")) AND PUBYEAR > 1985 AND PUBYEAR < 2024 AND (EXCLUDE (DOCTYPE, "er"))

Table 1. Used search equations

In the literature review protocol, the following inclusion and exclusion criteria were defined to select papers:

Inclusion criteria:

- Papers published up to December 2023
- Scientific papers, conference papers and literature reviews
- Papers including LEZ or Clean Air Zones among the study subjects of their research questions or objectives

Exclusion criteria:

- Papers that are not specifically related to urban areas, such as hospitals, schools, polar regions and rural regions
- Studies whose main focus was not to LEZs, such as research on irrigation policies in agriculture, analysis of chemical composition and size distribution of atmospheric particles, black carbon particles, photocatalysts, firework regulation, use of trams, tourist mobility, atmospheric pollutants emissions from construction machinery and drone detection
- Papers where LEZ is mentioned in the abstract as a possible alternative to address urban environmental pollution or as enabler for other strategies, but where the main research focuses on other topics, such as the use of electric or hybrid vehicles, battery state of charge, or consolidation centers
- Books and book chapters

The search yielded a total of 337 publications in WoS and 102 in Scopus. After removing 82 duplicated papers, there were 357 results left. There was no available access to read the complete version of 3 of them, but access was

obtained after requesting it to the authors. Finally, 148 papers were excluded based on the criteria above, leaving a total of 209 selected papers (Figure 1).

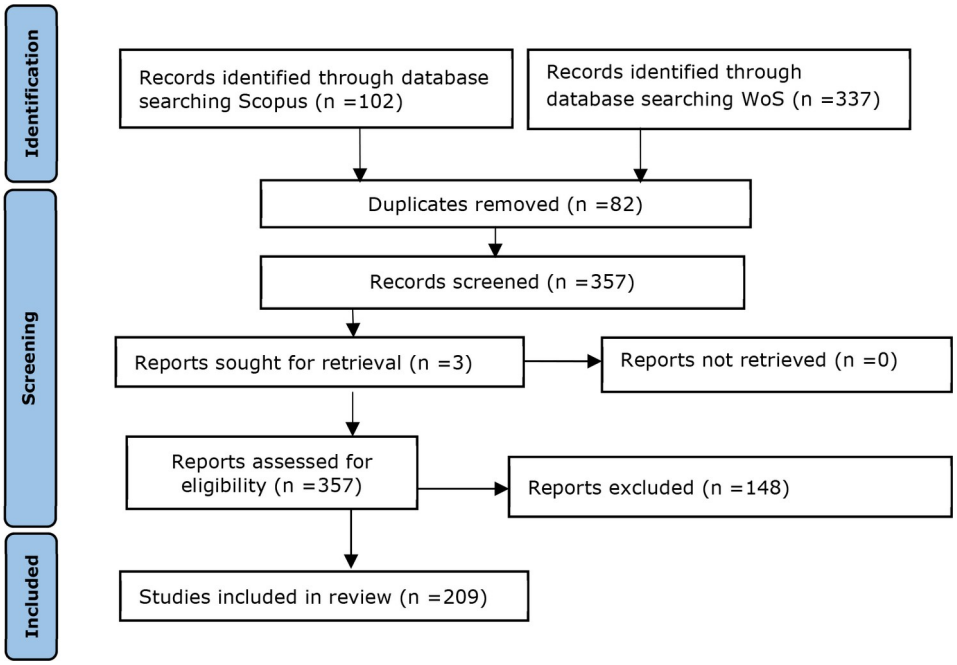

Figure 1. Reference selection using PRISMA flow diagram

Figure 2 shows the annual scientific production over the last two decades for the topics of the 209 papers selected in the literature review. It is notable that, from 2000 to 2011, the number of publications remained consistently low, ranging between one and two papers per year. However, in the last three years (2021-2023), there has been a notable increase in publications, indicating an increased interest in this research area lately.

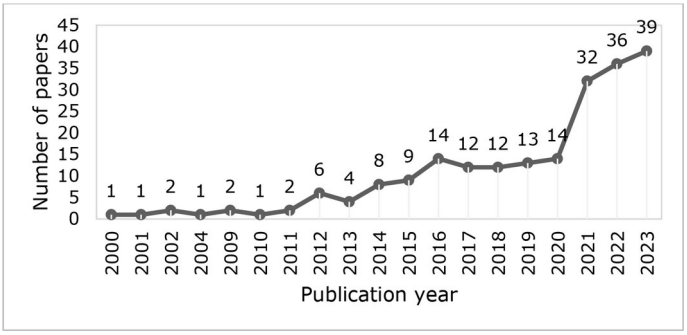

Figure 2. Number of published papers by year

In addition, 138 different sources were identified as the publishers of the selected articles. Table 2 shows the sources with more than 3 publications: 'Transportation Research Part D-Transport and Environment', 'Sustainability' and 'Atmospheric Environment' stand out as the main sources, featuring a higher number of articles in the LEZs field.

Three thematic research subcategories –identified in the papers selected in the literature review– are analyzed in this article. First, the impact of LEZ in several aspects was addressed. Then, the perception of people and involved participants in regard to LEZ implementation was examined. Lastly, alternative strategies –besides LEZ implementation– aiming to reduce the environmental impact produced by traffic on urban areas were evaluated. In each case, freight transport application is analyzed. These subcategories are detailed in the following subsections.

