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Examining low-emission zones in urban destinations: climate change action or further *touristification*?

Examinando las zonas de bajas emisiones en destinos urbanos: ¿acción contra el cambio climático o mayor *turistificación*?

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Abstract

The growing process of *touristification* and the effects of climate change are some of the most pressing issues for cities today. This research examines the complex relationship between the implementation of low-emission zones (LEZs) as a strategy to mitigate climate change and adapt urban spaces to its widespread ramifications, and the touristification of cities. The study analyses

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48 LEZs in Spanish cities, employing a combination of statistical (i.e., fsQCA) and spatial analyses. Despite presenting heterogeneous realities, the findings reveal a dual effect. On one hand, the implementation of LEZs and related pedestrianisation promote air quality improvement and reduces emissions. On the other hand, this traffic calming initiative leads to further touristification by facilitating commercial activity aimed at visitors, occupation of public space, and increased walkability of streets. However, results also indicate that the geographical display of LEZs responds to manifold factors that do not follow this logic in all cases. Three distinct categories of cities are identified according to different implementation strategies and objectives. An additional in-depth analysis of the case of Madrid, a major urban hub and tourist destination, is conducted to further illustrate this complex interplay of factors. This research, which looks at the ongoing implementation of a national law, demonstrates the close relationship between touristification and implementation of LEZs, while it paves the way for future research inquiries into the progression of air quality indices and tourism intensification processes within cities.

Keywords: urban tourism; pedestrianisation; Madrid; traffic calming; tourism carbon footprint.

Resumen

El creciente proceso de *turistificación* y los efectos del cambio climático se encuentran entre los principales problemas a los que las ciudades se enfrentan en la actualidad. Esta investigación examina la compleja relación entre la implementación de zonas de bajas emisiones (ZBEs) como estrategia para mitigar el cambio climático y adaptar los espacios urbanos a sus consecuencias, y la turistificación de los espacios urbanos. El estudio analiza 48 ZBEs en ciudades españolas, empleando una combinación de análisis estadísticos (i.e. fsQCA) y análisis espacial. Los resultados revelan un doble efecto: por un lado, la implementación de ZBEs y la peatonalización relacionada promueven la mejora de la calidad del aire y mitigan las emisiones. Por otro lado, esta pacificación del tráfico conduce a una mayor turistificación, al facilitar la actividad comercial orientada a los visitantes, la ocupación del espacio público y mejorar el tránsito peatonal en las calles. Sin embargo, los resultados también muestran que la implantación espacial de las ZBEs responde a múltiples factores que no siguen siempre esta lógica. Se identifican tres categorías distintas de ciudades según diferentes estrategias de implementación y objetivos. Por último, se realiza un análisis adicional en profundidad del caso de Madrid, un importante centro urbano y destino turístico, para ilustrar más a fondo esta compleja interacción de factores. Esta investigación, que ahonda en la implementación en proceso de una ley nacional, demuestra la cercana relación entre el desarrollo de ZBEs y la turistificación de las ciudades mientras asienta las bases para futuras

investigaciones sobre la progresión de los índices de calidad del aire y la intensificación del fenómeno turístico en las ciudades.

Palabras clave: turismo urbano; peatonalización; Madrid; pacificación del tráfico; huella de carbono turística.

1 Introduction

Human activities emitting greenhouse gases (GHG) drive current global warming. From 1990 to 2019, global GHG emissions rose to 59 ± 6.6 $GtCO_2$-eq., 12% higher than in 2010 and 54% higher than in 1990. Rising emissions, fuelled by unsustainable practices, exacerbate climate change impacts, including extreme weather, and threaten food security, health, economies, and ecosystems, causing over 250,000 deaths annually (Intergovernmental Panel on Climate Change, 2018; 2023).

Climate change intensifies heatwaves, worsens air pollution, and disrupts city infrastructure. Urbanisation also affects local warming and precipitation patterns (Intergovernmental Panel on Climate Change, 2023). Hasyimi and Azizalrahman (2018) state that cities, host over half the global population and produce 76% of carbon emissions. Thus, urban environments must be prioritised in combating climate change (UN Development Programme, 2024).

Due to insufficient structural and behavioural shifts (Steg, 2018), governments are enacting climate action plans (CAPs) and policies to mitigate environmental, social, and economic. Bassett and Shandas (2010) note that CAPs use land use and transportation strategies, focusing on visible actions like tree planting and immediate benefits like energy savings. Many European cities have exceeded the European Union's (EU) particulate matter (PM) air quality limits (European Environment Agency, 2019), highlighting a critical issue in the ongoing climate emergency. Numerous CAPs now incorporate low-emission zones (LEZs) to minimise the environmental and health impacts of vehicle emissions (Holman et al., 2015; Carslaw & Beevers, 2002). In these LEZs, only vehicles that meet specific regulatory standards are permitted entry (EIT Urban Mobility, 2022).

Due to higher temperatures and irregular precipitation, Spain is expected to be heavily impacted by natural hazards like wildfires, droughts, and heat waves (Chislett, 2023). In 2023, Spain had the second-highest number of heat-related deaths in Europe (8,353 people) (Martínez-Ron, 2024). Its tourism sector is also vulnerable, with some regions likely to see fewer visitors due to changing climate comfort (Matei et al., 2023). Recognising this reality, the *Spanish Climate Change and Energy Transition Act 7/2021*, aligned with the European Green Deal, mandated that municipalities with over 50,000 residents establish LEZs by 2023. Thus, 151 municipalities must restrict vehicle access to reduce traffic and improve environmental conditions. However, according to the Ministry for Ecological Transition and Demographic Challenge (METDC), by January 2024, only 19 had enforced it, and 70 had designed and mapped the project (METDC, 2024).

However, this traffic pacification process through LEZs implementation and derived increased walkability of many areas might increase tourism in popular urban destinations already suffering from overtourism (e.g. Palma de Mallorca, San Sebastián, Málaga, Barcelona) (De la Calle-Vaquero, Mínguez-García & García-Hernández, 2023; Perles-Ribes et al., 2023). Hence, it is unclear how LEZ implementation will affect tourism in these areas and the criteria for their placement (population benefits, commercial and tourism activity distribution, urban fabric, etc.). This research aims to examine the factors influencing the implementation and geographical distribution of LEZs in tourism cities.

While extensive research exists on the environmental impact of LEZs (e.g. Boogaard et al., 2012; Holman et al., 2015; Panteliadis et al., 2014), little has been done on their impact on urban and tourism dynamics. This study examines the implementation of LEZs, focusing on the interrelation between their geographical layout, tourism activity locations, and population distribution. This research addresses this gap by analysing LEZs in Spain, where tourism is vital and intertwined with urban dynamics and climate change. This country is increasingly becoming active in climate change policies, shifting towards renewable energy and reducing emissions (European Environment Agency, 2018).

The paper is structured as follows. After the introduction, we review evidence on urban tourism and climate change, including key mitigation and adaptation policies. Next, we outline the methodology incorporating descriptive, statistical, and spatial analyses. Following, we present a thorough analysis of the implementation of Madrid's LEZ project. Finally, we discuss the implications for tourism and urban management

2 Cities and climate change

2.1 Climate change in urban destinations

The relationship between cities and tourism is intricate. In recent decades, tourism has driven urban economic growth. Cities attract visitors with diverse activities, services, infrastructure, and transport hubs. Improved affordability and mobility have made short urban stays popular, making urban tourism one of the fastest-growing segments. Urban tourism contributes approximately 10% to local gross domestic product (GDP) in European cities (UN Tourism, 2024), as top European urban destinations receive 223 million arrivals annually, accounting for 36.47% of Europe's total arrivals (TourisMIS, 2023). The rapid post-pandemic recovery and increasing urban tourism contribute to cities' GHG emissions (City DNA, 2023), with high traffic and population density leading to notable waste generation and heat island effects (Hoornweg et al., 2011). Until a few decades ago, urban areas were not adequately recognised as significant carbon emission sources, and cities — constructed with heat-absorbing materials, impermeable soils, and high pollution levels — now face major air quality issues (Hebbert & Jankovic, 2013).

Environmental challenges in cities, intensified by global warming, also impact local tourism. These include severe droughts, floods, heat waves, and thermal discomfort (Clarke et al., 2022). Academics advocate for urban sustainable tourism to mitigate these adverse effects. Unlike traditional urban tourism, sustainable urban tourism integrates broader sustainability practices, addressing both supply-side (e.g. infrastructure innovations) and demand-side (e.g. customer interface activities) considerations, promoting environmental responsibility, local economic vitality, cultural sensitivity, and experiential richness (Miller et al., 2015; Scott & Cooper, 2010).

