

UNIVERSIDAD COMPLUTENSE DE MADRID
FACULTAD DE GEOGRAFÍA E HISTORIA



TESIS DOCTORAL

**Análisis de los patrones espacio-temporales de los servicios de
micromovilidad: situando BiciMAD en contexto**

**Spatiotemporal analysis of micromobility services: placing
BiciMAD in context**

MEMORIA PARA OPTAR AL GRADO DE DOCTOR

PRESENTADA POR

Daniela Arias Molinares

Directores

**Javier Gutiérrez Puebla
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“Let the dataset change your mindset.”

Hans Rosling

A la culpable de todo esto...
*mi queridísima Mentora **Dra. Rosa Virginia Ocaña.***

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Soy la hija de dos emigrantes que buscaban mejores oportunidades en nuevas tierras. Una barranquillera de 17 años y un asturiano de 18 que llegaban a Caracas con muchas esperanzas. Tras el pasar de los años, me tocó a mí ser la emigrante en búsqueda de mejores oportunidades. Y la oportunidad más grande que he tenido fue la *Universidad Complutense* y su Programa de Doctorado en Geografía. En Venezuela, estude Urbanismo de grado. Esta carrera se estructura en torno a talleres prácticos donde tienes un proyecto final y todas las materias teóricas que ves en el trimestre te ayudan a mejorar y complementar dicho proyecto. Uno de los últimos talleres de la carrera se centra en el tema del transporte y la movilidad, así que fue cuando vi todas las materias teóricas que para mí fueron verdaderamente alucinantes, como los modelos de planificación del transporte, la movilidad sostenible, herramientas digitales y el mundo SIG, etc. Me enamoré enseguida de la rama. Al terminar la carrera tenía un mar de conocimiento de un centímetro de profundidad, ya que este es el objetivo de la carrera de Urbanismo. Preparar a un perfil que se desarrollará como gestor urbano o planificador en un ayuntamiento por lo que tiene que saber un poco de todo y entenderse con múltiples profesionales sin entrar en detalle o la profundidad de cada área. Y esa profundidad fue la que quise adquirir con el Máster en Transporte Urbano, donde se tocaban más a fondo los conceptos y enfoques. Ahí me enamoré de la bici y me gané el apodo de "*Daniela la enBiciada*". Ahí supe que lo que quería, era trabajar en mejorar la movilidad urbana hacia patrones más sostenibles. Una vez defendido mi Trabajo de Fin de Máster (TFM), la situación en mi país se complicaba bastante así que decidimos meter nuestra vida en dos maletas y mudarnos a la Madre Patria.

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Abstract

Just as when doing a new food recipe, that we are very careful to have all the ingredients in place not to mess up the result, the same care should be taken into account when planning mobility. Using this simple analogy clarifies the problem addressed in this doctoral thesis: this is not necessarily happening as obsolete planning approaches are not considering all the “ingredients” or “mobility services” available to date. By usually considering only public transport systems, and the traditional modes that have been operating for decades, planners are lacking the whole picture. This whole picture is only captured when considering the new forms of mobility that have arisen in the last few years. They have changed the mobility paradigm putting the focus on transitioning from a car-oriented development into a proximity one. But as these new mobility forms are just beginning to be developed, studies regarding their spatiotemporal travel patterns still remain relatively underexplored, offering a research gap in which this thesis is framed. Our work intends to analyse these new forms of mobility, especially micromobility services, with a particular focus on BiciMAD (Madrid’s public bike-sharing system), but also on the more recently introduced shared moped and scooter services. Understanding who uses these services, how do they function, what are their dynamics and spatiotemporal travel patterns and what could their role be in the future of mobility, is the line of questioning that motivates this thesis. Therefore, the main research goal is to *explore, visualise and analyse micromobility services’ spatiotemporal travel patterns*. The thesis is focused on the analysis of the city of Madrid as a case study, which has been known as one of Europe’s most important shared mobility loving labs.

To explore user profiles and preferences, we used the annual BiciMAD survey conducted in 2019. Findings showed that almost 12% of respondents have registered and used other micromobility services, meaning that they are multimodal citizens. This helped us to identify two main user profiles: one related to users that are only subscribed to BiciMAD and other related to those subscribed to other dockless services. This latter profile tends to be younger and more multimodal as they do not own a car but rather have access to multiple travel apps. From this study we have also found that BiciMAD is substituting 8% of previously motorised trips and is promoting the use of personal owned bikes (9%) and other dockless micromobility services (9%).

Once we grasp an idea of who uses these services, we delve into the question of “how are they used?” analysing its spatiotemporal travel patterns (When and where). To that end, we have conducted four different empirical studies regarding spatiotemporal travel patterns by using different perspectives and methodologies that complement and give a general picture of how micromobility functions. The first empirical study analyses only BiciMAD, by considering over 21 million GPS records registered in one year (sept 2017-sept 2018) to visually explore cycling mobility patterns across the city. The most important origin-destination flows are revealed and differences according to type of users (frequent or occasional) are uncovered.

A second study uses Exploratory Spatial Data Analysis (ESDA) tools to analyse location patterns of micromobility services, taking the example of shared mopeds present in seven Spanish urban areas. Our findings showed that most trips start/end in the city centres and during the midday and afternoon hours, as users are picking up vehicles where others

have left it (fleet distribution less needed). Our methodology allowed us to identify when demand is more clustered and more self-balanced pointing to the most profitable areas. The assessment of both, the location of demand hubs, and the extent to which the system can balance itself, are important insights for both, transport authorities and operators.

Moreover, after focusing only in BiciMAD (station-based system) and then only in shared mopeds (dockless system), we continue in the third empirical study by combining both, station-based and dockless services, comparing spatiotemporal travel patterns of shared bikes, mopeds and scooters simultaneously. To that end, we used the Time Geography constructs to identify the landscape of micromobility services, detecting hot spot areas and location clusters that share a similar behaviour throughout space and time in terms of micromobility departures. Findings showed that bikes are the most important shared mode analysed in the city as it shows high departure counts maintained throughout the day while mopeds, and especially scooters gain importance especially towards the afternoon. Consistent with previous results, we found that central (midday) and late afternoon hours (from 18 to 20 hrs) are the most profitable time for micromobility operators, as hot spots are more homogeneously distributed. The areas of the city with more vitality in terms of micromobility are also identified: residential, mixed-residential, commercial, and work-related land uses that are closely linked to an intense usage during the entire day (morning and afternoon). Lastly, our study helped us to identify five types of places (location clusters) according to the mode analysed and the day of the week.

The fourth and last empirical study regarding spatiotemporal travel patterns addressed the impacts caused by the COVID-19 pandemic, by comparing behaviours between pre-COVID 19 and COVID times. Multiple regression analyses are conducted to assess how the two scenarios differentiate in relation to micromobility trips, generated or attracted, to or from different land uses, and during morning or afternoon peak hours. Results show that the most pandemic-resilient shared mode is bike-sharing, and that COVID-19 caused a downfall in ridership of approximately 10% (with BiciMAD even surpassing its trip records in September 2020), which is relatively lower compared to the 80% ridership drop reported by the public transport system. Our models reveal that residential and commercial areas gained importance after the pandemic, while workplace locations (office and industrial), educational and transport facilities lost relevance with teleworking and online studying. Results could help policy planners to begin to understand the effects of telework and if travel patterns during COVID-19 times could be maintained with telework measures being more consolidated.

Lastly, we propose a data-driven methodology to estimate potential micromobility usage in areas where companies are currently operating or new areas of the city where no service are offered yet. This could help policy planners address the location problem (where to allocate?) when implementing new infrastructure to promote micromobility services. For this study, we identified potential locations to implement mobility hubs in Madrid, as these kinds of infrastructure have demonstrated to facilitate intermodality between public transport and micromobility. Findings showed that common associated factors with micromobility usage are related to station's density, commercial land use and cycling infrastructure. Our results also showed that modelling micromobility usage altogether instead of individual modes provides better usage estimations.

Resumen

Al igual que cuando hacemos una nueva receta de comida, teniendo mucho cuidado de tener todos los ingredientes en su sitio para no estropear el resultado, se debe tener el mismo cuidado a la hora de planificar la movilidad. Utilizando esta simple analogía se clarifica el problema abordado en esta tesis doctoral: esto no necesariamente ocurre así, ya que los enfoques de planificación suelen estar obsoletos al no considerar todos los "ingredientes" o "servicios de movilidad" disponibles hoy en día. Al tomar en consideración sólo los sistemas de transporte público y los modos tradicionales que han estado operando durante décadas, los planificadores carecen del panorama completo. Este panorama sólo se captará al integrar las nuevas formas de movilidad que han surgido en los últimos años. Estas han cambiado por completo el paradigma de la movilidad poniendo el foco en la transición desde un desarrollo orientado al automóvil hacia uno de proximidad. Debido a que estas formas de movilidad son de reciente naturaleza, los estudios sobre sus patrones de viaje espaciotemporales aún permanecen relativamente poco explorados, lo que ofrece una gran oportunidad de investigación que es precisamente donde se enmarca esta tesis. Nuestro trabajo pretende analizar estas nuevas formas de movilidad, especialmente los servicios de micromovilidad, con un enfoque particular en BiciMAD (el sistema público de bicicletas compartidas de Madrid), pero también en los más recientes servicios de motocicletas y patinetes compartidos. Comprender quién utiliza estos servicios, cómo funcionan, cuáles son sus dinámicas y sus patrones espaciotemporales, así como el papel que podrían jugar en la movilidad futura, es la línea de cuestionamiento que motiva esta tesis. Por lo tanto, el principal objetivo de la investigación es *explorar, visualizar y analizar los patrones de viaje espaciotemporal de los servicios de micromovilidad*. La tesis se centra en el análisis de la ciudad de Madrid como caso de estudio, que ha sido conocida como uno de los auténticos laboratorios de la movilidad compartida más importantes de Europa.