Source	Papers
Transportation Research Part D-Transport and Environment	13
Sustainability	10
Atmospheric Environment	9
Transportation Research Part A-Policy and Practice	6
International Journal of Environmental Research and Public Health	5
Journal of Environmental Management	5
Environmental Pollution	4
Science of the Total Environment	4
Journal of Transport & Health	3
Transport Policy	3
Transportation Research Record	3

Table 2. Main sources and number of published articles, respectively

2.1. Impact Analysis of LEZ Implementation

Most of the 209 selected publications (76%) focus on the impact of LEZ implementation. Out of these 159 papers, 16 addressed two types of impact in their research, only 1 paper addressed three types of impact, and the rest focused on a single type of impact. Table 3 shows the impact types mentioned in the selected articles. Air quality and health stands out as the most frequently addressed topic, featured in 111 publications. This topic is followed in relevance by the following matters: influence on changes in transport modes, vehicle renewal, vehicle purchasing decisions, dismantling and necessary technology (18 publications); influence on the labor market, eco-innovation, business expansion and operational and financial efficiency (12 publications); energy efficiency (8 publications); economic impact for both users and businesses, including the impact on consumer spending decisions and housing cost (7 publications); and the social impact of people's mobility, accessibility to LEZs, and the respective green transformation of residents' lifestyles (6 publications). Other aspects are also considered, although to a lesser extent, so topics such as local authority land use efficiency, noise impact, urban freight transport, traffic intensity, road change and environmental justice have only 1 to 4 mentions each.

Only 3 papers focusing on the impact of LEZ implementation on urban freight transportation were identified. Tarriño-Ortiz, Soria-Lara, Silveira-Santos and Vassallo (2023) studied the impact of LEZs on retail sales activity in Madrid Central, including the evaluation of their efficiency in delivery and supply logistics operations. According to an entrepreneur survey, 36.7% consider the impact to be negative, attributing LEZ implementation to longer delivery times and increased shipping costs. In addition, the authors propose alternative delivery methods such as urban consolidation centers, use of bicycles and electric vehicles, highlighting that the use of electric vehicles is the most accepted measure (56% acceptance). It is noteworthy that large retailers gained more benefits from the implementation of the LEZ than smaller stores.

Dablanc and Montenon (2015) examined the impact of LEZs on transport and logistics companies in London and Berlin, observing the number of companies decrease by 15% to 30%, which has prompted the search for methods to improve the efficiency and modernization of the urban freight transport sector, such as operations reorganization, route optimization, collaboration between companies and creation of logistics centers for non-polluting vehicles.

Likewise, de Bok, Tavasszy and Thoen (2022) analyzed the impact of implementing a zero emission zone in combination with urban consolidation centers in the Netherlands. While they noticed an increase in the kilometers traveled by vehicle, this was mitigated by a higher logistics efficiency in terms of weight distributed per trip and a decrease in empty trips, due to delivery consolidation in consolidation centers, and a variation in the number of shipments per freight type as a result of the grouping of orders by routes.

These 3 studies agree on the strategy of using freight consolidation centers to improve urban logistics in the context of LEZs. However, there is a need for more research focused on concrete strategies to mitigate the challenges posed by LEZs in freight delivery activities. There should be an emphasis on medium and small logistics and transportation companies, particularly to recognize their possible lack of financial capacity to make required changes, such as replacing fleets with more environmentally friendly options. Hence, it is essential to find practical and affordable solutions.

LEZ impact type	Number of papers
Impact on air quality and health	111
Influence on changes in transport modes and vehicle renewal	18
Influence on the labor market, eco-innovation, business expansion and operational and financial efficiency	12
Energy efficiency	8
Economic impact for both residents and businesses	7
Social impact of people's mobility and accessibility to LEZs	6
Local authority land use efficiency	4
Impact on noise	3
Impact on urban freight transport	3
Impact on traffic intensity	2
Impact on road change	1
Environmental justice	1

Table 3. LEZ impact types in the selected papers

2.2. Public Acceptability of LEZ Implementation

The literature review reveals scarce research on the acceptability of LEZs, shown by the limited number of 12 available publications (Table 4). Kowalska-Pyzalska (2022) and Jiménez-Espada, García and González-Escobar (2023) note that the opinion of residents has been considered in all cases, but there is a notable lack of studies focused on the perception of business owners. In addition, more research targeting logistics companies or freight forwarders is urgently needed to understand how the integration of LEZs affects and is perceived in their sourcing and dispatch operations. Most of the available research focuses on European countries, which calls for more studies in emerging economies, such as Colombia, where the significant proportion of low-income people and limitations in mobility infrastructure pose additional challenges. For example, Basbas, Kladias, Kouvatas and Politis (2015) found in Greece that low-income people oppose the implementation of LEZs due to financial difficulties to access these areas or to acquire environmentally friendly vehicles. Similarly, Rashid et al. (2021) identified greater opposition in low-income communities due to financial concerns, as the investments needed from businesses to comply with environmental requirements may add to product costs. In summary, further research focused on the perception of entrepreneurs in emerging economies is crucial to ensure equitable and effective LEZs implementation and to promote sustainable mobility globally.

The selection of papers related to the acceptability of LEZs revealed significant factors influencing public perception of these policies (Table 5). Environmental awareness was highlighted as a crucial factor in 8 of the 12 selected publications, supported by the publication of Tarriño-Ortiz et al. (2021), who pointed out that individuals greatly interested in environmental issues are more likely to accept this type of measures. Environmental awareness in citizens is considered important for the acceptance of LEZs, as mentioned in Rizki et al. (2022). Also, trust in government appears as a key element, supported by studies –such as Oltra et al (2021)– that highlight its impact on the acceptability of measures to reduce air pollution.