2.2 Climate change mitigation and adaptation

The goal of limiting global warming to 1.5 °C set by the 2015 Paris Agreement now seems out of reach. Projections suggest global temperatures could exceed 2.0 °C by 2050 without rapid decarbonisation (UN Environment Programme, 2023). Climate change strategies include mitigation -reducing GHG emissions-, and adaptation -minimising impacts. Mitigation has been prioritised in climate policy, while adaptation mainly addresses natural hazards (Wang et al., 2023). Thus, most international treaties, like the Kyoto Protocol and the Paris Agreement, emphasise mitigation over adaptation (VijayaVenkataRaman et al., 2012).

However, climate change policy is highly fragmented (Kane & Shogren, 2000). Non-compulsory policies encourage voluntary emission reductions through subsidies, educational programs, and government investments. Mandatory policies enforce reductions via regulations or financial penalties, such as vehicle efficiency rules, building standards, and renewable energy requirements (Rhodes et al., 2017).

2.3 Urban Vehicle Access Regulations and Low-Emission Zones

The 2021 'EU Urban Mobility Framework' by the European Commission emphasises the need for environmentally friendly and convenient urban transportation. It aims to ensure equitable and accessible mobility for all, making city destinations reachable for residents and visitors (European

Commission, 2023). Urban vehicle access regulations are crucial for climate change policy. They aim to reduce carbon emissions, improve residents' quality of life by decreasing congestion and accidents, reduce heat islands, and support greening actions. These strategies can enhance urban appeal and overall liveability. Urban vehicle access regulations include traffic limitations like Low- or Zero-Emission Zones, pedestrian areas, and parking schemes to meet EU air quality standards. Over 70% of these regulations are low- or zero-emission zones, allowing access only to vehicles meeting specific standards (EIT Urban Mobility, 2022).

LEZs originated in the late 1990s with the establishment of *Miljözon* in Swedish cities, later evolving into a national framework in the 2000s. As cities grapple with effectively implementing and maintaining efficient and practical programs, many LEZs receive support from national projects with standardised criteria (Holman et al., 2015). By 2022, Europe had 320 LEZs in 15 countries, which are projected to exceed 500 by 2025, primarily due to the incorporation of LEZs in Spanish cities (Table 1).

Table 1. Number of European LEZs by country and year

Country	2022	2025	Affected vehicles	National framework
Italy	172	172	Various	No
Germany	78	78	All vehicles except motorbikes	Yes
United Kingdom	17	18	Heavy duty vehicles (HDVs) and light duty vehicles (LDVs), in London	No
Netherlands	14	14	Heavy good vehicles (HGVs)	Yes
France	8	42	HGVs	No
Sweden	8	8	All vehicles >3.5t	Yes
Austria	6	6	HGVs	Yes
Denmark	4	4	HDVs	Yes
Spain	3	149	All vehicles without environmental badge (EB) provided by the Spanish General Directorate of Traffic (plus, locally defined restrictions).	Yes
Belgium	3	4	Cars and LDVs that run on diesel with Euro 0, 1, 2, 3, or 4 standards, or on petrol with Euro 0 or 1 standards.	Yes
Norway	3	3	N.D.	Yes

Table 1. Continuation

Country	2022	2025	Affected vehicles	National framework
Czech Republic	1	1	HGVs	No
Finland	1	1	Buses and garbage trucks	No
Greece	1	1	All vehicles	No
Portugal	1	1	Cars and HGVs	No
Poland	0	2	All vehicles without EB provided by Minister of Climate and Environment (plus, locally defined restrictions).	Yes
Bulgaria	0	3	Passenger vehicles with up to 9 seats (M1) and goods transport vehicles with a maximum weight of 3.5 tonnes (N1, based on Euro standards).	Yes

Source: own elaboration based on Azdad, Stoll & Müller (2022), Bergeling & Marchetti (2024), Holman et al. (2015), LEZ Brussels (n.d.), METDC (2024) & Republic of Poland (2023)

LEZs restrict vehicle access through measures like time limitations, vehicle charges, car-sharing, or pedestrianisation (Cass & Faulconbridge, 2016). They are typically implemented in high-traffic areas with significant economic and social activity. The scope and characteristics of LEZs vary based on cultural, legal, and environmental factors and air quality goals (Holman et al., 2015; Vassallo-Magro et al., 2021). LEZs can be categorised by various criteria. Restrictions may limit specific vehicle types, as shown in Table 1 for major European LEZs. Spanish LEZs can also be classified by the days and times they are effective (METDC, 2024). LEZs may be temporary or permanent, either static or gradual, depending on their implementation process. According to their size and shape, LEZs can be:

- *Core*: Defined areas like city centres or historical centres.
- *Special*: Areas with unique characteristics, such as business parks or university campuses.
- *Ring*: A core with stricter rules and surrounding transition zones with gradual measures.
- *Punctual*: Specific street sections aimed at higher environmental quality and safety, often in historical centres or vulnerable areas (Madrid Autonomous Government, n.d.).

The impacts of LEZs have been studied for more than two decades. The environmental effect of these policies has been studied from different perspectives. Carslaw & Beevers (2002) focused their study on London's LEZ project and estimated that — due to the complex relationship between vehicles' emissions and the concentration of pollutants in the environment — more stringent measures would be necessary to reduce nitrogen dioxide (NO_2) levels. In contrast, Panteliadis et al. (2014) found notable reductions in air pollution after monitoring the implementation of the LEZ in Amsterdam. Holman et al. (2015) comparatively evaluated European LEZs in five EU countries (Denmark, Germany, Netherlands, Italy, and the UK), while Ezeah, Finney and Nnajide (2015) also analysed the cases of London, Munich and Berlin. In both studies, authors agreed that significant reductions were observed exclusively in German cities following the implementation of LEZ. In Spain, Lebrusán and Toutouh (2022) studied the effectiveness of the LEZ implemented in Madrid and confirmed a reduction in several pollutants within and out of the limited area.

Despite extensive literature, outcomes on LEZ impacts are found to be mixed. There is a gap in examining non-environmental impacts, such as local or tourism development. Some studies link pedestrianisation with commercial and tourism growth (Franco & Foronda-Robles, 2024; Kumar & Ross, 2006; Sastre et al., 2013), but few address LEZs' relationship with tourism and population distribution. This is crucial as overtourism is a pressing issue in many urban destinations, and while LEZs and pedestrianisation benefit the environment, they could also contribute to touristification.

2.4 LEZs, pedestrianisation and the touristification of cities

Over the years, cities have experienced significant transformations due to changing urban planning trends. Initially, the focus was on adapting spaces primarily for road vehicles (Lebrusán & Toutouh, 2022). The emphasis has recently shifted towards creating environments that promote public transport and reduce reliance on cars. LEZs and green spaces reinforce address climate crisis, while regenerating these areas boosts commercial performance (Balsas, 2017; Franco & Foronda-Robles, 2024).

The pedestrianisation of urban areas aligns with Lefebvre's (1991) concept of the 'right to the city,' creating accessible spaces that promote urban life. Walkability, which supports travel and leisure by redesigning urban spaces, ensures fair walking distances for everyone (Said et al., 2017). It is the cornerstone of a sustainable city. Walkable cities improve urban safety and residents' quality of life, as demonstrated by Barcelona's superblocks, which have reduced traffic fatalities and improved air quality (Bausells, 2016).

Thus, LEZs could be a double-edged sword. They may enhance cities' environmental performance by reducing pollution, noise, and GHG emissions, improving citizens' quality of life and boosting local commerce. However, they could also exacerbate touristification by encouraging more tourist-oriented businesses and sightseeing areas.

Urban commodification has rendered tourism and leisure essential components of city life (Harvey, 2015). Touristification replaces traditional economic activities with tourism-related ones (Ashworth & Tunbridge, 2004; Cocola-Gant, 2018; Torres-Outón, 2019). It conflicts with residential needs, influencing housing costs, types of businesses, public spaces, and air quality. Within historical centres, it can damage intangible heritage, diminishing its charm. This transformation reshapes neighbourhoods — resulting into a loss of authenticity — but differs from gentrification as tourists do not permanently reside there (Jover & Díaz-Parra, 2020). Touristification can lead to overtourism, which occurs when the limits of tourist destinations are exceeded (Peeters et al., 2018). Overtourism varies by destination and is influenced by local characteristics, populations, and visitors (Blázquez-Salom et al., 2023).

Saarinen, Rogerson & Hall (2017) argue that understanding tourism's geographical perspective requires studying its spatial organisation, power dynamics, public policies, resource management, and sector impacts. Therefore, exploring the relationship between LEZs (and related pedestrianisation), local populations, and touristification in crowded areas is crucial. Many Spanish cities (e.g. Barcelona, Madrid, Palma de Mallorca, Seville) face excessive tourism pressure, making them ideal for examining these issues (Ardura-Urquiaga et al., 2019; Crespí-Vallbona et al., 2021; Jover & Díaz-Parra, 2020). Hence, this research aims to respond to the following research questions (RQs):

- RQ_1. Is LEZs geographical outreach correlated with tourism activity location?
- RQ_2. Is LEZs geographical outreach correlated with local population distribution?
- RQ_3. How does the intensity of tourism activity influence the distribution of the local population and the design of LEZs in cities?
- RQ_4. What geographical patterns do LEZs tend to follow?