Comenzando por la exploración de los perfiles y preferencias de los usuarios, se utiliza la encuesta anual BiciMAD realizada en 2019. Los resultados muestran que casi el 12% de los encuestados se han registrado y utilizado otros servicios de micromovilidad, lo que significa que son usuarios multimodales. Esto nos ha permitido identificar dos perfiles de usuarios principales: uno relacionado con usuarios sólo afiliados a BiciMAD y otro perfil más joven y multimodal que utiliza servicios flotantes. Con este estudio también hemos encontrado que BiciMAD está sustituyendo 8% de viajes motorizados y está fomentando el uso de bicicletas personales (9%) y otros servicios de micromovilidad flotante (9%).

Una vez que tenemos una idea de quién usa estos servicios, nos centramos en la pregunta "¿cómo se usan?" analizando sus patrones de viaje espaciotemporales (cuándo y dónde). Para esto, realizamos cuatro estudios empíricos diferentes sobre patrones de viaje espaciotemporales utilizando diferentes perspectivas y metodologías que se complementan y dan una imagen general de cómo funciona la micromovilidad. El primer estudio empírico analiza sólo BiciMAD, considerando más de 21 millones de registros GPS (de septiembre de 2017-septiembre de 2018) para explorar visualmente los patrones de movilidad ciclista. Esto nos permitió identificar los flujos origen-destino más importantes y las diferencias según el tipo de usuarios (frecuentes u ocasionales).

Un segundo estudio utiliza las herramientas de Análisis Exploratorio de Datos Espaciales (ESDA) para analizar los patrones de ubicación de los servicios de micromovilidad, tomando el ejemplo de las motocicletas compartidas presentes en siete áreas urbanas españolas. Nuestros hallazgos muestran que la mayoría de los viajes comienzan/terminan en los centros de las ciudades y durante las horas del mediodía y la tarde, ya que los usuarios recogen los vehículos donde otros los han dejado (lo que hace menos necesaria la distribución de la flota). Nuestra metodología nos permite además identificar cuándo la demanda está más agrupada y más autoequilibrada, señalando las áreas más rentables. Estos resultados de dónde se localiza la demanda y cuándo es más equilibrada, son de vital importancia tanto para las autoridades de transporte como para los operadores.

Una vez estudiado sólo BiciMAD (sistema de bases fijas) y luego sólo las motocicletas compartidas (sistema flotante), continuamos con un tercer estudio donde combinamos ambos, servicios de bases fijas y aquellos flotantes, comparando los patrones de viaje espaciotemporales de bicicletas, motocicletas y patinetes compartidos de forma simultánea. Para ello, utilizamos los conceptos de la Geografía del Tiempo, detectando los puntos calientes y clústeres que comparten un comportamiento similar a lo largo del espacio y el tiempo. Los resultados muestran que las bicicletas son el modo más importante, ya que presentan un alto número de orígenes que se mantienen durante todo el día, mientras que las motocicletas, y especialmente los patinetes, van ganando importancia hacia las horas de la tarde. De forma consistente con previos resultados encontrados, el horario central (mediodía) y el de la tarde (de 18 a 20 h) son los más rentables para los operadores de micromovilidad, ya que los puntos calientes están distribuidos de manera más homogénea. También se identifican las áreas de la ciudad con mayor vitalidad en términos de micromovilidad: aquellas con usos del suelo residencial, mixto-residencial, comercial y de trabajo que están estrechamente ligados a un uso intenso durante todo el día (mañana y tarde). Por último, se identificaron cinco tipos de localizaciones (clústeres) según el modo analizado y el día de la semana. Esta clasificación del tipo de localizaciones puede servir a los operadores para identificar las zonas y horarios que aumentan su rentabilidad.

El cuarto estudio aborda los impactos causados por la pandemia de COVID-19, al comparar comportamientos entre tiempos pre-COVID 19 y COVID. Se realizaron análisis de regresión múltiple para evaluar cómo se diferencian los dos escenarios en relación con los viajes de micromovilidad, generados o atraídos, hacia o desde diferentes usos del suelo, y durante las horas pico de la mañana o la tarde. Los resultados muestran que el modo compartido más resistente a la pandemia fueron las bicis compartidas, y que el COVID-19 provocó una caída en el número de pasajeros de aproximadamente un 10 % (con BiciMAD incluso superando sus récords de viajes en septiembre de 2020), que es relativamente menor en comparación con los 80 % de caída de pasajeros reportada por el sistema de transporte público. Nuestros modelos revelan que las áreas residenciales y comerciales ganaron importancia después de la pandemia, mientras que los lugares de trabajo (oficinas e industriales), las instalaciones educativas y de transporte perdieron relevancia con el teletrabajo y el estudio en línea. Los resultados podrían ayudar a los planificadores de políticas a comenzar a comprender los efectos del teletrabajo y si los patrones de viaje durante los tiempos de COVID-19 podrían mantenerse con las medidas de teletrabajo más consolidadas.

Finalmente se propone una metodología para estimar el uso potencial de micromovilidad en áreas donde las empresas están operando actualmente o nuevas áreas de la ciudad donde aún no se ofrece el servicio. Esto podría ayudar a los planificadores de políticas a abordar el problema de la ubicación (¿dónde ubicar?) al implementar nueva infraestructura para promover los servicios de micromovilidad. Para este estudio, identificamos ubicaciones potenciales para implementar los llamados Mobility Hubs en Madrid, ya que este tipo de infraestructura ha demostrado facilitar la intermodalidad entre el transporte público y la micromovilidad. Nuestros resultados muestran que los factores comunes asociados al uso de estos modos compartidos están relacionados con la densidad de las estaciones de BiciMAD, el uso comercial del suelo y la presencia de infraestructura ciclista. Nuestros resultados también mostraron que modelar el uso de micromovilidad en conjunto en lugar de modos individuales proporciona mejores estimaciones.

1. Introduction

1.1. A timely and relevant topic

We now live in a digital era. People access information, buy things or travel to places only with the use of their smartphones. Ongoing megatrends such as population growth, ageing, urbanisation, economic development, digitalisation and environmental awareness are rapidly changing people's lifestyles and thus, their mobility behaviour (Casady, 2020). Landwise, the world's cities occupy just 3% of the World's land, but account for 60–80% of energy consumption and 75% of carbon emissions (Flügge, 2017). With the current climate emergency, achieving sustainable mobility is at the heart of many global and regional public policies, like the 2030 Agenda for Sustainable Development (United Nations, 2015), the 17 Sustainable Development Goals set by the United Nations (United Nations, 2016) or the more recent Sustainable and Smart Mobility Strategy (European Commission, 2020). The task is clear: a transition from a car-oriented development into a proximity one, in which humans and the environment are placed at the core. In the transport arena, collaborative economy, Information and Communication Technologies (ICT), improved Geographical Information Systems (GIS), new data sources and advanced processing and programming capabilities, are all enabling a new mobility paradigm, promising a shift to a more sustainable travel path.

If we look backwards to where we come from, as well as to the present where we are now and forward to where we will be, we can begin to understand how this new mobility paradigm has evolved. Departing from the fact that the attractiveness of the private car relies in the possibility to travel door-to-door at any time needed and in a comfortable manner, then efficient strategies need to keep up, by offering the same or an improved service that could cover the first/last mile of trips with multiple and convenient travel options at a very competitive price. This goal seemed difficult years ago, but emergent trends are favouring the general idea of *using things conveniently, rather than owning them*. In this context, shared mobility has become one of the most relevant transport innovations (Fulton, 2018; Tirachini, 2020). By covering travel demands for those low or unserved areas by public transport systems, shared mobility is facilitating the needed multimodality and intermodality to substitute door-to-door car trips. Each person now more than ever before, has *the option*, to not own a car but instead, *use* public transport and different shared vehicles to satisfy her/his travel demands.