Paper	Respondents	Study zone
Player, Prosser, Thorman, Tirion, Whitmarsh, Kurz et al. (2023)	Residents	Bath, United Kingdom
Morton, Mattioli & Anable (2021)	Residents	Scotland
Basbas et al. (2015)	Residents	Volos, Greece
Kowalska-Pyzalska (2022)	Residents	Poland
Tarriño-Ortiz, Soria-Lara, Gómez & Vassallo (2021)	Residents	Madrid, Spain
Rizki, Irawan, Dirgahayani, Belgiawan & Wihanesta (2022)	Residents	Jakarta, Indonesia
Sfendonis, Basbas, Mintsis, Taxiltaris & Politis (2017)	Residents	Thessaloniki, Greece
Oltra et al., 2021	Residents	Barcelona, Spain
Jiménez-Espada et al. (2023)	Residents	Cáceres, Spain
Rashid et al. (2021)	Residents	Bradford, United Kingdom
Seter, Arnesen & Moscoso (2023)	Private vehicle drivers	2 Norwegian cities
Oltra, Sala, López-Asensio & Germán (2023)	Residents	Spanish provinces

Table 4. Research on the acceptability of LEZ: respondent type and study zones

Key factors for LEZs acceptability	Papers
Environmental awareness	8
Trust in government	7
Demographic characteristics	6
Perception of LEZs benefits	5
Impact on travel and mobility	4
Vehicle renewal subsidies	3
Public communication or participation campaigns	3
Values and attitudes	3
Willingness to pay	2
Cost-benefit balance	1
Social equity	1
Improved infrastructure for mobility transition	1
Increased public transport services	1
Promotion of carpooling	1
Personal and social norms	1
Cost of LEZ implementation by authorities	1
Perceived legitimacy of the process	1
Financial impact	1
Optimism towards technological change and adaptability	1
Frequency of access to the LEZ	1
Type of activity to be carried out in the LEZ	1

Table 5. Key factors and their frequency in LEZ acceptability according to the literature review selected

The perception of LEZs benefits was another determining factor in several studies. According to Morton et al., (2021), perceiving benefits such as pollutant matters reduction and air quality improvement can increase public

support. Moreover, demographic characteristics, such as respondent gender, age, and socioeconomic status, were shown to play a significant role in LEZs acceptability, as found by Player et al. (2023), who observed that residents with higher educational attainment showed more acceptance to the proposal.

The impact on travel and mobility was a relevant factor, suggesting that the acceptance of LEZ is influenced by accessibility considerations, as mentioned by Sfendonis et al. (2017). These findings emphasize the complexity of factors influencing the acceptability of LEZs and underline the importance of addressing multiple dimensions to promote the successful adoption of these policies in urban settings. However, the lack of research assessing the factors that impact businesses acceptability of LEZs is noteworthy, especially involving actors related to the urban distribution of goods, given their relevance in the competitiveness and economic development of cities.

2.3. Complementary Transportation Strategies of LEZ Implementation

2.3.1. Business Strategies

Out of 209 publications related to LEZs, only 8 address alternative business strategies for freight transport to reduce environmental pollution. Table 6 provides details on this information and specifies the sources and cities or countries where these measures have been evaluated or analyzed. It is to be noted that most of these studies are focused on Europe.

Business strategies	Source	City/Country
Freight consolidation centers	Rashid et al. (2021)	Bradford, UK
	de Bok et al. (2022)	Holland, Netherlands
	Dablanc & Montenon (2015)	Berlin, Germany; and London, UK
	Deveci et al. (2022)	Undefined
	Tarriño-Ortiz et al. (2023)	Madrid Central, Spain
	Awasthi (2016)	Undefined
Vehicle routing optimization	Dablanc & Montenon (2015)	Berlin, Germany; and London, UK
	Awasthi (2016)	Undefined
Nighttime reception and deliveries	Yang et al. (2017)	Beijing, China
Changes in freight dispatch and receipt schedules	Awasthi (2016)	Undefined
Associativity or collaboration between companies to share vehicles and resources	Awasthi (2016)	Undefined
	Dablanc & Montenon (2015)	Berlin, Germany; and London, UK
Acquisition or rental of environmentally friendly vehicles and vehicle fleet renewal through clean technologies.	Awasthi (2016)	Undefined
	Tarriño-Ortiz et al. (2023)	Madrid Central, Spain
Integration of business operations with public policies	Deveci et al. (2022)	Undefined
Cargo bike use	Ceccato & Gastaldi (2023)	Padua, Italy
	Tarriño-Ortiz et al. (2023)	Madrid Central, Spain

Table 6. Alternative business strategies other than LEZ to mitigate environmental impacts

For example, the study by Deveci, Pamucar, Gokasar, Delen, Wu and Simic (2022) uses a multi-criteria analysis methodology to select the best policy to optimize urban freight transport. The results indicate that the creation of a logistics center, aimed at reducing costs and time is the alternative with the highest acceptance. The optimization and integration of business operations and public constraints are next in importance. Implementing a zero-emission zone comes third.

On the other hand, the work of Yang, Sun, Lan and Yang (2017) analyzes the implementation of policies to limit cargo vehicle traffic to reduce congestion and environmental pollution. Accordingly, they suggest that the public

sector consider diverse strategies, such as extending transport permits or passports to authorized vehicles, promoting nighttime deliveries, increasing penalties for illegal traffic, and investing more in media advertising of regulatory policies.

Awasthi (2016) is the only author whose publication focused on reviewing business strategies that support or complement LEZ implementation to reduce environmental pollution. This paper presents operational strategies aimed at small and medium-sized businesses to address LEZ implementation. These strategies comprise four approaches: maintain current operations, make changes to delivery logistics (such as routes and schedules), adapt delivery vehicles (through purchase, rental or sharing), and adjust business strategy (through collaboration with other companies or outsourcing).

In summary, as illustrated by Table 6, research proposes various business strategies to improve urban freight transport. These strategies include the creation of freight consolidation centers, vehicle routing optimization, nighttime deliveries and receptions, changes in freight dispatch and receipt schedules, promotion of associativity or collaboration between businesses to share vehicles and resources –whether through partnerships, mergers or outsourcing–, acquisition or rental of environmentally friendly vehicles, and vehicle fleet renewal through clean technologies. The use of cargo bikes is also considered as a sustainable option.

2.3.2. Authority-Defined Strategies

The literature review identified some policies and strategies defined by local authorities that complement LEZ implementation and have the aim of reducing environmental pollution in urban areas, especially the pollution produced by freight transport. These strategies are compiled in 12 selected publications (Table 7) and are for both private and freight vehicles.