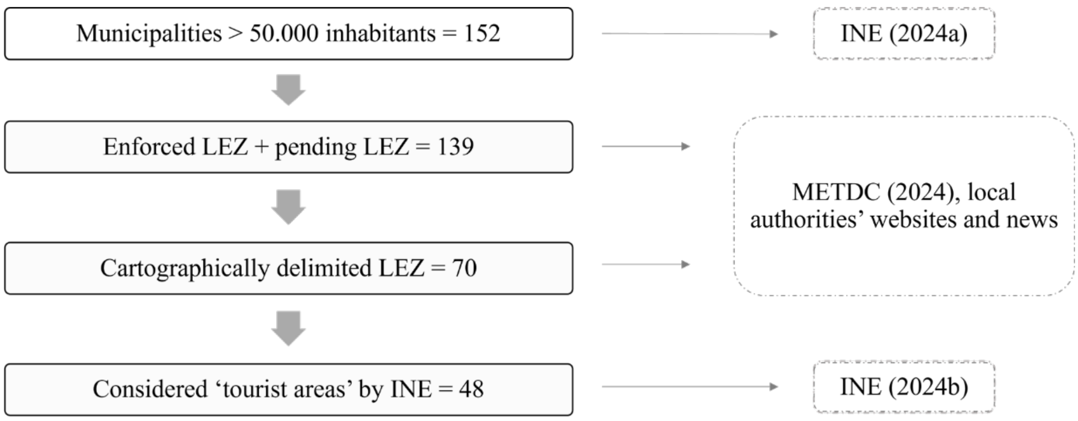
3 Methodology

3.1 Sample definition and data collection

This research identified urban areas with LEZs. As of 2024, the National Institute of Statistics (in Spanish, INE) 152 Spanish municipalities reported populations over 50,000 (INE, 2024a).

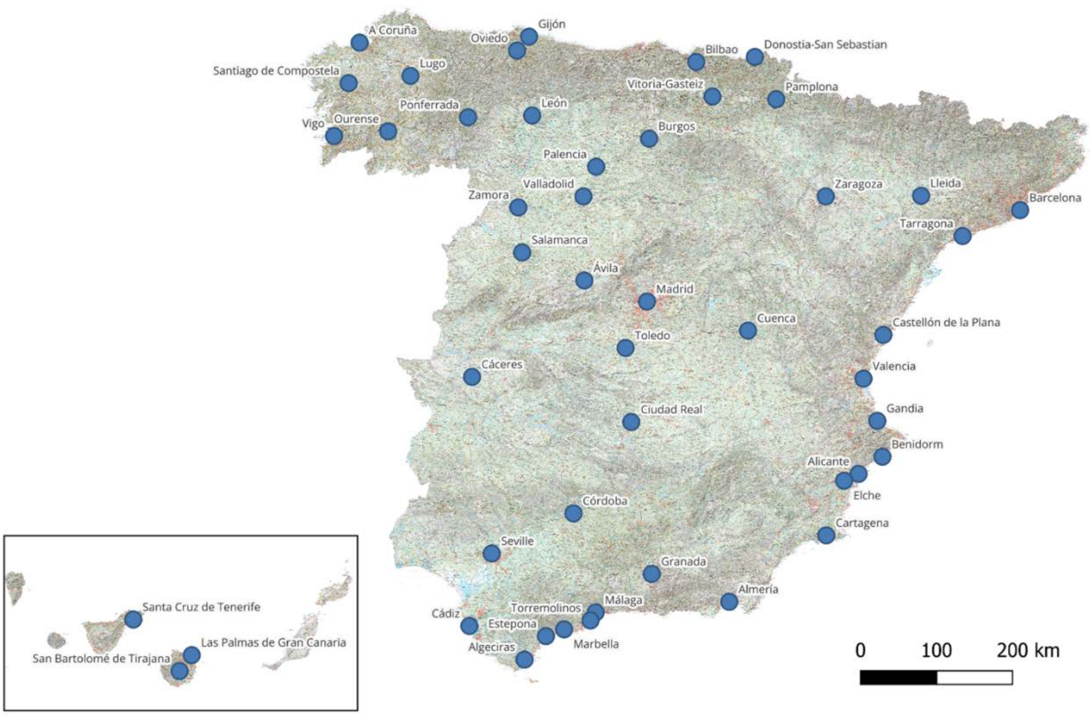
However, only 139 municipalities have implemented or are developing LEZ projects as of December 2023. Of these, only 70 have geographically delimitated their LEZ areas, making them eligible for this study (METDC, 2024). Verification was done through official local and regional authority websites and by media sources when necessary (e.g. Blanco Orozco, 2023). To avoid bias from low-tourism municipalities, we selected the classified as "tourist areas/spots" by the National Institute of Statistics (INE, 2024b), resulting in a sample of 48 Spanish cities (Figure 1 & Figure 2).

Figure 1. Sampling process and data sources



Source: own elaboration

Figure 2. Spanish cities with LEZs



Source: own elaboration

Besides the LEZ projects sourced from official local council data, demographic and tourism variables are included in the analysis. Paulino, Lozano and Prats (2021) highlight the importance of accommodation and tourist service locations in a destination's appeal. Thus, accommodations, tourist information offices, historical centres, and main attractions are proxies for tourist movement patterns (Beritelli et al., 2020). These elements also align with Burtenshaw, Bateman and Ashworth's (2021) components of central tourist districts.

Using coordinate data from hotels (sourced from SEGITTUR and the Spanish Ministry of Industry and Tourism), we consider accommodations key points in tourist journeys. 'Hotels within LEZ' and 'Non-hotels within LEZ' categories are distinguished here. The former exclusively encompasses hotels, while the latter includes all other types of accommodations, mainly consisting of short-term rentals (tourist apartments or "tourist dwellings") (de la Calle-Vaquero & García-Hernández, 2023).

Tourist information offices and historical centres were also mapped as distinct locations, considered key 'space consumption' areas (Zhang et al., 2023) (i.e., "tourist-historic cities" defined by Ashworth & Turnbridge, 2000). To map each city's tourist area, we identified the 15 most prominent attractions based on Google Reviews, avoiding potentially biased destination management organisations' websites. Population distribution analysis by neighbourhood or district relies on census data from municipalities, regions, and the National Statistics Institute.

Beyond the joint analysis of these cities, this paper conducts an in-depth case study of Madrid using an explanatory sequential design mixed method (Ivankova et al., 2006). An intensive-explanatory analysis has been conducted to examine the particularities of Madrid's LEZ. This approach is ideal for describing real-world settings, conceptualising these realities, and deriving practical and theoretical conclusions (Gerring, 2006; Yin, 2009). Madrid's LEZ, the first in Spain, was implemented in 2018 and restructured in 2021. It is one of the most restrictive regarding permitted vehicles and size. Its uniqueness makes it an ideal subject for a single-case study, exemplifying emerging LEZs in Spain and a city with intense tourism activity. This analysis used archival records and diverse documentation sources, including media clippings, administrative documents, and academic research (Yin, 2009). Moreover, these findings have been validated through on-site fieldwork and later mapped.

3.2 Data analysis

We employ spatial and statistical techniques to investigate the relationship between the geographical distribution of tourist attractions, population density, and LEZs. Firstly, we utilised Geographical Information Systems (GIS) to map traffic-restricted areas and analyse their proximity to areas heavily impacted by tourism and their relationship with population data. This analysis aimed to explore the correlation between the distribution of tourism and LEZs. A point coincidence analysis in QGIS 3.32.3 was conducted by overlaying data layers to determine the number of tourist accommodations, information offices, historical centres, and attractions within LEZ areas.

Secondly, the Fuzzy-Set Qualitative Comparative Analysis (fsQCA) was selected for its capacity to determine whether specific conditions or combinations of conditions are necessary or sufficient for a given outcome, providing a more nuanced alternative to traditional regression models. This set-theoretical method enables us to uncover consistent patterns of causality across various cases, making it particularly suitable for datasets that do not adhere to linear multivariate models (Pappas & Woodside, 2021). Aggregated descriptive and qualitative-comparative analyses assessed the relationship between tourism activity and the population within low-emission zones (LEZs) in Spanish urban destinations ($RQs_{1\text{-}3}$). Using fsQCA 4.1, we evaluated the explanatory power of several key variables, including the density of tourism accommodations and attractions within LEZs, as well as the tourism pressure. Cities were ranked based on the outcomes of these statistical analyses.

To complete the findings, we further investigate through a case study the project Madrid 360°, a unique LEZ project in Spain, following Yin's (2009) case study protocol (Table 2).

Table 2. Case study research design components

Components	Our approach
Unit of analysis	Madrid 360° project (single case study), Madrid municipality.
Study questions	• What type of LEZ does the case study respond to? Why? • How is it implemented? • How is Madrid 360° responding according to the expected results? (i.e., environmental impacts) • How is Madrid 360°'s implementation affecting the urban and tourism flows? • How does these relate to overtourism and touristification issues?