Thus, looking backwards to the first decade of the 21st century, we see the consolidation of shared mobility services with car-sharing and bike-sharing systems. In its early stages, bike-sharing systems operated essentially, with the use of transport/intelligent cards and as station-based models (also called docked services), meaning that the bike is picked-up from and returned to a fixed station. Taking the analogy of web development, this first decade represents the web 1.0 of the new mobility paradigm. The next decade, especially from 2017 on, has been marked by the burst of new forms of mobility, coining the term *micromobility* and being the present context or web 2.0 of the mobility paradigm. Micromobility involves all low-speed shared mobility, including the already well-established bike-sharing programs, but also new travel options, like mopeds (also known as moped-style scooter-sharing or moto-sharing) and scooters (also known as kick-style scooter-sharing) (Shaheen & Cohen, 2019). In this second decade, two main innovations have taken place: 1) most of the services are dockless (also called free-floating), meaning that the vehicle is picked up and returned to any location within a certain geographic area (geofence); and 2) most of them are rented using only a smartphone (no need for transport/intelligent cards). Lastly, if we look forward to the future, the beginning of the third decade of the century is bringing new challenges: the more complex the mobility ecosystem becomes, the more necessary it is to integrate all the mobility offer in a single place, reducing the

hassle for subscribers. This idea is known as Mobility as a Service (hereafter, MaaS), and it seems to be the future path or web 3.0 of the mobility paradigm.

Building upon this contextual framework of the new mobility paradigm (past web.1- shared mobility introduction, present web.2- micromobility burst and future web.3-MaaS), our work shares with previous studies, that it focuses mainly in BiciMAD, Madrid's public bike-sharing system, but it differs from them in the perspective taken. Instead of analysing only BiciMAD as an isolated object of study, we analyse it in its current context: a growing mobility ecosystem with many other micromobility operators in place (web 2.0 of the mobility paradigm) and evaluating its role in a possible future MaaS offering (web 3.0). In other words, we are interested in understanding BiciMAD's micromobility spatiotemporal travel patterns, but from a holistic perspective, including as well the recently implemented dockless micromobility services.

The subject of study is relevant as it concerns bike-sharing systems that have proved to positively influence people to adopt a more sustainable travel behaviour (López-Carreiro, 2021; Munkácsy, 2017; Romanillos, 2018; Velázquez Romera, 2019). But most importantly, it concerns micromobility as a whole which, due to its recent nature, is not fully integrated in the traditional modelling and planning processes. We consider as effort-worthy the intention to understand these new forms of mobility in order to integrate them accordingly in the planning processes of the new digital era. A quick search in Google Play yields the inevitable: with more than 60.000 travel apps and shared mobility services available, these new forms of mobility *are here to stay* (Fulton, 2018; Y. Li & Voegelé, 2017). The sooner we plan for them, the better the mobility ecosystem will work. And especially now, as these many travel options are highlighting the need for a single, easy-to-use application that integrates them all (Matyas, 2018; Mulley, 2017). The combination of both, public transport and shared mobility is key in MaaS. Scientific literature has delved exhaustively in the analysis of public transport systems, but these new shared services need further development, making it, not only a relevant, but a timely or trending topic of research. These services are just beginning to operate and generate profit, and transport authorities are still needing information regarding their spatiotemporal travel patterns in order to create policies and strategies that help in their improvement. Both authorities and service operators, are hungry for new insights related to micromobility's dynamics. This need for knowledge became even more relevant after the COVID-19 pandemic, from which services are still recovering, and authorities are still facing many uncertainties.

To tackle this problem, our work intends to analyse the new developed micromobility services, with a particular focus on BiciMAD, as the *"new thing"* in the mobility paradigm of Madrid. Understanding who uses these services, how do they function, what are their dynamics and spatiotemporal travel patterns and what could be their role in a possible MaaS offering, is the line of questioning that motivates this Thesis. Contrarily to other previous studies that used only surveys, the workflow we follow continues the line of research established by (Romanillos, 2018), analysing a different type of data source: trip data (using GPS records) and considering dockless shared services implemented. Consequently, we analyse both, station-based and dockless services and we do this by using both, survey and trip data. In the next section, we outline with more detail the research questions that frame the research.

1.2. Research questions and objectives

The following research continues the path of those studies that analyse the digital footprint of station-based bike-sharing systems, but also the relatively more recent implemented services: dockless shared mopeds and scooters. Based upon this approach, the most important research questions that we aimed to address are described next.

1.2.1. Research questions

RQ1. What is the new mobility paradigm and the elements that characterise it?

With this question we aim to describe the elements that characterise the new mobility paradigm (current context, micromobility services and Mobility as a Service). The disruptive changes that have occurred in the last decades are to be broadly addressed as they are the breeding ground that enabled new forms of mobility and concepts like Mobility as a Service (MaaS). Consequently, after describing the current context we aim to define and characterise micromobility and MaaS as the new elements in the mobility paradigm. With micromobility being characterised as one of the three most important revolutions of transport (Fulton, 2018) with a market valued in the billions of dollars (Wiggers, 2019), it is important to know what the term means, how it differs from other concepts and when and where did it appear. Additionally, in order to establish the current state of the art on the topic of study, it is key to make an exhaustive revision of previous studies regarding micromobility and especially those that analyse spatiotemporal travel patterns using Big Data, in the particular form of GPS records (trip data). This first part of the Thesis will help us to set our theoretical framework and understand the context of the burst of new micromobility services by describing the new mobility paradigm, identifying the key research gaps and areas of contribution of our work to existing literature.

RQ2. How does the mobility ecosystem in Madrid look like, and what are the current initiatives towards sustainable mobility?

According to Y. Li & Voegelé, 2017, in order to implement MaaS, two main conditions are required: a consolidated public transport system and a varied shared mobility offer. This latter condition is what we intend to address with this research question. We aim to conduct an exhaustive diagnosis of the shared mobility ecosystem in Madrid. It is important to describe the current mobility ecosystem in order to set the geographical context of our study and grasp the importance of these new shared services when planning new policies and regulations that could help improve their functioning and promote the shift to a more sustainable travel behaviour.

RQ3. Who uses BiciMAD and other dockless micromobility services and how are their travel preferences similar/different?

When planning new policies, authorities need to have a market target defined. To this end, we intend to answer the question of who uses BiciMAD and other dockless micromobility services and how different or similar are their characteristics and travel preferences. It is relevant to create user profiles when designing new policies and regulations to make them more efficient. Previous studies that only considered BiciMAD subscribers, found out that the majority of them are young highly educated males (Munkácsy, 2017; Romanillos, 2018). In our study, we aim to verify or contrast these findings with updated data and considering also the subscribers to dockless modes. To our knowledge, this will be the first attempt to categorise and compare simultaneously, user profiles for docked and dockless services in Madrid. Based on their travel preferences, we also want to address the substitution effect. The substitution effect refers to the extent to which a subscriber starts using a particular mode in substitution of another one. In concrete, we intend to answer the subsidiary question “RQ3.1. To what extent are micromobility services competing/complementing with BiciMAD and/or the public transport system?”. This is highly relevant as it is important to address the extent to which BiciMAD and dockless micromobility services are substituting car trips, which will be the sustainable path to follow instead of competing against public transport, shared modes or walking.

RQ4. What are the spatiotemporal travel patterns of micromobility services and how can we visualise and analyse them?

Visualising and analysing micromobility spatiotemporal travel patterns can be crucial to understand their particular dynamics. We intend to see if micromobility subscribers follow a similar or different pattern according to the shared mode used. The temporal analysis regards exploring the yearly, monthly, daily and hourly behaviour to find the preferred time to use each of the services. On the other hand, spatial patterns regard the exploration of the areas of the city that behave as hot spots or important zones in terms of micromobility usage. We intend to analyse the preferred origins and destinations and the characterisation of these areas where these services thrive (clusters). As a subsidiary question of the main one, we intend to address: “RQ4.1. Does micromobility behaves differently depending on the context and what could operators learn from micromobility trip data?”. This question is key to address whether the services behave differently according to the urban area studied, and how can operators take better decisions based on their trip data.

Another subsidiary question of the main one is related to the COVID-19 pandemic: “RQ4.2 How did the COVID-19 pandemic affect BiciMAD and other micromobility services?”. Sudden changes in urban mobility were caused due to the COVID-19 pandemic. As an effort to mitigate its rapid spread, lockdowns were imposed causing many changes in travel behaviour, not yet exactly quantified, or understood, offering numerous possibilities for exploration. A global event of this type could happen any time. Therefore, with this question we aim to explore how a global extreme event, like the COVID-19 pandemic, affected spatiotemporal travel patterns in micromobility services and which are the lessons and findings to be retained if possible future events like this are repeated. We want to address the pre-COVID and COVID behaviour focusing of the extent to which the services’ usage levels dropped and how did they recover. This could be of help for policy planners and transport authorities to plan for a more pandemic-resilient public transport and micromobility services. This research is relevant, as new pandemics could arrive, and the public transport systems and micromobility services have to be prepared and offer safety measures to maintain usage level.

The main research question and the two subsidiary questions involve the transversal interrogation of how spatiotemporal travel patterns can be visualised using trip data. We aim to explore new types of visualisations (innovative graphs, infographics and visual illustrations) that can be considered according to the focus of the study.

RQ5. Based on the understanding of micromobility spatiotemporal travel patterns, how can we estimate its potential usage to allocate new mobility infrastructure?