A study by Ocampo-Giraldo, Gonzalez-Calderon and Posada-Henao (2019) assesses truck emissions in Medellín, Colombia, considering vehicle traffic restrictions in time slots. They found that the number of trips is not reduced as merchandise must be delivered. The authors suggest that technological changes could be a better alternative than restrictions. However, this study does not consider the LEZ strategy as it was not yet planned in the city in 2019.

On the other hand, Rizki et al. (2022) examine restriction preferences in Jakarta, Indonesia, regarding restricted vehicle types and limitation strategies, which include parking fees, emissions-based restrictions and circulation schemes based on plate number (even/odd).

De Almeida, Silveira, Jeneulis and Fuso-Nerini (2021) assess transportation policies to mitigate climate impact in Curitiba, Brazil. Some noteworthy strategies are incentives for acquiring environmentally friendly vehicles, creating zero emission zones and LEZs, promoting bicycle and public transportation use, and reassigning public spaces to encourage bike use, walking and public transportation.

The work by Quarmby et al. (2019) emphasizes the importance of combining diverse road-transport related measures to improve air quality in urban areas, including reducing speed limits, implementing LEZs, creating barriers that promote air quality by combining vegetation and artificial materials, as well as investing in infrastructure to encourage the use of alternative transportation, such as bicycle, bus, and electric vehicles.

Meanwhile, de Borger and Proost (2013) examine government policy measures to reduce externalities such as pollution and noise. Such measures include speed limits, urban tolls, infrastructure investments to mitigate externalities (such as acoustic barriers, speed bumps, traffic lights and pedestrian sidewalks), technology used to manage traffic and the creation of LEZs.

In their study, York-Bigazzi and Rouleau (2017) address strategies to improve traffic control and, in turn, the environment. The strategies include lane management, speed control, restrictions and fees, traffic management systems and infrastructure, and actions to reduce commuting.

Mirhedayatian and Yan (2018) focus on support policies for freight-transport electric vehicles, including subsidies, restricted access and tax deductions.

Focusing on India's context, the study by Hezam, Basua, Mishra, Rani and Cavallaro (2023) classifies zero-carbon emission measures for transportation in smart cities. They report the implementation of zero-emission zones to be the primary strategy, followed by initiatives related to low-emission energy production and the promotion of environmentally friendly vehicles through incentives.

Finally, Sousa-Santos, Sundvor, Vogt, Grythe, Haug, Høiskar et al. (2020) discuss a variety of traffic control strategies in Oslo, Norway, which include the increase of urban tolls, free public transportation, odd-even driving restrictions, creation of preferred lanes for low-emission vehicles, increase of parking rates, and LEZs implementation. According to the study, LEZ stands out as one of the most effective measures.

Regulatory policy strategies	Source	City/Country
Prohibition of vehicle circulation in time slots	Rashid et al. (2021)	Bradford, UK
	de Almeida et al. (2021)	Curitiba, Brazil
	York-Bigazzi & Rouleau (2017)	North America
	Ocampo-Giraldo et al. (2019)	Medellín, Colombia
Broader outreach of regulatory information	Yang et al. (2017)	Beijing, China
Management of fees or restrictions for parking of non-environmentally friendly vehicles	Sousa-Santos et al. (2020)	Oslo, Norway
	York-Bigazzi & Rouleau (2017)	North America
	Rizki et al., (2022)	Jakarta, Indonesia
Congestion pricing	Rizki et al. (2022)	Jakarta, Indonesia
	Mirhedayatian & Yan (2018)	Undefined
	York-Bigazzi & Rouleau (2017)	North America
	de Almeida et al. (2021)	Curitiba, Brazil
Emission-based restriction	Rizki et al. (2022)	Jakarta, Indonesia
	Mirhedayatian & Yan (2018)	Undefined
	de Almeida et al. (2021)	Curitiba, Brazil
Priority lanes for environmentally friendly vehicles	York-Bigazzi & Rouleau (2017)	North America
	Sousa-Santos et al. (2020)	Oslo, Norway
Road space rationing	Sousa-Santos et al. (2020)	Oslo, Norway
	Rizki et al. (2022)	Jakarta, Indonesia
Improved issuance system if truck circulation licenses	Yang et al. (2017)	Beijing, China
Taxes for non-environmentally friendly vehicle purchases	de Almeida et al. (2021)	Curitiba, Brazil
Subsidies for energy-efficient vehicles	Hezam et al. (2023)	India
	Mirhedayatian & Yan (2018)	Undefined
	Pamucar, Deveci, Canıtez, Paksoy & Lukovac (2021)	London, UK
	de Almeida et al. (2021)	Curitiba, Brazil
Speed management to mitigate the stop-start nature of traffic	de Borger & Proost (2013)	Undefined
	York-Bigazzi & Rouleau (2017)	North America
	Quarmby et al. (2019)	Honolulu, USA
Improved charging network for electric vehicles	Quarmby et al. (2019)	Tallinn, Estonia
	Pamucar et al. (2021)	London, UK

Table 7. Public policy strategies other than LEZ to mitigate environmental impacts

3. Pilot Zone Description

Downtown Medellin (Colombia) is a highly frequented and emblematic area that plays an important economic and business role in the city. Its importance has led to a significant growth in both formal and informal commerce and a large influx of people, private vehicles, public and freight transport (Figure 3). This heightened commercial and service activity has turned downtown Medellín into a highly crowded area, making traffic and people congestion part of its day-to-day reality, exacerbating its security, informality and mobility problems.

Historically, downtown Medellín has faced security, informality and mobility issues that have resulted in significant control and public order challenges. In turn, this has affected the perception of security in the area and has caused other associated issues, posing challenges to public administration and affecting the development of commercial activities and logistical operations.