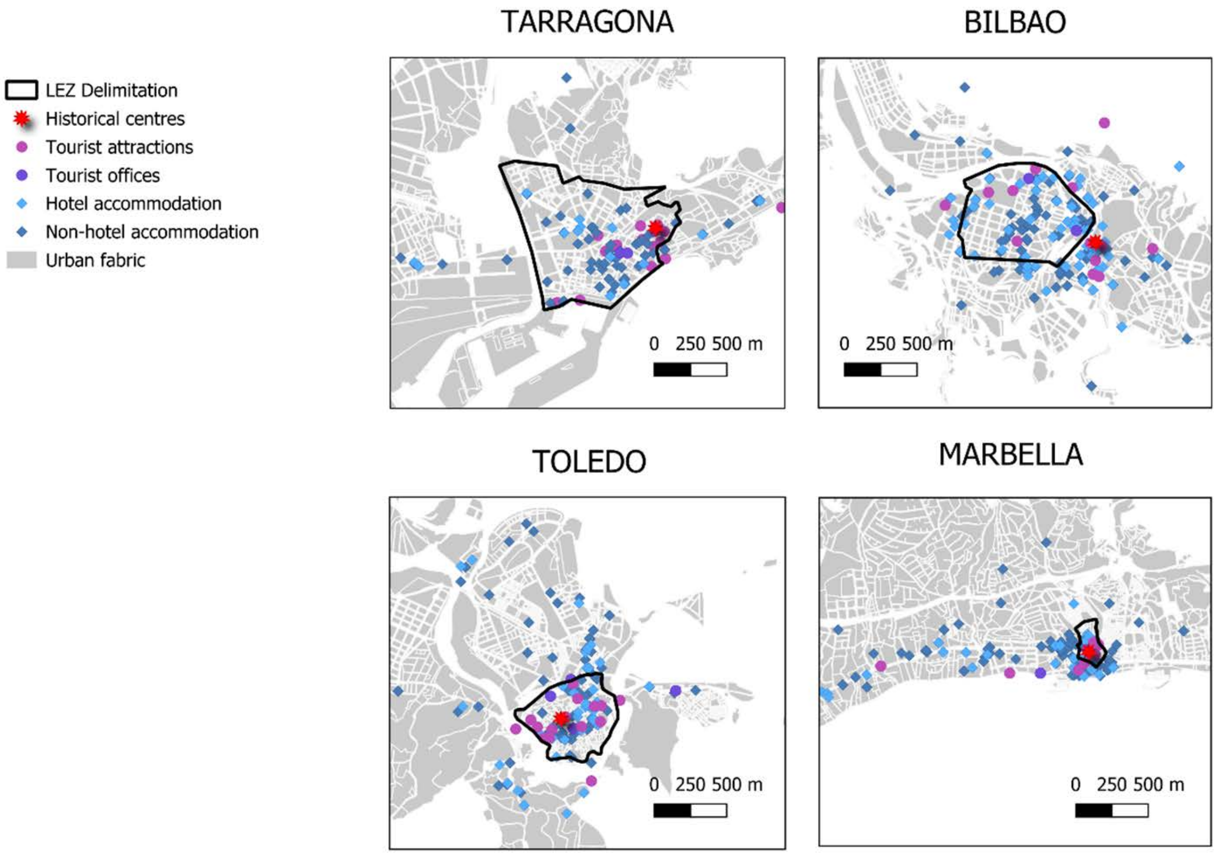
Source: Yin (2009)

4 Analysis of results and discussion

4.1 A geographical outlay of LEZs and tourist activity

Geospatial data on LEZ boundaries, tourist accommodations, main attractions, and historical centres in 48 municipalities were mapped for analysis. Figure 3 illustrates selected examples from the Spanish cities under analysis. The Supplementary Material file provides a comprehensive cartographic analysis of the entire sample. The quantitative results of the data captured in these maps are presented below.

Figure 3. Cartographical representation of the LEZs
in Tarragona, Bilbao, Toledo and Marbella



Source: own elaboration

4.2 Descriptive and inferential results of LEZs' analysis

Table 3 shows the complete descriptive results of the main variables analysed in this study. Disaggregated data can be found in the Supplementary Material file. Due to missing values in the non-hotel tourist accommodations variable of the SEGITTUR dataset, the k-nearest neighbour technique was used in RStudio (2024.12.0+467) to impute the seven missing values. This method is suitable for limited datasets (n=48).

In terms of size, Spanish cities with over 50,000 residents range from 12km² (Cádiz) to 1,750km² (Cáceres). Cities with large rural areas around the urban core may skew results, so population data is also considered. Madrid has the largest population (3,332,035 in 2023), followed by Barcelona (1,660,122), being the only cities with over a million inhabitants (INE, 2024a) (Appendix I).

Table 3. Descriptive analysis

Variable	Mean	Median	Std. Dev.	Min.	Max.
City extension (km²)	257.92	145	335.14	12	1750
LEZ extension (km²)	15.50	0.83	81.64	0.07	562.88
Tourist arrivals/population ratio	4.40	2.49	6.37	0.90	32.51
Population living within LEZ	17.59%	9.71%	22.98%	0.12%	100%
Historical centres within LEZ	77%	-	-	-	-
Tourist attractions within LEZ	51.80%	56.45%	30.90%	0%	100%
Non-hotel accommodation within LEZ	37.26%	34.62%	25.50%	0%	99.90%
Hotels within LEZ	37.60%	33.33%	27.45%	0%	100%

Source: own elaboration

Spanish LEZs average 15.50km², covering about 6% of urban space. Except for Barcelona (80km²), Madrid (56km²), and Valencia (35km²), other cities have LEZs under 8km². 77% of historical centres fall within LEZs. These vibrant and historically significant centres are crucial to cultural heritage and tourism, impacting all social groups (Pérez-Martín, 2017). They are crucial for urban economic and tourism development despite restricted vehicle movement. Tourist accommodations and attractions in LEZs account for 37.60% and 51.80%, respectively, with 17.9% of the local population residing within LEZs. Repeated maximum values are rare but occur in Madrid and Barcelona for several variables.

The fsQCA was used to explore the relationship between tourism activity and the population within LEZs. The analysis focused on identifying patterns and conditions that might influence the presence of LEZ populations in these cities. The outcome variable was the percentage of the population within the LEZ, and the conditioning variables included:

- Outcome variable: Population within LEZ (%).
- Conditioning variables:
    - Arrivals/population ratio (%).
    - Hotels within LEZ (%).
    - Non-hotel accommodations within LEZ (%).
    - Tourist attractions within LEZ (%).

Using the necessary conditions technique, the results in Table 4 were obtained. With minimum thresholds of >0.75 for Consistency and 0.25-0.65 for Coverage (Dul, 2016; Pappas & Woodside, 2021), these results show a strong correlation between the increase in LEZ resident population and the concentration of accommodation facilities and tourist attractions. Thus, except for the ratio of arrivals to inhabitants (i.e., RQ_3), the relationship between population distribution in Spanish municipalities and tourism development variables is demonstrated (i.e., RQ_{1-2}).

Table 4. Necessary conditions analysis

Conditioning variable	Consistency	Coverage
Arrivals/population ratio	0.504291	0.594090
Hotels within LEZ	0.906271	0.642489
Non-hotel accommodations within LEZ	0.929373	0.661965
Tourist attractions within LEZ	0.893069	0.532468

Source: own elaboration

This research provides valuable insights into the potential combinations of conditioning variables that could influence outcomes, particularly regarding population density within LEZs. Although no combination of variables fully optimised the desired outcomes, the analysis revealed interesting patterns that deserve further exploration. *Path 1*, which has the highest raw coverage at 80.59%, shows considerable significance; however, its consistency indicates that there is room for improvement regarding reliability. *Paths 2* and *3* demonstrate moderate coverage and suggest potential factors influencing the outcome, but they require further refinement to be considered reliable predictors. *Path 4* is notable for its impressive consistency of 84.08%, suggesting it can serve as a dependable predictor under certain conditions, although its lower coverage limits its broader explanatory power.

This suggests that, although the conditioning variables identified in this analysis are crucial for explaining the observed outcome, other unconsidered variables, such as non-tourism-related factors, significantly influence the urban population distribution across municipal districts. These findings establish a solid foundation for refining the analysis and enhancing the understanding of the dynamic relationships between tourism activity and population density within LEZs.

4.3 Discussion of LEZs' analysis

The statistical analysis in this article highlights the crucial impact of accommodation and tourist attraction density within the LEZ on the population distribution across the urban area. By examining these variables, common patterns have been detected that allow the classification of Spanish LEZs into three distinct groups.