Micromobility services’ usage is complex and not easily predictable because it is influenced by a diverse set of factors. Analysing these set of factors associated their usage is crucial to understand micromobility behaviour and predict potential usage in new areas of the city. Understanding the common associated factors of micromobility usage and how they vary from one mode to another is a crucial knowledge that cities and transport authorities need for planning the allocation of new infrastructure. We intend to offer a data-driven methodology to estimate potential usage and plan the expansion micromobility infrastructure. This input information could be of help for transport authorities to feed decision-making processes and invest resources more efficiently to promote a shift to a more sustainable travel behaviour.

RQ6. What is the future of the mobility paradigm and what’s the role of micromobility services in it?

With mobility options growing every day, the need to have them integrated in a single app is becoming relevant as users may find it difficult to navigate through all the information sources,

applications, tickets, and journey planners. MaaS is offered as a solution to this problem. Therefore, it is important to understand what the concept means as it is often referenced as the future of urban mobility and a key element in the new mobility paradigm. Exploring different definitions, perspectives of the concept, the actors involved and the obstacles to implement it could be crucial when defining the policies or paths to follow for cities. An integral overview of the concept of MaaS could help us identify the elements that need to be in place when enabling this idea and when establishing the role of micromobility services in a possible future MaaS offering for Madrid.

1.2.2. Main research goal, and specific objectives

1.2.2.1. General objective

The main research goal of this Thesis is to ***explore, visualise and analyse micromobility services' spatiotemporal travel patterns***. Our main focus is put on BiciMAD, Madrid's public bike-sharing system, but the service is analysed in the current context of a growing mobility ecosystem where other dockless services coexist, enabling comparisons to be made. Additionally, we set the theoretical framework to explore the role that micromobility services could have in a possible MaaS offering or Mobility as a Service, a concept that is often referenced as the future of the mobility paradigm.

1.2.2.2. Specific objectives

OB1. Conduct a scoping state-of-the-art review on shared mobility, micromobility and MaaS to establish the theoretical framework for the thesis and outline the future mobility path for Madrid.

The first objective of the thesis is to conduct a scoping review of literature concerning the concepts that will set the theoretical framework for the research. To that end, we will revise the concepts of smart cities and its smart mobility pillar. We will also describe the context (climate crisis, tech-advances, new data sources, etc) in which these new forms of mobility are bursting. Next, we will revise the shared mobility, micromobility and MaaS definitions and the current literature development regarding micromobility spatiotemporal travel patterns.

OB2. Diagnose Madrid's mobility ecosystem.

Being characterised as one of Europe's most important shared mobility living labs, Madrid is home to many micromobility operators and their fleets. However, no specific study is found related to the exact number of shared mobility fleet in the city and its characterisation. Hence, we will conduct one of the first-known academic diagnostics of the mobility ecosystem, contextualising our study area. We will search, revise and classify all the companies that have been operating in the city and the regulations and city plans that have come in place to set the ground rules for operators.

OB3. Explore BiciMAD and dockless micromobility subscribers' profiles and preferences.

Our next objective will involve the exploration of the socio-demographic characteristics of BiciMAD and dockless micromobility's subscribers and their preferences for the different services. We intend to analyse user profiles and how they are similar/different, trip purposes, modes that are being substituted and the extent to which docked and dockless services are complementing or competing with public transport and the private car. For this part of the study, we will conduct a survey to BiciMAD users and offer findings related to the aspects that they find relevant to adopt these services.

OB4. Visualise, analyse and understand spatiotemporal travel patterns and dynamics of micromobility services.

After having a clearer idea of who uses micromobility services, we will delve into the analysis of their digital footprint, by analysing trip data to extract spatiotemporal travel patterns. To that end, we aim to conduct a two-folded purpose analysis: 1) an exploration of BiciMAD service by itself, as it is the first and most consolidated shared service in Madrid and 2) the comparison of BiciMAD with other dockless services (mopeds and scooters). In both of these studies, we aim to identify the preferred time and place for using micromobility in Madrid.

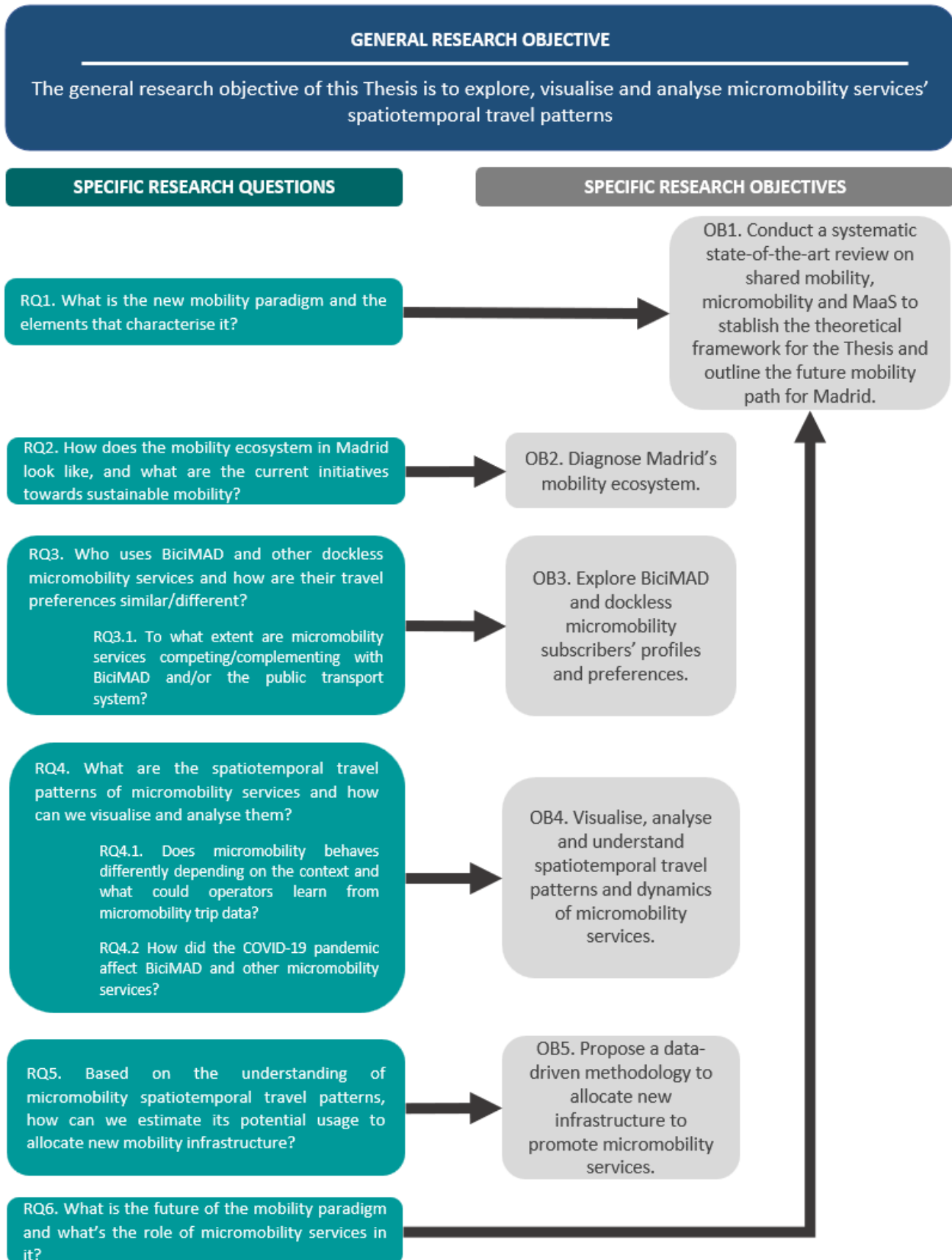
To tackle the first subsidiary question related to the behaviour of micromobility according to different context (cities) and the key findings for operators, we will consider shared moped services implemented in seven Spanish urban areas and we will analyse the spatiotemporal travel patterns to see if they have variations and analyse them. The objective is to exploit trip data to feed and help in the decision-making processes of micromobility operators in their day-to-day logistical tasks (battery recharging, maintenance and fleet collection or distribution).

To address the second subsidiary question related to the impact that COVID-19 pandemic had on micromobility services, a comparison of the two scenarios will be made (pre-COVID and COVID times). The objective is to measure and estimate the impacts of the pandemic and recommend policies that promote pandemic-resilient cities. To that end, we will try to assess the changes caused by lockdowns. Our analysis will help to identify possible implications for transit policy with the consolidation of telework and online studies. All these studies will try and explore different types of visualisations for an innovative source of data like GPS records (trip data).

OB5. Propose a data-driven methodology to allocate new infrastructure to promote micromobility services.

By considering different sets of variables, we will try to identify, analyse and model the common influential factors associated with micromobility's usage. Using trip data, socio-demographic characteristics and built environment variables could help in the understanding of micromobility's behaviour. Based on this understanding, we aim to propose a data-driven methodology to estimate potential usage for micromobility services when planning the implementation of new infrastructure like mobility hubs to facilitate intermodality between public transport and the new forms of mobility and for current-operating or non-covered areas of the city. Our findings could be useful to feed decision-making processes and address the location problem that many transport planners face. The relationship of the research questions and objectives is summarised in Figure 1.1.