High traffic congestion in the area has led to problems affecting air quality. According to measurements of the air quality network in Medellin, monitoring stations showed that one of the points with the highest pollution load is the city center, which has a high concentration of pollutants (Area Metropolitana del Valle de Aburrá, 2022). Upon analyzing historical data, it became evident that during 75% of the year, the concentration levels of pollutant particulate matter smaller than 2.5 microns (PM2.5) are higher than those allowed by national regulations, so the city center is classified as a "High-Pollution Source Area – Class I" (Secretaría de Movilidad, 2023).

The implementation of an Urban Protected Air Zone –or low emissions zone (LEZ)– is one possible mitigation measure. While this measure can mitigate the issue, it would affect businesses and factories in the area since it would significantly impact urban logistics. The implementation of restrictive measures such as an LEZ poses specific challenges given the complex logistical and socioeconomic dynamics, as well as the need for small and medium-sized companies to adapt to regulations that may not be easy to adopt due to their economic situation.

It should be noted that the downtown area has developed over time with a commercial and business nature, unlike many other countries where the city center is characterized by being a tourist, historical and cultural area. Given its context and commercial tendency, LEZ implementation would significantly impact the urban logistics of the area.

Figure 3. Downtown Medellín image (Google, 2022)

To determine the strategies to be implemented by the city government in the future LEZ, a key area was selected as a pilot zone because it is representative of the city center. This study aims to understand stakeholders' perceptions and logistical needs, including freight flow. The purpose is to propose alternative strategies that make it easier for business establishments and factories to adapt to the possible regulations established by LEZ, particularly regarding logistics.

4. Methodology

The study seeks to analyze the logistics of business establishments in downtown Medellín to identify problems and possible strategies to face the future LEZ, using a representative area as a sample. For this purpose, a research instrument was designed with closed and open questions, and it was then applied to the logistics staff of these establishments. Until now, there was no characterization of the zone logistics that could serve as a reliable support to make decisions on the strategies to be implemented in the LEZ.

To this end, we considered the following research questions:

RQ-1: How do freight delivery and reception logistics behave in the establishments in the selected area?

RQ-2: What are the key issues limiting efficient freight delivery and dispatch on business establishments?

RQ-3: What are the strategies, proposed by businesses in the area to problems of freight loading and unloading, that align with the objectives pursued by LEZ implementation?

RQ-4: What is the perception of establishments in the LEZ pilot zone about the viability of nighttime loading and unloading and the use of cargo bikes as alternative measures?

The study is based on selecting participants and a representative corridor on the zone, collecting data through interviews focused on freight logistics, and analyzing this information to propose strategies that are aligned with implementing policies in the LEZ in downtown Medellin, while considering the urban logistics of the zone. This paper aims to provide significant input to understand the logistics situation, identify challenges, propose solutions and support decision-making aimed at improving air quality in the area, while knowing its impact on the logistical operation of businesses in the LEZ of Medellin.

The methodology used in the study is divided into three main stages: selecting participants and a corridor for the interviews; identifying variables and designing instruments; and processing information and evaluating proposals. Figure 4 shows the stages and processes involved.

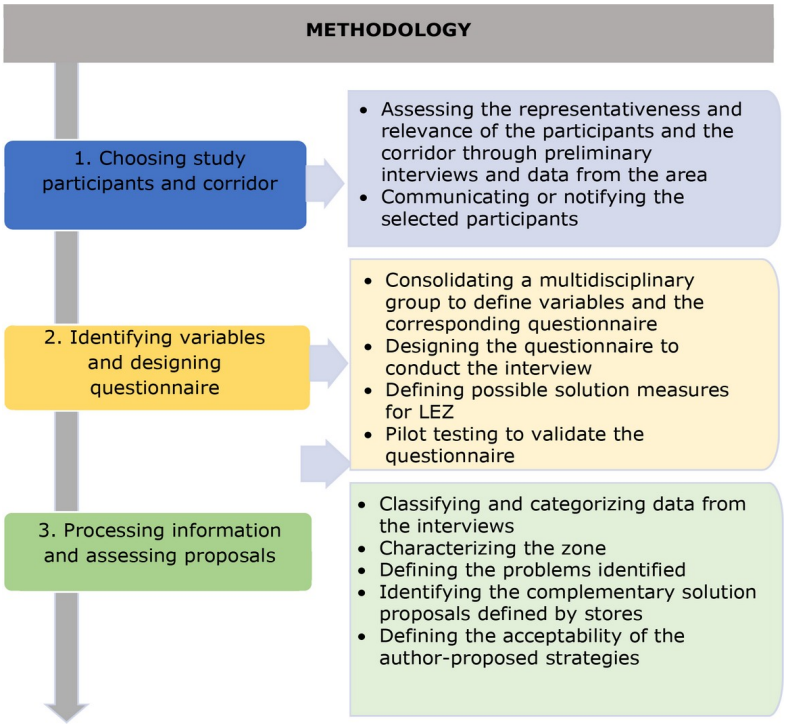

Figure 4. Research methodology description

4.1. Selecting Participants and a Corridor for Interviews

The first step is to select a representative area that illustrates the general behavior of the LEZ in downtown Medellín. This will allow relevant decisions to be made when implementing policies in the area. The corridor was chosen for its complexity and commercial representativity. Figure 5 shows the selected area, which has a significant traffic and commercial flow and consists of 9 blocks –approximately 900 meters– on *Avenida Colombia.*