The *first group* comprises nearly 80% of the studied cities (n=37), exhibiting values close to the study's average (Figure 4). Given its size, this group is distinguished by its heterogeneous characteristics. While smaller municipalities, such as Torremolinos, are also encompassed within this group, it is predominantly characterised by municipalities exceeding 100 km^2 in area (62%). Indeed, nearly 20% of these municipalities have a surface area surpassing 300 km^2 (e.g., Cáceres or Málaga). Likewise, cities with a relatively high population density (1,000 inhabitants/km^2) predominate (62%), with 30% of these cities showing a density exceeding 2,000 inhabitants/km^2 (e.g. A Coruña or Bilbao).

However, these cities also share relevant patterns that allow us to better understand the expected results of implementing their LEZs in the medium and long term. With less than 20% of the population in restricted areas and about 40% of visitors staying within the LEZ on average, these projects do not seem aligned with the need to improve environmental indicators for the local community.

Ashworth & Turnbridge (2000) defined tourist-historic cities as urban areas where historical and cultural heritage play a significant role in terms of economic and social characterisation of the place. In Europe, particularly in Spain, historical centres are where most of the urban heritage is concentrated (de la Calle-Vaquero & García-Hernández, 2023). Within the heterogeneity of the first group, a relevant subgroup of cities declared World Heritage Cities by UNESCO can also be identified: Ávila, Cáceres, Córdoba, Salamanca, Santiago de Compostela, Tarragona and Toledo.

Either through national legislation for heritage protection under figures such as Bien de Interés Cultural (Spanish figure for heritage register and protection) derived from the *Spanish Act of Historical Heritage 16/85,* or through other protection figures such as World Heritage City by

UNESCO, tourist-historic cities protect the heritage they host through policies of traffic access limitations or zoning. While such protective measures enhance the tourism attractiveness of the heritage they guard —leading to a notable rise in visitor numbers (García-Hernández et al., 2017)— these urban areas are less exposed to road traffic simply because this type of protection shields them. They also present urban fabric characteristics (e.g. narrow streets) that facilitate restricted traffic. In many of these cities, traffic restrictions and pedestrianisation of historical areas were already implemented before the national law on LEZs was adopted.

However, in all these cities declared World Heritage Cities by UNESCO, the authorities have opted to locate their LEZ in areas which were already previously preserved with another type of protection status (Supplementary Material file). Therefore, we may infer that the impact of LEZs in these cities will not attain the magnitude observed in other cases analysed in this study due to the opportunity cost associated with their implementation here, which precludes their implementation in areas with the highest pollution levels.

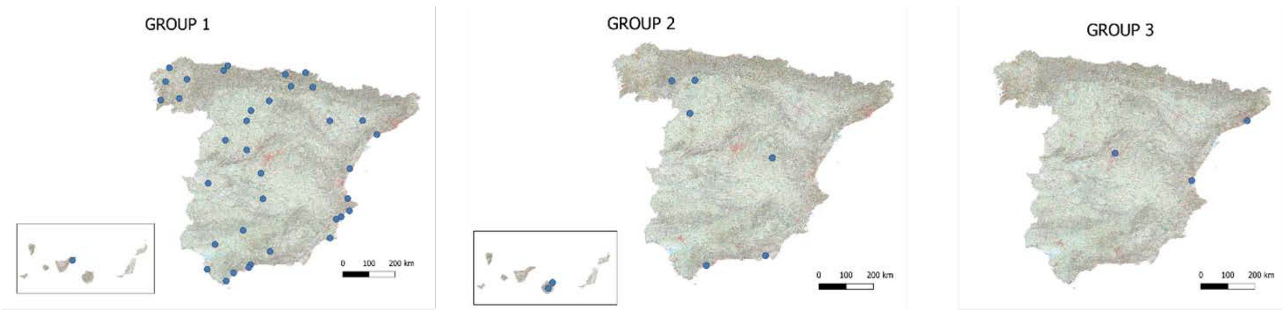
A similar phenomenon is observed in other tourist-historic cities within this first group, including A Coruña, Donostia/San Sebastián or Granada. Although these cities may not possess abundant monumental landmarks, they still attract a significant number of tourists. This attraction is largely attributable to the intricate urban fabric and the distinctive layout of buildings and spaces within their most historical districts (García-Hernández et al., 2017).

Remarkably, the city of Sevilla is included in this first group, which a priori could be assumed to be better aligned with the cities included in group 3. This is due to the unusual location of this city's LEZ, which is placed in an area of the city with a very low population density. This decision could stem from the fact that the old quarter of Sevilla, designated as a Declared Historic Site since 1982, is protected under the Spanish Act of Historical Heritage 16/85, which imposes the need to create Special Protection Plans for all Historic Sites Declared to be of Cultural Interest (Sevilla City Council, 2013).

The significance of Sevilla's historical centre might suggest alignment with the previously mentioned instances, yet this particular case stands apart. Although this initiative had not yet been implemented at the time of this research's publication, the Sevilla City Council put forth the *Respira Plan* for this particular area, which more aptly addressed the unique morphology and socio-economic characteristics of the city's central districts (Parejo, 2022).

Broadly speaking, within group 1, the LEZs implementation in previously safeguarded regions would force the traffic calming of these urban areas where such measures have not yet been executed, and these areas may attract more visitors due to the pacification of appealing urban spaces (Franco & Foronda-Robles, 2024). This traffic pacification often involves privatising public spaces, like creating bar and restaurant terraces and increasing commercial activity. If this occurs in historical centres, the resulting commerce will likely be more transient and visitor-oriented (Casado-Buesa, López-Gay & Blanco-Romero, 2024; García-Hernández et al., 2017). This threat is particularly perilous for cities like Alicante, Donostia/San Sebastián, Málaga, and Palma de Mallorca, facing high tourist pressure and social instability due to overtourism (De Vivar, 2024; Faulkner, 2024; Hidalgo-Giralt et al., 2023). Thus, the proposed LEZs may further touristy already overcrowded areas. Although tourism pressure lacks sufficient explanatory power, the density of tourist accommodations and attractions shows a relationship with population distribution in LEZ areas. There is a close relationship between LEZ locations and areas frequented by visitors. These findings align with similar research (Franco & Foronda-Robles, 2024) and demonstrate the dual impact of policies like pedestrianisation.

Figure 4. LEZs by group



Source: own elaboration

The opposite is the case for cities classified in the *second group*, where municipalities like Cuenca and Almería show consistent patterns (Table 5). This group accounts for the extreme values in the descriptive analysis. These have a defined tourist area, separate from the residential nucleus. Despite limited LEZ coverage, the restricted areas are in commercial, residential, or industrial zones, covering a low proportion of tourist accommodations and attractions. Here, LEZ projects aim to protect urban areas primarily inhabited and used by the local community.

Table 5. List of cities in group 2

City	Tourist attractions within LEZ	Accommodation within LEZ	
		Hotels	*Non-hotels*
Almería	0%	0%	0%
Cuenca	0%	5.56%	15.56%
Las Palmas de Gran Canaria	0%	0%	0.51%
León	0%	5.71%	11.46%
Marbella	30%	9.26%	6.90%
Ponferrada	0%	33.33%	28%
San Bartolomé de Tirajana	0%	6.87%	8.33%
Zamora	0%	14.29%	-

Source: own elaboration

The *third group* includes large Spanish cities: Barcelona, Madrid, and Valencia. These municipalities have the most ambitious LEZ projects in terms of geographical coverage (Barcelona 80km^2, Madrid 562km^2, Valencia 35km^2). These projects cover nearly the entire municipal area, with over 80% of the population and a high percentage of accommodations and tourist attractions within the restricted zone (Supplementary Material file). Unlike the previous two groups, while the LEZ should impact the city's environmental variables, its effects on tourism development may be diluted due to the larger territory and unified restriction measures. The following section explores the specifics of these LEZs via the Madrid 360° project case study.