Figure 1.1 Relationship between research questions and objectives.



Source: own elaboration.

1.3. Thesis structure and summary of the content

The thesis is structured in twelve chapters. The first one introduces the research, the main goal and the specific objectives defined in order to respond a number of research questions and it ends with the structure of the work.

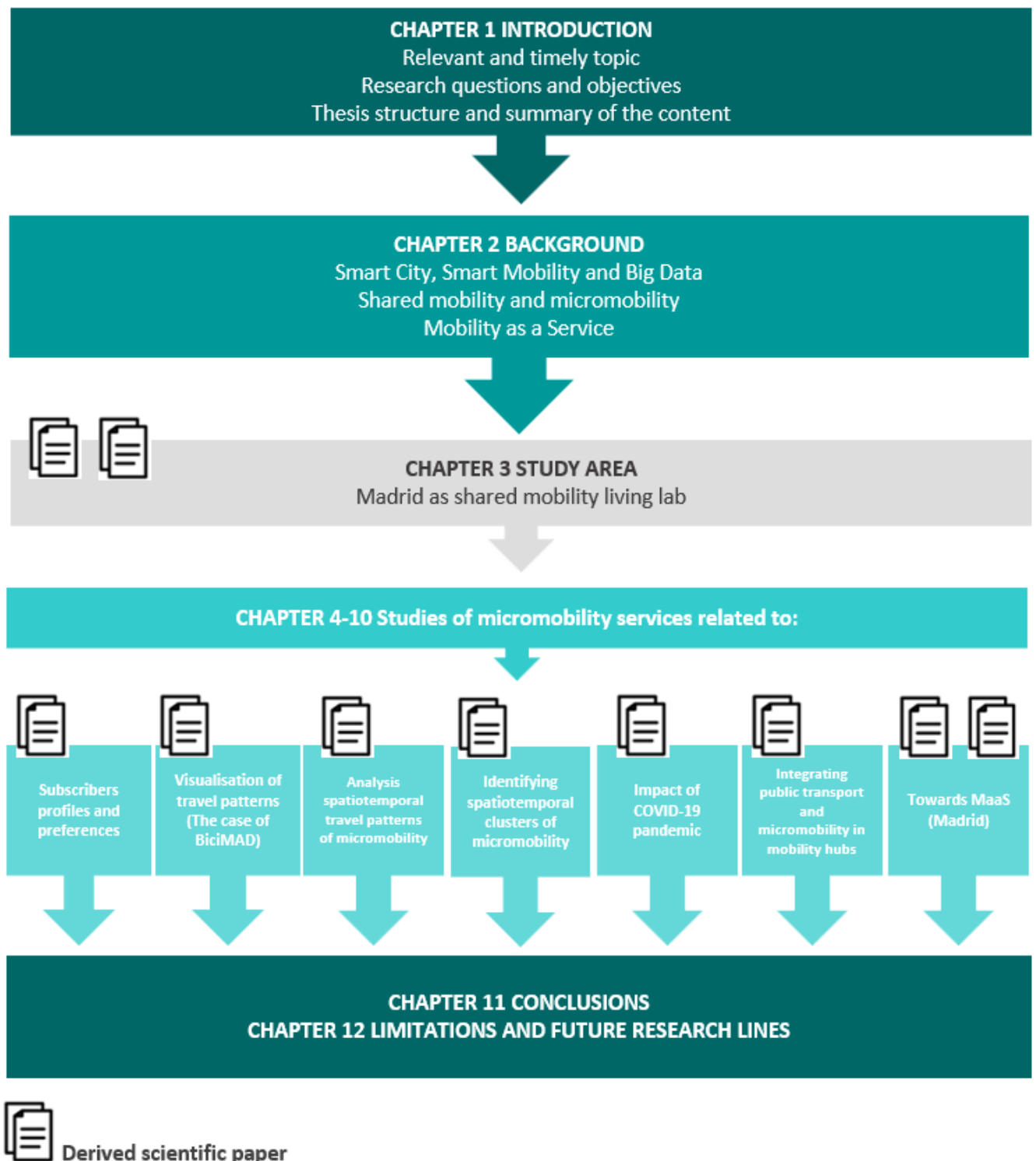
The second section sets the theoretical framework, by providing an overview of the concepts that frame the investigation. Firstly, we highlight the most important characteristics of the Smart City model and its pillar related to Smart Mobility, as well as the trends related to new data sources and techniques/tools used in recent mobility studies. Next, we revise the concept of micromobility and MaaS as main topics of the thesis. It is important to highlight that the background chapter is a brief introduction of the main concepts, as each consecutive study has its own revision of the particular scientific literature of interest (in the background or introduction section of the papers). Additionally, in this first chapter we briefly describe the concept of MaaS, as it is furtherly developed in the last chapter of the thesis outlining the future of the mobility paradigm for Madrid.

The third chapter introduces Madrid as the case of study, providing the necessary local context. This part of the thesis describes Madrid's general mobility patterns and characteristics. Lastly, it describes the main findings obtained from a diagnosis of the current micromobility services operating in the city and the relationships in this complex ecosystem.

From the fourth to the tenth chapter, we present the different studies conducted. The fourth chapter relates to the study of BiciMAD and dockless micromobility user profiles and preferences. The fifth chapter delves into the spatiotemporal travel patterns of BiciMAD services while the sixth regards the exploration of how travel patterns are maintained or vary across different context (seven Spanish cities) and how trip data could offer information for micromobility operators in their decision-making processes. The seventh chapter analyses spatiotemporal travel patterns of micromobility services to find the clusters or areas of the city with more vitality. This chapter includes all modes studied (bikes, mopeds and scooters) allowing comparisons to be made. Chapter eight evaluates the impacts of the COVID-19 pandemic on micromobility services. This study has a dual purpose: 1) doing a similar exploration of spatiotemporal travel patterns as the previous studies but focusing on the pre and post pandemic periods and 2) modelling demand for these services. Due to this duality in its objectives, we consider this study as a good intermediation between the analyses of travel patterns and usage modelling. The ninth chapter delves into the modelling approach, analysing the factors associated with each shared service's usage and then the common factors to all of them. Based on these models, we then propose a data-driven methodology for allocating new mobility infrastructure. Lastly, chapter 10 discusses the concept of MaaS with more detail and outlines the role of micromobility services in a future MaaS app for Madrid offering guidelines for governance and implementation strategies based on the findings from the analysis of micromobility data.

Finally, the last chapter offers conclusions and policy recommendations for transport authorities and micromobility operators. Limitations and future research lines are lastly offered in chapter 12. This structure of the work can be summarised in Figure 1.2.

Figure 1.2 Thesis structure



Source: own elaboration.

1.4. List of derived publications, conferences and research stay
1.4.1. Publications

The results of this thesis have been already published or are being published in different Scientific Journals. A complete list of the academic papers is provided next.

1. ***The Ws of MaaS: Understanding mobility as a service from a literature review (2020)***
IATSS Research, Elsevier SCI Ltd., JCR Impact Factor 2021: 0,67, Q3.
Authors: Arias-Molinares, Daniela; García-Palomares, Juan Carlos.
DOI: 10.1016/j.iatssr.2020.02.001
Available at: <https://doi.org/10.1016/j.iatssr.2020.02.001>
[Total citations in Scopus](#): 49, 2nd most cited article from [IATSS Research](#)
2. ***Shared mobility development as key for prompting mobility as a service (MaaS) in urban areas: The case of Madrid (2020)***
Case Studies on Transport Policy, Elsevier, JCR Impact Factor 2021: 0,65, Q3.
Authors: Arias-Molinares, Daniela; García-Palomares, Juan Carlos.
DOI: 10.1016/j.cstp.2020.05.017
Available at: <https://doi.org/10.1016/j.cstp.2020.05.017>
[Total citations in Scopus](#): 24
3. ***Examining spatio-temporal mobility patterns of bike-sharing systems: the case of BiciMAD (Madrid) (2021)***
Journal of Maps, Taylor & Francis Ltd., JCR Impact Factor 2021: 2,657, Q2.
Authors: Talavera-García, Rubén; Romanillos, Gustavo; Arias-Molinares, Daniela.
DOI: 10.1080/17445647.2020.1866697
Available at: <https://doi.org/10.1080/17445647.2020.1866697>
[Total citations in Scopus](#): 9
4. ***Exploring the spatio-temporal dynamics of moped-style scooter sharing services in urban areas (2021)***
Journal of Transport Geography, Elsevier SCI Ltd., JCR Impact Factor 2021: 5,899, Q1.
Authors: Arias-Molinares, Daniela; Romanillos, Gustavo; García-Palomares, Juan Carlos; Gutiérrez, Javier.
DOI: 10.1016/j.jtrangeo.2021.103193
Available at: <https://doi.org/10.1016/j.jtrangeo.2021.103193>
[Total citations in Scopus](#): 1, [View counts \(Scopus\)](#): 47
5. ***Exploring micromobility services: Characteristics of station-based bike-sharing users and their relationship with dockless services (2021)***
Journal of Urban Mobility, EIT Urban Mobility.
Authors: Arias-Molinares, Daniela; Julio, Raky; García-Palomares, Juan Carlos; Gutiérrez, Javier.
DOI: 10.1016/j.urbmob.2021.100010
Available at: <https://doi.org/10.1016/j.urbmob.2021.100010>
[Total citations in Google Scholar](#): 4
6. ***On the path to mobility as a service: a MaaS-checklist for assessing existing MaaS-like schemes (2022)***
Transportation Letters, Taylor & Francis Ltd., JCR Impact Factor 2021: 2,844, Q3.
Authors: Arias-Molinares, Daniela; García-Palomares, Juan Carlos; Gutiérrez, Javier.
DOI: 10.1080/19427867.2022.2038987
Available at: <https://doi.org/10.1080/19427867.2022.2038987>
[Total citations in Google Scholar](#): 3 [View counts \(journal\)](#): 464