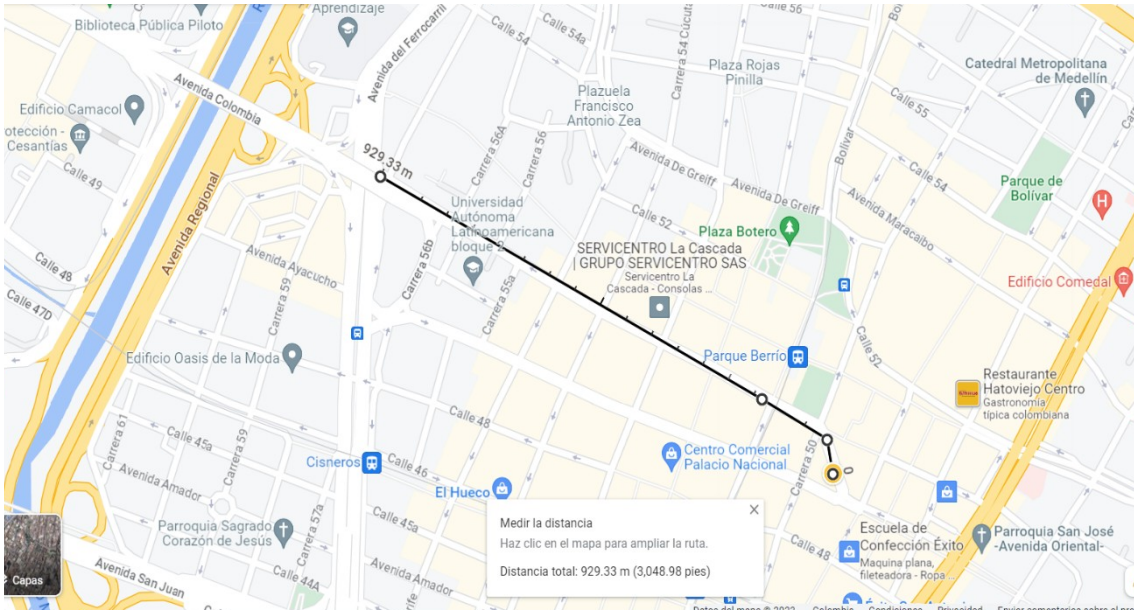

Figure 5. Selected corridor: Avenida Colombia (Google, n.d.)

The area was selected based on technical criteria of experts familiar with the area, including representatives of transport unions, freight senders, academics and mayoral officials with experience managing the city downtown area. Hence, the selected area was considered valid and the one to better represent all characteristics and problems that may be found in the rest of the areas included in the future LEZ.

The approach of this study was to take a census of 100% of the establishments in the selected corridor, rather than a representative sample. The purpose was to obtain an exhaustive and detailed view of the logistics situation in the studied area. Besides, there was no exact information on the typology, quantity and characteristics of the businesses in the area that would allow for stratified sampling.

The study covered all establishments, regardless of their economic activity, excluding only homes or chapels. A total of 105 businesses engaged in commercial, manufacturing and service activities were identified and subject to the survey.

4.2. Identifying Variables and Designing the Questionnaire

This stage involved identifying variables and designing an instrument to characterize the logistics of the selected establishments. Academic researchers, representatives of the logistics business sector and local authorities participated in this process. The literature review allowed identifying some possible strategies to be evaluated in this study. Then, experts analyzed them considering the specific characteristics of the study area to determine which strategy could be more viable and effective in the local context and focusing on solutions that entrepreneurs could implement to improve loading and unloading logistics and contribute to the LEZ objectives.

The survey included questions on the acceptability of proposals such as nighttime loading and unloading and using cargo bikes in the LEZ. It also inquired about other strategies aligned with by LEZ implementation objectives proposed by businesses in the area to address loading and unloading issues. Below are the topics considered in the interview instrument:

- Establishment characterization: type and total area.
- Freight receipt and dispatch logistics: type, frequency, schedules, volume, type of packaging.
- Physical infrastructure used and available for receipt and dispatch.
- Freight transport: vehicle type, business hours, frequency, required times.
- Identification of companies that collect or dispatch within the city center.
- Questions addressed to the staff in charge of the establishments in the pilot zone to identify the existing challenges and possible alternative solutions to optimize the freight logistics in the LEZ.
- Questions about the acceptability of two proposed actions to be implemented in the LEZ from the perspective of the establishments in the pilot zone: nighttime loading and unloading and use of cargo bikes.

These data are essential to understand the current logistics situation and the needs of businesses affected by the new regulations. The data also provide information on stakeholders' perceptions and opinions, which is essential to understand their position, needs and possible solutions from their perspective. Understanding these proposals is essential to designing more effective and realistic policies.

Before the interviews were conducted, the research instrument underwent a validation process and was pilot tested. Likewise, the interviewers were trained to properly understand the concepts and variables to be studied.

In order to characterize the sector and its logistics, the instrument was applied to all commercial, productive, and service stores located in the corridor, where the interviewees were responsible for freight logistics in the stores. The total number of interviewees was 105.

4.3. Processing Information and Assessing Proposals

The third step is analyzing the information collected. Data is classified into quantitative and qualitative categories, the latter being the perceptions, opinions, and proposals identified by the interviewees. Data analysis is conducted, grouping the information by categories, and then integrating the results to assess and propose solutions for urban freight logistics in the evaluation area.

These results provide an opportunity to assess the acceptability and feasibility of preliminary actions proposed by local authorities. This information is valuable to validate and adjust government decisions in the implementation of LEZs, and it provides a solid basis for decision-making; thus, preventing decisions from being considered only by government actors without regard to the needs and perceptions of local storekeepers and to how these decisions will impact the operation of stores and factories in the LEZ.

5. Results and Discussion

5.1. Characterizing the Zone

Most stores (30%) sell household appliances, electronics and home products. The next most common stores are textiles and clothing (15%) and food (14%).

Regarding zone characterization, 93% of the businesses in this area are classified as micro-enterprises. This classification is granted to businesses with less than 10 employees and assets valued at less than 500 current legal monthly minimum wages. Out of this percentage, 90% of stores focus on sales activities, while the remaining 3% are engaged in manufacturing.