4.4 Madrid 360° Environmental Sustainability Strategy

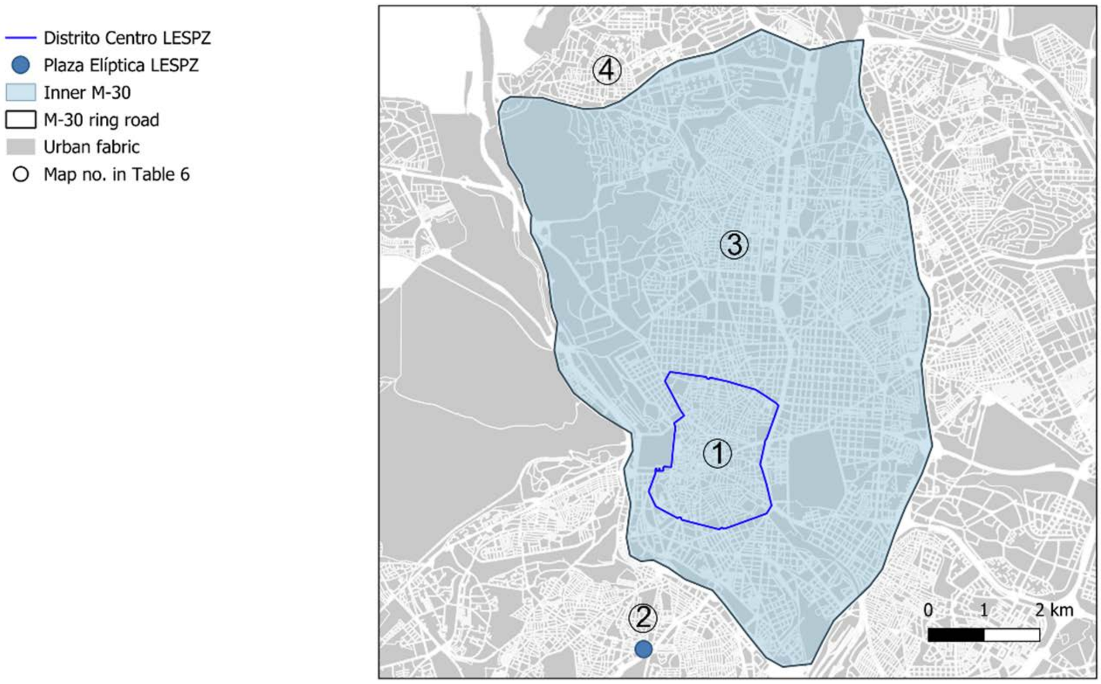
The Destination Sustainability Index praised Madrid for its comprehensive sustainability efforts, highlighting its consistent performance in destination management, socio-cultural, and environmental aspects (De Marchi, Becarelli & Di Sarli, 2023). Madrid ranks among Europe's top five urban destinations (TourMIS, 2023). Recent tourist influx has intensified touristification in some neighbourhoods, causing gentrification and sparking local opposition (Ardura-Urquiaga et al., 2019; Gómez-Bruna et al., 2023). This duality makes Madrid an exemplary subject for comprehensive analysis.

Intense motorised travel in Madrid's metropolitan area is the primary source of GHG emissions, with road traffic generating 74.4% of local emissions (Madrid City Council, 2017). Since 2011, EU air quality limits for nitrogen oxides (NO_x) and ozone (O_3) have often been exceeded, for instance in 2018, when 34 days with poor air quality were registered. Certain weather conditions, like thermal inversion, hinder pollutant dispersion, especially in autumn and winter. To combat this, Madrid's local government introduced the 'Plan A' air quality plan in 2017, featuring 'Madrid Central' LEZ as a key measure. Madrid Central, launched on November 2018, spanned 5 km^2 in central districts of Madrid, and it aimed to improve air quality and make the city centre more pedestrian-friendly. Initially introduced by a left-wing coalition, it sparked significant political debate over its effectiveness and impact on commuters and businesses (Lebrusán & Toutouh, 2022). Since May 2019, the ruling right-wing coalition has introduced the 'Madrid 360° Environmental Sustainability Strategy', which continues the LEZ project with minor adjustments (Vassallo-Magro et al., 2021).

Madrid 360° aims to reduce emissions and improve air quality, renew vehicle fleets, enhance public transport, integrate transport modes, improve road safety, and foster innovation. This is implemented through a gradual LEZ covering the entire municipality (Madrid City Council, 2019) and 21 pedestrianisation works in several districts (Madrid City Council, n.d.-a). Numbers displayed in Figure 5 refer to map numbers enumerated in Table 6.

In response to aggravated pollution in specific parts of the city, Madrid designated 'Low Emission Special Protection Zones' (LESPZ) in 'Distrito Centro' (DC) and 'Plaza Elíptica', effective from December 2021. These zones enforce vehicle circulation and parking restrictions based on environmental classification and speed limits. Vehicle access to the Madrid LEZ and LESPZs is controlled by automated Optical Character Recognition (OCR) cameras inside and outside the M-30, along with traffic officer controls (Madrid City Council, n.d.-b).

Figure 5. Madrid 360° LEZ project implementation process



Source: own elaboration, based on Madrid 360 (2024)

Table 6. Timeline of Madrid 360° LEZ

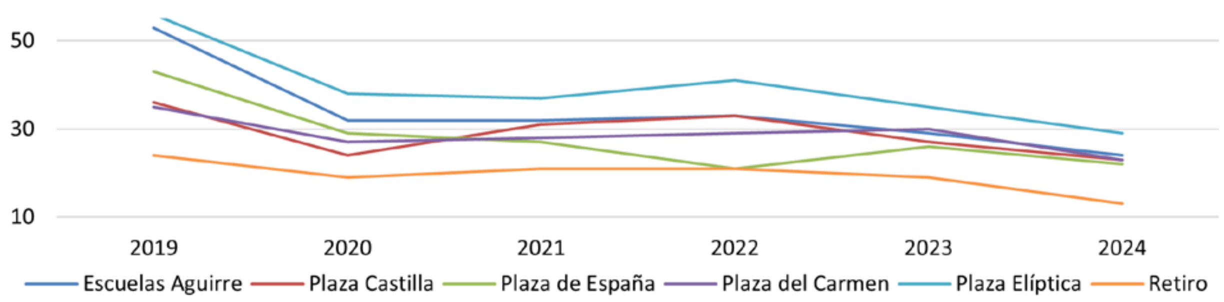
Map no.	Timeline	Enforced measure
1	September 2021	Only vehicles with an environmental badge (EB) can enter Distrito Centro (DC), and those with B or C labels must use indicated parking lots.
2	November 2021	Non-resident vehicles lacking an EB are prohibited from entering the new special protection LEZ (i.e., Plaza Elíptica).
3	January 2022	Access and circulation prohibited for cars without an EB inside the M-30 motorway ring road.
4	January 2023	Cars without an EB not allowed to enter and circulate on the M-30 motorway.
5	January 2024	Non-EB cars cannot drive citywide unless registered locally.
6	January 2025	Petrol vehicles before 2000 and diesel vehicles before 2006, regardless of residency, are prohibited from circulating in the city.

Source: Madrid City Council (2019)

The following aspects have conditioned the current implementation of the Madrid 360° project. Firstly, the *Spanish Climate Change and Energy Transition Act 7/2021*, which promotes vehicle electrification, justifies the LEZ access limitations. Secondly, the city's sensitivity to climate change and the need to meet EU pollution standards required an LEZ covering the entire municipality (Madrid City Council, 2019). Finally, varying pollution levels across districts, as shown by the city's 24 air quality meters, support the creation of special protection zones and the gradual implementation of the Madrid 360° project (Madrid City Council, n.d.-b).

The municipal Air Quality Commission confirmed a reduction in pollutants in 2022 and 2023, especially NO_2 levels. Since 2019, NO_2 concentrations have significantly declined, meeting the EU's annual limit of 40 µg/m^3. In 2022, no monitoring station exceeded this threshold, and in 2023, even the most challenging stations, like Plaza Elíptica, showed improvements (35 µg/m^3 and 31 µg/m^3). Figure 6 shows data from monitoring stations in and around the LEZ, but Lebrusán and Toutouh (2022) have also illustrated the efficacy of these public policies beyond the confines of LEZ. For two consecutive years, Madrid complied with *Directive 2008/50/EC* (Madrid 360, 2023), but the recent EU regulation revision placed Madrid and other major Spanish cities outside the permissible limits (Planelles, 2024).

Figure 6. NO_2 annual mean value (µg/m3) in Madrid (different stations)



Source: own elaboration based on Madrid City Council (2024)

Due to its size and urban and tourism relevance, this paper now focuses on the LESPZ of the DC. The DC contains 8 main tourist attractions and the historical city centre (Figure 7). Over 49% of hotel accommodation and 32% of non-hotel accommodation are located here. Analysis shows that the distribution of these tourist resources and facilities is uneven across the six neighborhoods in the district (Table 7).