7. ***Micromobility services before and after a global pandemic: impact on spatio-temporal travel patterns (2022)***
International Journal of Sustainable Transportation, Taylor & Francis Inc., JCR Impact Factor 2021: 3,963, Q2.
Authors: Arias-Molinares, Daniela; García-Palomares, Juan Carlos; Gutiérrez, Javier.
DOI: 10.1080/15568318.2022.2147282
Available at: <https://doi.org/10.1080/15568318.2022.2147282>
[Total citations on media](#): 9
8. ***Exploración del impacto de la pandemia COVID 19 en los sistemas públicos de bicicletas compartidas: los casos de Madrid (BiciMAD) y Buenos Aires (EcoBici).***
Revista de Transporte y Territorio, Instituto Geografía-Universidad de Buenos Aires, JCR Impact Factor 2021: 0,02, Q4.
Authors: Arias-Molinares, Daniela; Gutiérrez, Andrea; Ocaña-Ortiz, Rosa Virginia.
Status: In press, it will be available online before 31/12/2022.

Papers under revision:

9. ***Uncovering spatiotemporal micromobility patterns using the Time Geography framework.***
Journal of Geographical Systems, Springer Heidelberg, JCR Impact Factor 2021: 2,417, Q3.
Authors: Arias-Molinares, Daniela; Romanillos, Gustavo; García-Palomares, Juan Carlos; Gutiérrez, Javier.
Status: second revision submitted, waiting for editor's decision.
10. ***Where to allocate Mobility Hubs? Data-driven methodology from micromobility's usage.***
Journal of Transport Geography, Elsevier SCI Ltd., JCR Impact Factor 2021: 5,899, Q1.
Authors: Arias-Molinares, Daniela; Xu, Yihan; Büttner, Benjamin; Duran-Rodas, David.
Status: in the process of submitting to journal.

In addition, two book chapters has been published:

11. ***Las nuevas formas de movilidad en las ciudades: de los servicios de movilidad compartida a la movilidad como servicio (2022).***
Book: Gago-García, C., Córdoba-Ordóñez, J., Alonso-Logroño, M.P., Jordá-Borrell, R., Ventura-Fernández, J. (coords). Territorios comunes, miradas compartidas: aproximaciones desde la Geografía (pp. 149-164). Valencia. Universitat de Valencia (UPV). ISBN: 978-84-1118-062-7. (DOI:10.7203/PUV-OA-078-8).
Authors: Arias-Molinares, Daniela; Gutiérrez, Javier.
Available at: <https://www.casadellibro.com/ebook-territorios-comunes-miradas-compartidas-ebook/9788411180719/13315758>
12. ***Nuevas formas de movilidad en la ciudad (2022).***
Book: Río-Fernandez, J. A., Lois-González, R.C. y Beltrao-Sposito, M.E. (Editores) (2022). El mundo visto de las ciudades (pp. 583-590). Editorial Tirant Humanidades. ISBN: 974-84-18970-21-4.
Authors: García-Palomares, Juan Carlos; Arias-Molinares, Daniela.
Available at: <https://editorial.tirant.com/co/libro/el-mundo-visto-de-las-ciudades-9788418970214>

1.4.2. Conferences

The research conducted throughout this thesis has been presented in the following conferences:

Table 1-1 List of conferences where research results were presented.

Conference	Type	Year	Product	Title	Authors	Date	Place
Congreso de la Asociación Española de Geografía (AGE)	National	2019	Presentation	Análisis dinámico de la movilidad como servicio a partir del Big Data (Jornada de Doctorandos)	Arias-Molinares, D.	22-25 October	Valencia
			Presentation	Let's agree on something: What is Mobility as a service?	Arias-Molinares, D. and García-Palomares, J.C.		
		2021	Presentation	Movilidad como Servicio, micromovilidad y tiempos de pandemia (Jornada de Doctorandos)	Arias-Molinares, D.	14-17 December	La Laguna
			Poster	A casi tres años de Madrid Central: ¿Cuál es su aceptabilidad por parte de usuarios de BiciMAD?	Arias-Molinares, D., García-Palomares, J.C. and Gutiérrez, J.		
		2018	Presentation	Bike and train intermodality: What are users considering when commuting?	Arias-Molinares, D. and Flórez, J.	6-8 June	Gijón
Congreso de Ingeniería del Transporte (CIT)	National	2021	Presentation	Exploring the spatio-temporal dynamics of moped-style scooter sharing services in urban areas	Arias-Molinares, D., Gutiérrez, J., García-Palomares, J.C., Romanillos, G. and Talavera-García, R.	6-8 July	Burgos
		2019	Poster	Movilidad como servicio: ¿Qué es y cómo funciona?	Arias-Molinares, D.	28 October	Madrid
Phday Geografía e Historia	National	2021	Presentation	Servicios de micromovilidad de Madrid después de la pandemia COVID-19	Arias-Molinares, D.	4 de October	Madrid
		2022	Presentation	Cubes are the new black! Potencial de la Geografía del Tiempo para el análisis de datos de servicios de micromovilidad	Arias-Molinares, D.	4 de October	Madrid
Conferencia ESRI	National	2019	Presentation	El mapa de la movilidad como servicio: concepto y contexto	Arias-Molinares, D.	29-30 October	Madrid
Congreso Online de Movilidad Urbana Sostenible (COMUS)		2022	Presentation	Al día con la MiC-OVID-romovilidad	Arias-Molinares, D.	15 April	Madrid
XLVII Reunión de Estudios Regionales (XIV Congreso AACR)	National	2022	Presentation	Nuevas formas de movilidad en las ciudades: de la movilidad compartida a la Movilidad como Servicio (MaaS).	Arias-Molinares, D., García-Palomares, J. C., Gutiérrez, J.	19-22 October	Granada
			Presentation	Servicios de micromovilidad antes y después de una pandemia global: impacto de la COVID-19 en los patrones espaciotemporales de las nuevas formas de movilidad.	García-Palomares, J. C., Arias-Molinares, D., Romanillos, G., Gutiérrez, J.		
XIX Congreso de Tecnologías de la Información Geográfica (TIG)	National	2022	Presentation	Cubes are the new black! Potencial de la Geografía del Tiempo para el análisis de datos de servicios de micromovilidad	Arias-Molinares, D.	12-14 September	Saragossa
Jornada de Materiales	National	2022	Poster	Movilidad como servicio y micromovilidad: ¿Qué son y cómo funcionan?	Arias-Molinares, D.	24 February	Madrid
Congreso Latinoamericano de Transporte Público Urbano (CLATPU)	National	2021	Presentation	A cinco años de la introducción del concepto de movilidad como servicio: ¿Estamos cerca de una definición estándar?	Arias-Molinares, D.	29-1 July	Monterrey, Mexico
The International Geographic Union (IGU)	International	2021	Presentation	Mobility preferences and willingness to pay for MaaS	Condeco-Melhorado, A., Arias-Molinares, D. and Tinelli, F.	16-20 August	Istanbul, Turkey
			Presentation	The debate around Mobility as a service: What are we agreeing and disagreeing on?	Condeco-Melhorado, A., Arias-Molinares, D. and García-Palomares, J.C.		
International Conference on MaaS (ICoMaaS)	International	2022	Presentation	Micromobility services before and after a global pandemic: COVID-19 impact on spatio-temporal travel patterns	Arias-Molinares, D., García-Palomares, J.C. and Gutiérrez, J.	18-22 July	Paris, France
		2022	Presentation	Willingness to pay for a MaaS offering: the case of Madrid.	Arias-Molinares, D.	28-30 November	Tampere, Finland

Total: 12 national and 4 international

Source: own elaboration.