Given their characteristics, it is complex for these businesses to adapt their operations to a LEZ. It should be noted that businesses in this area will not be able to adopt models similar to those of developed countries, since out of the sample of vehicles that go into the zone for freight load and unload, 65% are between 6 and 10 years old and 28% are older than 10 years, which mean they all are diesel and gasoline vehicles. It is difficult to renew the vehicle fleet and even more challenging to migrate to electric vehicles, as retailers depend on their suppliers vehicles, especially considering that only 19% of retailers have their own vehicles.

Out of the vehicles that enter the zone for loading or unloading operations, 45% are trucks, 15% are vans or automobiles and 13% are motorcycles; while 25% of the freight receipt and dispatch is done by foot or hand trucks and only 1%, by bicycle. This means that alternative methods of transport account for 26% of freight movement. In contrast, 73% of the transport is done by diesel or gasoline vehicles. The results did not display any movements done by electric vehicles.

The volume of logistical operations for freight distribution in the area is remarkably high since more than 50% of the establishments must perform several daily dispatches (loading operations) and receive different vehicles with merchandise (unloading operations). On average, each business receives 4 motor vehicles daily that load or unload merchandise or both.

This operation is mainly conducted in the morning, when 54% of the stores load and unload merchandise. The busiest hours are from 8 AM to 10 AM. (34%).

5.2. Problems Identified in the Zone

The logistical problems in the area include the area and businesses lacking an adequate logistics infrastructure: 83% of the vehicles park in public spaces to carry out their loading and unloading operations, competing for limited spaces because only 8% of them operate in the loading and unloading zones. This situation occurs due to the lack of parking controls for private cars, buses and street vendors, which is also one of the most significant problems in the area.

Most interviewees (30%) stated that the major challenge is to comply with the permitted schedules. The main cause is traffic congestion, which, to a large extent, is caused by the number of buses affecting mobility and schedule compliance. They also deem the time allotted for their operation to be too short.

For 22% of the interviewees, the major problem is the lack of authority control in the zone regarding norm compliance, parking, and road obstruction by buses and street vendors. Insecurity in the zone, also related to lack of control, is the main issue for 7% of the interviewees.

According to 15% of them, the main problem is the lack of adequate loading and unloading areas, besides the fact that they are scarce and inadequately located.

Vehicles remain parked on the road, carrying out their loading and unloading operations for an average of 32.4 minutes.

5.3. Complementary Solutions in LEZ Proposed by Businesses

Entrepreneurs in the zone were asked how their loading and unloading operations could be improved, and 22% of them made proposals focused on improving control of the zone in terms of regulation compliance and parking time control, improving the signage of loading hours and zones, and regulating the occupation of public space.

Likewise, 20% of the entrepreneurs stated that improving loading and unloading logistical operations should be centered on better loading and unloading zones in terms of quantity, location and signage. They also propose designing loading and unloading zones in certain areas and relocating bus stops.

For 16% of the entrepreneurs, loading and unloading hours should be modified to improve operations. Instead of having only one slot in the morning, there should be another one in the afternoon, or the time allocated for these operations should be longer.

5.4. Acceptability of Author-Proposed Actions to Be Implemented in the LEZ

An interdisciplinary team –consisting of academic researchers (authors of this study), representatives from the logistics business sector and local authorities– was in charge of proposing two alternatives to implement in the LEZ to reduce environmental impact and improve freight management efficiency. These two key solutions are nighttime loading and unloading and freight distribution using cargo bikes.

As a means of assessing the acceptability of these measures, store managers were consulted about the feasibility of implementing these strategies, which provided the following results:

Only 8% of the managers consider it viable to implement nighttime loading and unloading. In contrast, 32% of them do not think that this proposal is viable due to the insecurity in the zone, and 54% deem it unviable due to their business hours and the subsequent additional costs, considering that 80% of the businesses in the zone are closed by 7 PM. Moreover, a working day would be lost when employees rotate to change shifts. It is essential to mention that in downtown Medellin, loading and unloading freight during night hours increases the costs from 10 to 20% –according to store owners– and around 25% –according to transporters– (Vargas-Rodríguez, 2015)

As for distribution on cargo bikes, 27% of people consider it feasible, while 72% dismiss it. From the latter group, 40% of people mention the size or weight of merchandise as the main challenge; 4% speak about merchandise type; 5% refer to security reasons, 7% consider that quantities and time would not be efficient using bicycles; 4% mention distance; and 12% simply does not deem it viable without specifying or knowing the reason. Most companies that do not consider this type of transportation viable are those that deal in household appliances, machinery, furniture, and textiles. In contrast, those that do consider it viable are mainly electronics, miscellaneous, hardware stores, drugstores, and food businesses.

5.5. Analysis of the Interviews

Based on this context and the analysis of the results, the main problems for the efficient freight logistics development of the businesses in the area were the following:

- Most establishments are micro-enterprises primarily engaged in selling products, relying on their suppliers' vehicles and significantly dependent on diesel and gasoline vehicles with a high average age. Logistical operations are centered on motor vehicles, especially trucks. The presence of alternative methods, such as bicycles, is minimal.
- The area lacks adequate logistics infrastructure, and many vehicles are parked on public roads for loading and unloading operations.
- Other problems identified include traffic congestion, lack of authority control, public space occupation, and limited loading and unloading zones.

Finally, upon analyzing the interview results, some possible alternatives for solutions to improve freight logistics in the LEZ located in downtown Medellin are outlined:

- Local authorities should implement solutions to improve mobility and shorten vehicles' time in the area. These solutions might include improvements in zone control, clear signage of loading and unloading areas and hours, and the creation of exclusive parking areas for these operations so that vehicles do not have to compete for space with buses, street vendors and vehicles parked on public roads. Likewise, local authorities must create strategies for communicating and spreading information on regulations and educational strategies accompanied by zone signage and authority control both on-site and with camera systems that guarantee regulation compliance.
- Improving the logistics infrastructure for these operations would free up space for logistics activities, leading to decongestion and air quality improvement.
- The possibility of extending the permitted loading and unloading hours is being considered, but there are limitations to night operations, such as insecurity and additional costs.
- Flexible hours for loading and unloading should be considered, focusing on minimizing additional impacts and reducing congestion. It should be noted that more flexible hours would not necessarily imply more vehicles in the area; instead, the operation volume would be the same but distributed over clearly delimited time slots.
- Alternative transportation initiatives should expand beyond electric vehicles, which are difficult to finance for small businesses in the zone. On the contrary, to reduce dependence on motor vehicles, another type of alternative loading and unloading vehicles –such as specialized freight transport bikes– should be evaluated and pilot tested (Alvarez, Echavarria & Restrepo, 2020). However, merchandise type, distances,

safety, and efficiency should be considered when designing freight distribution systems for certain businesses in the area.