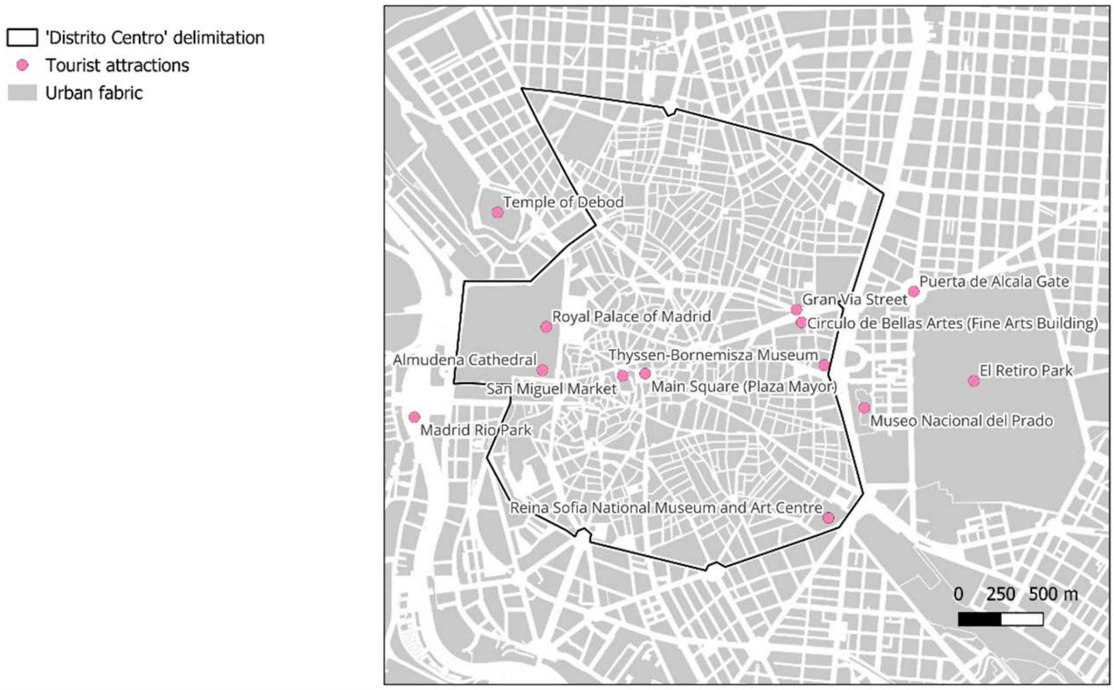
Sol, the smallest and least populated neighbourhood in the district, has the highest density of tourist accommodation in DC. It is also the site of the main pedestrianisation works under the Madrid 360° project. Figure 8 illustrates the streets that have newly been pedestrianised. The points indicated in this figure correspond to the images in Appendix II, which graphically depict the current tourist and commercial status of the analysed area. The Madrid 360° initiative significantly impacts this area. Puerta del Sol square, the neighbourhood's centre, serves as an urban corridor connecting several of the city's most frequented attractions, such as Plaza Mayor and Gran Vía.

Table 7. DC descriptive data

Neighbourhood	Population		Extension		Hotels		Non-hotel accom.	
	Total	*DC*	*Total (m²)*	*DC*	*Total*	*DC*	*Total*	*DC*
Palacio	23,501	16.82%	1,328,721	26.66%	34	15.18%	70	11.48%
Embajadores	46,204	33.08%	1,031,591	20.70%	20	8.93%	66	10.82%
Cortes	10,816	7.74%	531,461	10.67%	53	23.66%	120	19.68%
Justicia	18,219	13.04%	720,618	14.46%	25	11.16%	100	16.40%
Universidad	32,783	23.47%	952,106	19.11%	29	12.95%	103	16.89%
Sol	8,164	5.84%	456,371	9.16%	61	27.23%	152	24.92%

Source: own elaboration

Figure 7. Main tourist attractions of Madrid located in DC



Source: own elaboration

Urban corridors connect urban grids to facilitate the distribution of services (Zahrah et al., 2017). In Madrid, four main corridors link key tourist attractions: Puerta del Sol-Plaza Mayor, Gran Vía, Paseo del Prado, and Plaza España-Palacio Real. All these corridors (except for the Plaza España-Palacio Real corridor, established in 2021 specifically for its architectural significance) accommodate vehicles and pedestrians, fulfilling their dual role of physical space and connectivity (Jones et al., 2007).

Figure 8. Madrid 360° pedestrianisation works in DC

Source: own elaboration, based on Madrid City Council (n.d.-a)

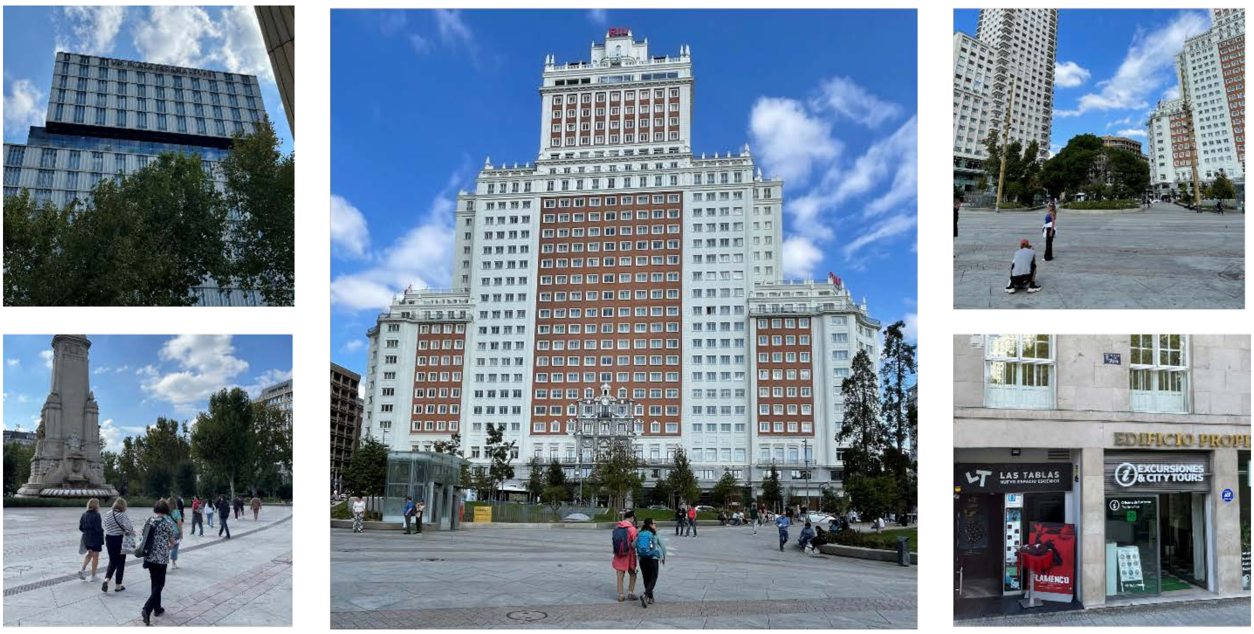
Puerta del Sol and its adjacent pedestrian streets (e.g., Calle Espoz y Mina and Carrera de San Jerónimo) have primarily served as commercial corridors. However, due to their strategic location between attractions and the high volume of nearby accommodations, these corridors are evolving into tourist corridors within the CTD. As depicted in Figure 9 the Madrid 360° initiative is transforming these urban corridors into links, but this jeopardises their 'space' character for residents (Jones et al., 2007).

Figure 9. Newly pedestrianised Carrera de San Jerónimo and Espoz y Mina Streets

Source: the authors

Recent redevelopments, such as the Plaza España remodelling completed in late 2021, have significantly impacted urban dynamics, creating the Plaza España-Palacio Real corridor. Recognised as a major achievement (Calvo, 2020; Viejo & Catalán, 2021), this redevelopment attracted substantial hotel investment, leading to the openings of Riu Plaza España in 2020 and VP Plaza España in 2023. Similar to the Sol district, pedestrianisation and urban pacification of heritage and tourist areas are notably increasing visitor concentration, corroborating previous statistical findings (Figure 10).

Figure 10. Plaza España with new hotels and pedestrian areas



Source: the authors

In the 2023 elections, various proposals outside the Madrid 360° project suggested remodelling Paseo del Prado, from Plaza Cibeles to Glorieta de Atocha. Though not finalised, these proposals aim to pacify the traffic in this central museum axis. Suggestions include pedestrianisation for better habitability and creating a 'green network' or sustainable transport lane for bicycles and zero-emission buses or trams (Barragán, 2023). Given the strategic location and past experiences with traffic calming and pedestrianisation, future redevelopment decisions will be crucial.

4.5 Discussion of Madrid's LEZ analysis

The initial Plan A and the later Madrid 360° initiative are generating clear benefits. As proved by several authors (Duque et al., 2016; Ezeah et al., 2015; Holman et al., 2015; Panteliadis et al., 2014), the results obtained by the monitoring stations demonstrate a considerable improvement in air quality in the city of Madrid that reduces health risk for locals and visitors, as well as an improvement of the quality of life and city experience (Madrid City Council, 2019). The latest Madrid Quality of Life and Satisfaction with Public Services Survey shows that traffic congestion and cleanliness are the top concerns among residents, with pollution as the third most significant issue. Municipal air pollution control services are among the worst-rated (Madrid City Council, 2023). Furthermore, with the European Union's regulations becoming stricter, Madrid must, as Bigazzi and Rouleau (2017) and Carslaw & Beevers (2002) suggest, make a bigger effort to comply with established parameters.

The recent urban transformations developed in Madrid can be correlated with several phenomena identified by Comendador-Sánchez, Hernández-Ramírez, and Santos-Pavón (2024) in main squares of Spanish cities. The processes of *aesthetisation* and *museumisation*, the advent of new spatial uses —such as, the *hotelisation* process (De la Calle-Vaquero, 2019) witnessed in Plaza España— alongside *eventisation* and *neo-monumentalisation,* are among the defining attributes that characterise the new reality of the central district of Madrid.