1.4.3. Awards

The research conducted throughout this thesis has received the following awards:

1. 1st place-prize for Social Sciences category in the 3-Minute thesis Contest #3MT organized by the Complutense University (2022). One of the 4 winners out of 61 participants.
2. 1st place-prize in the XI UCM Scientific Dissemination Contest awarded by the Oficina de Transferencia de Resultados de Investigación (OTRI-UCM) from Complutense University (ed. 2022). The only winner in the "Infographics" category and part of the 17 winners out of 80 participants.
3. 2nd place-prize in the VI edition of the PhDay organized by the Doctoral School of the Complutense University (EDUCM) (2022).
4. 2nd place-prize in the first edition of the "PhD Slam" of the UNA Europe inter-university network, which constitutes a network made up of nine (9) European universities. The competition involved a first round of evaluation to select representatives from each university and a second round of evaluation where the eight finalists explained their research in 7 minutes. Press release UNA EUROPE: <https://www.una-europa.eu/stories/phd-slam-meet-our-winners> (2021).

1.4.4. Research stay

Finally, a part of this research (corresponding to chapter 9 of the doctoral thesis, and to scientific article number 9 listed in this section) has been carried out at the Technical University of Munich (TUM) in the [Research Group Accessibility Planning](#) (Munich, Germany) in a period of three months, from May 29 until august 31 of 2022.

2. A new mobility paradigm: the burst of micromobility services

Urban densification, congestion and pollution levels are making necessary the creation of new strategies aimed at reducing car-dependency. One of the most successful innovations, concerns electric vehicles and with them, the emergent new shared mobility services. Two main changes have occurred during the past several years enabling their expansion. On the one hand, a change in people's lifestyles, that now base their consumption on immediacy and "access to", instead of ownership (especially young generations). Based on this life philosophy, consumers are benefiting from lower costs derived from using shared goods and services while avoiding the waste of resources (Cohen, 2019; Leismann et al., 2013). On the other hand, technological solutions are being disruptive. To name only a few of them related to the mobility sector, we could highlight the rapid development and high penetration of smartphones, the speed of connectivity (4G and 5G networks), the availability of new mobile payment, positioning and geolocation systems, as well as the Internet of Things (Big Data and greater information processing and storage capacity). These co-existing conditions have facilitated the generation of a new mobility paradigm, in which technology is playing a central role, and thus academics and experts are referring to this phenomenon using the concept of Smart Mobility. This section aims at outlining the theoretical framework of the thesis within the Smart City model and the rise of Big Data, as well as briefly overviewing the main concepts related to shared mobility, micromobility and Mobility as a Service (MaaS).

2.1. Mobility in the 21st century: Smart City, Smart Mobility and Big Data

Almost four decades ago, the concept of sustainable development was introduced for the first time as the kind of "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987, p. 5). This report introduced the 17 Sustainability Goals that all the Nations should aim to accomplish by 2030 (see Figure 2.1). In 1992 a new report called "Agenda 21" discussed the concept of sustainable mobility, defining it as a system that generates access to opportunities and economic needs, while being environmentally and socially efficient and equitable, avoiding the negative transport impacts (United Nations, 1992). Since then, the need to better manage how we move or how we move goods around has been one of the world's most complex tasks and partly, that is why it involves multiple disciplines. Whether by moving less or moving more efficiently, mobility is starting to be conceived differently.

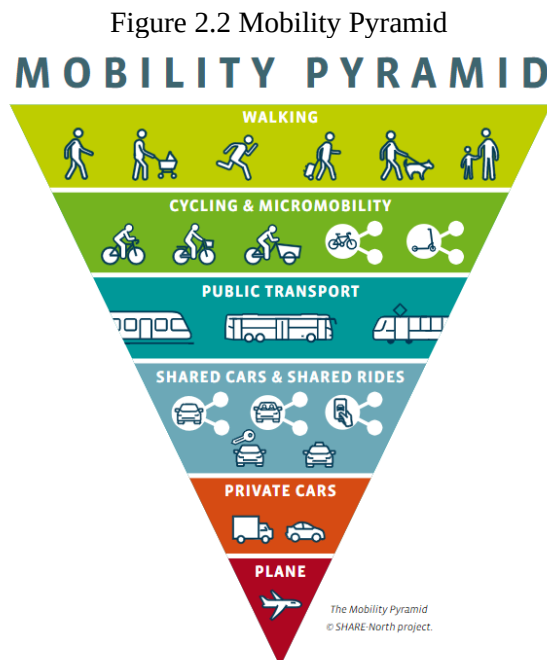
Figure 2.1 Sustainability goals to achieve by 2030



Source: (United Nations, 1987).

The idea of sustainability is generating new conceptual frameworks, one of them being the Smart City model. The European Commission considers the Smart City "a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business" (European Commsision, 2014, p. 10).

In this regard, the Smart Mobility concept finds its terminological home as one of the six design elements of a Smart City, besides Smart Governance, Smart People, Smart Living, Smart Economy, and Smart Environment (Directorate General for Internal Policies, 2014). Smart Mobility has been defined as a “visionary, yet feasible mobility of the future. It is applicable and capable of being used by anyone, independent of location or region, unbiased by utilization period and length, individual capabilities and budget” (Flügge, 2017, p. 2). Others simply refer to it as “the use of digital technology, connected transportation and accessibility systems which contribute to the creation of a sustainable and efficient traffic system” (Finck et al., 2020, p. 62). But in general, the concept promises to deliver a more sustainable and efficient mobility and accessibility options in the form of a multimodal system of connected, on-demand vehicles with flexible personalised services that are supported by real-time information (Docherty et al., 2018). Hence, cities are now shifting their attention from keeping cars moving to making it easier to walk, cycle and play on their streets. In this context, smart mobility solutions are going to be sustainable if they promote active mobility (pedestrian and bicycle), and public transport while also discouraging the use of private automobiles, following the principle of the mobility pyramid (Machado et al., 2018) (see Figure 2.2).



Source: (SHARE-North, 2021)

Being a novel and complex concept, there are many definitions for Smart Mobility, but all of them are closely related with mobility solutions based on information technologies (IT). By revising the literature, (Jeekel, 2017) identifies four main elements that characterise Smart Mobility: first, it includes vehicle technology (e.g. alternative fuels, electric mobility, autonomous driving and vehicle dynamics); second, it is supported by intelligent transport systems such as connected vehicles or intelligent traffic management; third, it requires large amount of data on transportation, weather and traffic conditions that correspond to the real-time demand of passengers; and fourth, it includes the development of new mobility services such as shared mobility and multimodal transportation.

Regarding the third element of Smart Mobility (Big Data), the term “Smart” refers to an *informed* city, and this information is now being generated and captured in a different way. For the first time in history, we live in a highly connected society. These connections generate a digital footprint with huge amounts of data, also known as Big Data (Gutiérrez Puebla et al., 2020). This

has been enabled by the rapid developments in Information and communications technologies (ICT) which have increased the capacity to generate, process and exchange data. Big Data is being generated in real time and is exhaustive in scope and resolution; instead of data being derived from a travel survey applied to a sampled population during a specific period, it is now obtained from a continued survey of every traveller (Kitchin, 2016b). And this transformation from slow and sampled data to fast and exhaustive data has been enabled by the “roll-out of a raft of new networked, digital technologies embedded into the fabric of urban environments that underpin the drive to create smart cities” (Kitchin, 2016b, p. 2). Camaras, sensors, GPS, a multitude of smartphones and sharing economy apps are continually sending data that can be processed and generate an immediate response with the data flow. In other words, we are seeing a radical expansion in the volume, range and granularity of the data being generated about people and places (Kitchin, 2016b).

These connected sensors (also referenced as the Internet of Things) are generating a large flow of information, mostly automatically, but more recently, it could also be generated by the user (web 3.0 revolution) as they can produce interactions (especially through social media). Every time we make a call, search on the internet, send an email, interact in social media, use a transport/bank card or move around the city with a GPS navigator, we are leaving a digital footprint behind (voluntarily or not voluntarily) (Osorio-Arjona, 2020). One of the most important data sources to address urban mobility issues is GPS records, which offer the exact coordinates (location) and timestamp (date) of each movement (Gutiérrez-Puebla et al., 2020). GPS records allow knowing the spatial and temporal distribution of trips throughout the day. This digital footprint is becoming highly useful to analyse mobility patterns. Therefore, the definition of Big Data is typically characterised by the 3V's: 1) *Volume* making reference to the massive amounts of data, 2) *Velocity* as the data is being created, processed and stored at high speeds, allowing real-time analysis to be conducted, and 3) *Variety* as the data types (structured, semi-structured and non-structured data) and sources (GPS records, bank cards, transit cards, phone antennas, social media, etc.) are very different. Building upon this characterisation, (Gutiérrez-Puebla, 2018) proposes to consider two additional V's: 4) *Veracity* as the data needs to be accurate and liable to explain the studied phenomenon and 5) *Value* as data by itself is worthless and it is the analysis and evaluation of patterns in data that have a real value as they can offer insights and knowledge to improve decision-making processes.

Today more than ever before, transport authorities and planners require Big Data that could help them to find travel patterns and understand mobility behaviour in order to create better-informed policies. This is especially needed now, with the rapid changes that are occurring with transport innovations and for example, the more recent external events, like the COVID-19 global pandemic and the Ukrainian war, that have a direct effect in people's lives. In the past, mobility surveys were the most important source of information to plan cities as they offer detailed information. However, these surveys have a high cost, and it causes them to be less frequent (they are usually conducted every 10 years). Even though they offer great detail of the current situation, like a high-quality picture, they soon become obsolete. Today's technologies advances offer access to new and cheaper sources of data, with higher spatiotemporal granularity, like a real-time video of the city dynamics (Gutiérrez-Puebla, 2018; Osorio-Arjona, 2020).