- To develop these strategies, it is fundamental to support small and medium-sized enterprises (SMEs) with incentives and vehicle renewal programs that adapt to their financial capacity.
- Conduct a detailed analysis of the costs and benefits of implementing freight consolidation centers in conjunction with alternative distribution methods (bicycles and hand trucks) to reduce traffic flow in the area. This alternative requires the support of local authorities to coordinate collaboration between businesses, which includes warehouses or consolidation centers, sharing transport and public incentive policies.
- Cargo bikes might be a good bet for Colombia as an alternative to mere restrictive policies, since most businesses in the zone are SMEs without electric vehicles or resources to renew their fleets given their environmental and demographic background. This situation makes it difficult to comply with LEZ regulations, as stated in the study by Pye, Norris, Searl, Watkiss, Wilkins and Pooley (2006) that investigates the impact of LEZs in London. Their study suggests that smaller businesses are affected by LEZ implementation since they could not recover investments made in vehicle renewal to comply with restrictions and this might even lead to employment reduction.
- Night operations are a challenging topic in the zone. Evaluating this alternative's financial and social viability demands a thorough study because safety and cost mitigation strategies must support it.

In summary, the proposed solutions should focus on improving the logistics infrastructure, reviewing regulations and schedules, setting up educational strategies, introducing sustainable and viable transportation alternatives that are in line with the characteristics of the businesses in the area, providing support to SMEs, and conducting a detailed economic analysis to implement effective changes in the logistical operation of the area affected by the implementation of a LEZ in downtown Medellin.

6. Conclusions

Downtown Medellin faces significant challenges that affect its logistic operation and air quality. Traffic congestion, resulting from a lack of control and regulation in loading and unloading areas, hinders commercial operations. More effective regulation and control strategies should be implemented in the area to remedy this situation. Such strategies include defined schedules and specific areas reserved exclusively for these activities, promoting more efficient mobility and fluid logistics.

There is a proposal to explore sustainable transport alternatives, such as specialized freight transport bikes, to reduce dependence on motor vehicles and, in turn, contribute to reducing environmental pollution. Likewise, to effectively transition into more sustainable practices, it is fundamental to support small and medium-sized enterprises with incentives and vehicular renewal programs that adapt to their financial capacity.

Moreover, educational strategies should be implemented to raise awareness among entrepreneurs and drivers about the importance of complying with rules and regulations. Improved and clear signage about loading and unloading hours and areas and establishing specific areas for these operations would help optimize zone organization and avoid inappropriate public space occupation.

The circumstances described for the implementation of a low emission zone (LEZ) in Medellin are significantly different when compared with LEZ implementation in Europe. These differences are evident in Medellín's infrastructure, socioeconomic dynamics, and logistical complexity that demand specific strategies tailored to this context for LEZ to be successful in the city.

In Europe, LEZ have been implemented in predominantly urban areas with a historic, tourist and cultural orientation. These areas tend to have infrastructures more suited to their nature: high availability of public transport alternatives, more environmental awareness and a greater tendency to adopt cleaner technologies. In contrast, downtown Medellín is characterized by its intense commercial and business activity, filled with micro-enterprises

dependent on cargo vehicles and with a logistics infrastructure less suitable for transitioning to lower emission technologies.

Differences between countries can be observed in economic capacity and commercial agents' adaptability: while in Europe, the adoption of electric vehicles and alternative transport systems is higher, in Medellin, micro-enterprises have financial and structural limitations that make it more challenging to adopt cleaner technologies quickly. Most of the fleet runs on diesel or gasoline and has a high average age. Thus, the transition to a cleaner technologies proposal is a significant financial challenge. For example, traffic restrictions based on the vehicle age, while applied in other countries, would render impossible the logistical operation in downtown Medellín.

Therefore, LEZ implementation in Medellín requires specific considerations. It requires strategies that address not only regulation and control but also logistics infrastructure, offering financial aid, supporting policies for small and medium-sized enterprises, and providing viable transportation alternatives for the zone. Adapting to LEZ in Medellin requires considering the socioeconomic reality, logistical complexity and commercial structure of the city, focusing on sustainable and feasible solutions within the local context.

In addition, the nature of downtown Medellin –a decidedly commercial zone– creates a complex logistical dynamic in which freight supply (loading and unloading) is fundamental to the daily operations of micro-enterprises. Space constraints, traffic congestion, and lack of adequate zones for these logistical operations pose additional obstacles to successful LEZ implementation in this zone.

The literature review of publications prior to this study and related to low emission zones (LEZs) shows that most studies focus on evaluating the environmental impact of these zones before and after implementation. However, it appears that there is a significant lack of research specifically addressing the impact of LEZ in urban freight transport: only 3 of the publications considered in this paper examine this topic. This knowledge gap offers a potential area for future research. Furthermore, it is essential to state that research on the business acceptance of LEZ is overall limited, more even so in countries with emerging economies. This implies there is another potential research area.

Likewise, there is a noticeable lack of studies examining business strategies that support or complement the implementation of LEZs with the objective of reducing air pollution. This paper contributes to this research topic by addressing the analysis of freight logistics in a developing country within a LEZ before its implementation.

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