This study shows the link between increasing touristification and gentrification trends and the traffic pacification efforts in popular tourist areas, especially the neighbourhood of Sol. The findings support prior research by Franco and Foronda-Robles (2024), which suggests that in historical centres and commercial areas, pedestrianisation strategies for emission reduction can amplify the socio-economic impacts of tourism.

5 Conclusions and implications

The primary aim of LEZs is to improve air quality and mitigate emissions, particularly in urban areas with elevated concentrations of PM and GHG (Holman et al., 2015). While several studies have explored the environmental impact of LEZs (e.g. Carslaw & Beevers, 2002; Ezeah et al., 2015;

Panteliadis et al., 2014), the broader implications of these urban planning measures have not been sufficiently examined.

This study sought to explore the intersection between LEZ implementation, climate change mitigation, and urban tourism dynamics. By examining population distribution, tourism activity, and LEZ areas in 48 Spanish cities, we explored how LEZs and pedestrianisation are related to urban touristification. Our findings revealed diverse population distributions, urban characteristics, and tourism levels, resulting in distinct profiles for each city. Additionally, we conducted an in-depth analysis of Madrid, a key example of LEZ implementation in a major hub for urban tourism.

The combination of statistical and geographical analyses has effectively addressed the research questions. The statistical analysis highlights the significant influence of tourism-related variables within the LEZ on the distribution of the population throughout the urban area (i.e. $RQs_{1\text{-}3}$). Although the ratio of tourist arrivals to local population does not clearly define the extent of the impact on residents, our study demonstrates a clear link between tourism infrastructure —such as accommodations and attractions— and the areas affected by LEZ policies. This connection underscores the role of LEZs in shaping the urban experience, with implications for environmental management and tourism development.

Common patterns have been detected to classify Spanish LEZs into three distinct groups (i.e., RQ_4). This study underscored the close interrelationship between cities experiencing high tourism pressure and the specific areas designated for implementing LEZs. This phenomenon is particularly evident in Group 1 cities, which comprise 80% of the total and are predominantly medium-sized Spanish cities. This group includes cities that already suffer from high tourist pressure, such as Donostia/San Sebastián or Málaga. LEZs here benefit a small portion of the local population and are not designed for residential areas. Instead, they focus on central and historical areas heavily influenced by tourism, where residents have often been displaced. Implementing LEZ in previously protected urban areas (e.g. historical centres) may contribute to further touristification.

Madrid is an advanced example of LEZs, and its implementation has positively impacted the environment. Current restrictions in the city centre have increased touristification in already congested areas like Sol. However, with the Madrid 360° strategy, more districts will implement LEZs, though the impact on tourism and residents' mobility is still unknown. This will positively affect the city's environment and mark another milestone in Madrid's fight against climate change.

In terms of implications, the lax application of the *Spanish Act* on climate change and LEZs will impact tourism, the environment, and local communities. This paper suggests potential increases in tourism concentration and intensification in pacified city areas, leading to more touristification and gentrification. Mobility flows for residents and tourists will also be affected, with new pedestrian areas facilitating tourist activities, as proven by the statistical and field research developed in this study (e.g. Figure 10). Alternatives may be needed to support residents' daily activities.

Due to severe travel restrictions in city centres, changes in transport patterns for domestic tourists are expected. Tourist accommodations located in less central areas or outside LEZs may become more appealing to those using private or polluting vehicles. Additionally, using electric vehicles from shared mobility companies could increase for medium-distance travel, moving beyond their current focus on last-mile services.

While a more favourable shift in the perception of politics regarding LEZs has been observed, (Lebrusán & Toutouh, 2022), political interests notably influence the implementation of these measures. For example, the 2023 municipal elections led to government changes that halted ongoing LEZ initiatives such as those in Gijón. Nevertheless, the research conducted by López-Asensio et al. (2021) reveals that nearly 80% of citizens hold LEZs in high regard. They perceive it as a measure that mitigates traffic congestion, noise pollution, and urban grime, thereby enhancing their health and overall quality of life. This raises a broader question about whether LEZ policies are primarily designed to benefit public welfare or serve political agendas.

The latter half of 2025 will be an elucidating period as municipalities fully implement their LEZ regulations in compliance with national legislation. Local governments' responses to emerging social challenges will be crucial in assessing their long-term commitment to climate change mitigation and sustainable urban development.

5.1 Limitations of the paper

Despite its contribution, this study has several limitations. First, while inclusive of all eligible municipalities, the sample size remains limited to Spanish cities. Future research should expand the geographic scope to compare LEZ implementation in different national contexts, where regulatory frameworks, tourism dependencies, and urban structures may vary significantly.

Second, the study relies on data sourced from the Ministry for Ecological Transition and Demographic Challenge (METDC, 2024) for LEZ boundaries. However, some listed LEZs represent planned but not yet operational restrictions, raising concerns about potential greenwashing by municipal governments (Medina, 2024). Additionally, the METDC database does not consistently provide historical or comparative data, limiting our ability to assess longitudinal trends.

Another limitation is the absence of qualitative data regarding stakeholders' prospects. While the study integrates statistical and spatial analyses, interviews or surveys with residents, business owners, and policymakers could yield a more profound understanding of how LEZs influence urban life beyond the quantitative indicators. Qualitative methodologies would enhance our understanding of these urban areas' social and economic transformations. Future research should employ qualitative methods to tackle this limitation.

Furthermore, the absence of standardised open data among municipal authorities complicates cross-city comparisons. Many cities do not provide detailed, publicly accessible data on population distribution, business activity, and air quality metrics at a neighbourhood level. As a result, this study had to rely on estimations for population distribution within LEZs, which may introduce minor discrepancies in the results.

Future research should continue monitoring the nearly 100 Spanish cities that have not yet implemented LEZ policies. Longitudinal studies assessing air quality, mobility patterns, and business transformations in LEZ zones will be crucial to understanding the full impact of these measures over time. By addressing these limitations, future studies can further refine our understanding of the relationship between LEZs, climate action, and urban tourism, providing more comprehensive insights for policymakers, urban planners, and scholars.

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Appendix I. Spanish city descriptives

City	Extension (km2)		No. tourist arrivals (2023)	Population (2023)
	City	*LEZ*		
A Coruña	38	4.937	467,534	247,376
Algeciras	86	0.388	222,904	123,639
Alicante	201	7.486	830,855	349,282
Almería	296	0.441	349,556	200,578
Ávila	231	0.501	296,385	57,741
Barcelona	98	80.342	8,285,168	1,660,122
Benidorm	39	0.840	2,237,086	72,342
Bilbao	41	1.979	1,121,750	346,096
Burgos	107	2.114	498,106	174,451
Cáceres	1.750	0.095	282,341	96,215
Cádiz	12	1.350	286,873	111,811
Cartagena	558	1.207	332,460	218,050
Castelló de la Plana	109	0.770	238,690	176,238
Ciudad Real	285	1.554	149,486	75,303
Córdoba	1.255	2.509	922,468	323,763
Cuenca	911	0.136	178,440	53,512
Donostia/San Sebastián	61	1.193	914,892	188,743
Elche	326	3.862	214,912	238,293
Estepona	138	0.580	388,346	76,975
Gandía	61	0.385	305,427	78,108
Gijón	182	2.150	393,841	268,313
Granada	88	4.546	1,738,581	230,595
Las Palmas de Gran Canaria	101	0.065	416,390	378,027
León	39	0.309	431,313	121,281
Lleida	212	3.208	229,199	143,094

Appendix I. Continuation

City	Extension (km^2)		No. tourist arrivals (2023)	Population (2023)
	City	*LEZ*		
Lugo	330	0.379	158,310	98,214
Madrid	606	562.880	9,894,521	3,332,035
Málaga	395	4.396	1,517,311	586,384
Marbella	117	0.166	733,705	156,295
Ourense	85	0.600	135,361	104,250
Oviedo	187	0.609	526,349	217,584
Palencia	95	0.779	105,733	76,331
Pamplona	25	0.477	366,964	205,762
Ponferrada	283	0.373	113,212	62,963
Salamanca	39	1.516	718,214	143,954
San Bartolomé de Tirajana	333	1.088	1,752,587	53,912
Santa Cruz de Tenerife	151	0.793	258,642	209,395
Santiago de Compostela	220	0.303	934,021	98,687
Sevilla	141	1.226	3,016,537	684,025
Tarragona	55	3.137	244,211	138,262
Toledo	232	1.096	592,093	86,070
Torremolinos	20	0.161	1,199,077	70,434
Valencia	135	3.434	2,072,643	807,693
Valladolid	197	3.129	424,304	297,459
Vigo	109	0.745	524,509	293,652
Vitoria-Gasteiz	277	0.829	348,116	255,886
Zamora	149	0.084	124,290	59,259
Zaragoza	974	0.609	1,137,611	682,513

Source: IGN (n.d.) & INE (2023, 2024a)

Appendix II. Puerta del Sol and its newly pedestrianised adjacent streets

Appendix II. Continuation

Source: the authors