Therefore, authorities and transport planners now have a more holistic perception of what they want to analyse and evaluate by complementing traditional and new data sources. As stated by (Kitchin, 2016b), the main consequence is a new data-driven urbanism which is changing how we know, plan, and govern cities. The result is a highly responsive urban governance in which big data is prefiguring, setting the urban agenda and influencing/controlling how cities respond and perform. That is the main reason why, as stated by (Romanillos, 2018), it is better to understand Big Data as the enthusiasm and hype around the rapid expansion and sharing of data.

Data availability is helping researchers and policy makers in their tasks to grasp and understand with high detail, processes that were not previously considered, that were under sampled, kept private or simply poorly analysed. The open data movement is now pushing an agenda of transparency and encouraging authorities to provide open and usable datasets that third parties can use to create useful platforms and research outputs (Romanillos, 2018).

But these technologies have their pros and cons, and we can clearly see its benefits, but we also need to make a harder effort to recognise and imagine ways to minimise its hidden “pernicious” effects (ethical issues concerning privacy, datafication, dataveillance and geosurveillance, and data uses such as social sorting and anticipatory governance) (Kitchin, 2016b). As the famous architect Cedric Price once asked in 1996 the provocative question: “technology is the answer, but to what was the question?”, we need to also start asking “what do these technologies do *for* and *to* whom?”. Some experts recommend complementing different sources of data (big and small), rather than to just supporting all decisions on big data, as “cities need to be framed as a fluid, open, complex, multi-level, contingent and relational systems that are full of culture, politics, competing interests and wicked problems that often unfold in unpredictable ways” (Kitchin, 2016b, p. 11). Reducing this complexity to modelling outputs could be considered reductionist and an overly technocratic understanding of cities’ governance (Cardullo & Kitchin, 2019; Kitchin, 2016a).

Therefore, it is crucial to understand that technological solutions on their own are not going to solve the deep-rooted structural problems in cities as they do not address their root causes but rather only enable the more efficient management of those problems’ manifestations (Cardullo & Kitchin, 2019). As stated by (Cardullo & Kitchin, 2019) we need to move beyond the perception of citizens as mere *consumers* or *users* within a marketplace of services that are under civic paternalism (elites decide what is best for all). These experts propose to adopt the smart city but also the *smart citizenship* model in which:

- The smart city would be orientated towards reflecting and serving the interests of citizens, rather than to be subservient to the interests of state and market.
- Promote a more inclusive and deliberative framing of citizen participation including extensive public consultation, collaboration, and co-production.
- Reorient smart city initiatives to instrumental issues, but also more normative concerns such as fairness, equity, democracy, and social justice.

In other words, smart citizenship requires citizens to be *active* participants of decisions rather than just *passive* policy receivers. Just as Figure 2.3 shows, this participation involves a more critical-thinking perception of the contexts, speeches, initiatives and whatever new technology that arises, bringing more social science into the study of smart cities, shared mobility and MaaS like may studies have done (Ben-Elia & Benenson, 2019; E. Desjardins et al., 2022; Duran-Rodas et al., 2021).

Figure 2.3 Mafalda cartoon illustrating smart citizenship. English translation: Dad to little son: “This is for chewing, not to swallow”, Mafalda: “whose speech?”.



Source: (Quino, 1993).

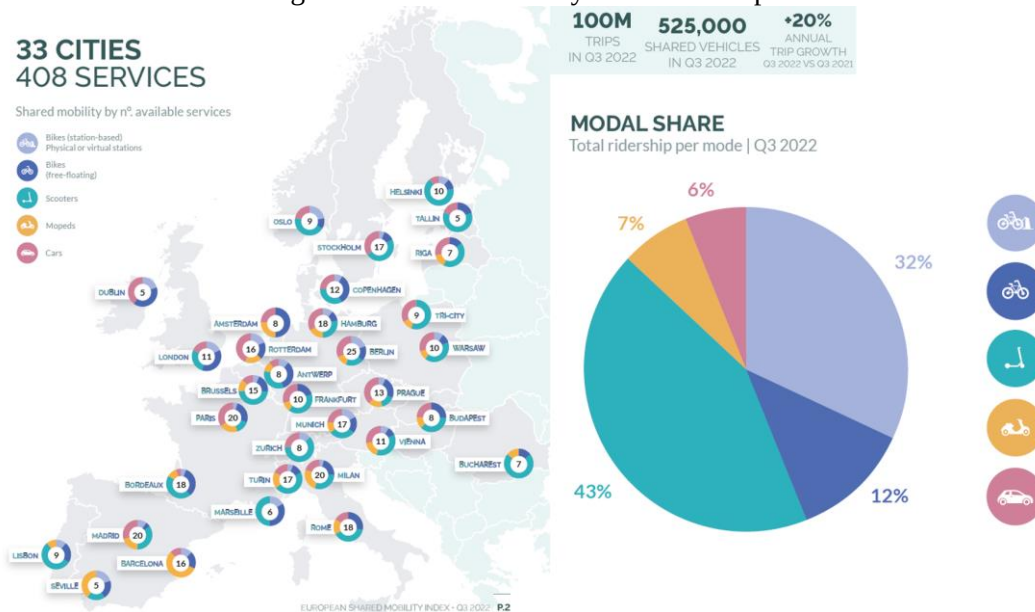
However, with this in mind we should *chew* these new technologies as they do provide many benefits to city managers and citizens while implementing measures to minimise its disadvantages (Kitchin, 2016b). Consequently, in order to reduce CO2 emissions in the atmosphere caused by the motorised transport sector, many cities are using Big Data to create and promote new sustainable strategies. Some of the most important ones involve the conversion of central roads into pedestrian promenades, the addition of new cycle lanes and the reduction of speed limits. We have also seen the consolidation process of bike-sharing systems, initiated in 1995 with Copenhagen’s Bycykler program, and followed by the Paris, London, Helsinki, Boston, New York, Montreal, Hangzhou and many other cities around the globe. But more recently, the mobility ecosystem has become more complex with the introduction of shared mobility and micromobility services worldwide.

2.2. The “new thing” in the mobility paradigm: Shared mobility and micromobility services

In its most recent Smart Mobility Strategy, the European Commission has highlighted the importance of shared mobility services as they have demonstrated to be crucial for intermodality and the public transport system’s resilience (especially after the COVID-19 pandemic outbreak) (European Commission, 2020). In this context, some experts are stating that shared mobility is being one of the three most important transport revolutions and thus, the automobile sector is starting to envision itself as a shared mobility provider, instead of just car manufacturers (Fulton, 2018). With the climate and economic crisis, shared mobility has grown exponentially in many cities around the globe. It has been defined as a short-term access to shared vehicles, according to user needs and convenience, rather than requiring vehicle ownership (Shaheen et al., 2009, 2016; Shaheen & Cohen, 2019). With the exception of car-sharing, all other vehicles are for individual use and have low speeds (most up to 30km/hr). In this sense, the term micromobility was coined to refer to these small, lightweight and low-speed shared modes as mopeds, bicycles and scooters (Khamis, 2021; Shaheen et al., 2019; Shaheen & Cohen, 2019). Micromobility offers the same benefits of shared mobility in general, such as the reduction of noise and air pollution and the promotion of intermodality with public transport. But in addition, it offers greater flexibility by avoiding congestion, reducing parking space needed and in the case of mopeds, they provide greater speed, the possibility of traveling medium distances and a very attractive way to overcome the slopes in cities that are not flat (Aguilera-García et al., 2020). All these advantages are well known by users, and to a large extent, they are the cause of micromobility’s popularity in the recent years. Additionally, these new forms of movement require a much lower vehicle production compared to what will be needed if each vehicle was dedicated to a single person (who would probably keep it parked most of the time) (Aguilera-García et al., 2020; Arias-Molinares, Julio, et al., 2021).

The most recent European Shared Mobility Index (Fluctuo, 2022), which monitors more than 30 European cities (408 services), indicates that in third quarter of 2022 (Q3- June to September) there were 100 trips made in shared modes resulting in a 20% growth in ridership compared to the same quarter of 2021. With a global European fleet calculated 525.000 vehicles, most of these trips are made in shared scooters (43%), followed by station-based bike-sharing (32%). Madrid is one of the leading cities with a shared mobility index of 20 as Paris and Milan and just behind the city of Berlin (index = 25) (see Figure 2.4).

Figure 2.4 Shared Mobility Index in Europe



Source: (Fluctuo, 2022).

Micromobility companies basically manage a fleet of vehicles and offer them to their subscribers as a rental service for a given time (hours, minutes, etc.). They generally work through applications on smartphones, which has become widespread among a large part of the population. In fact, a recent study concludes that 68% of the global population owns a smartphone, and this percentage is even higher in the case of Spaniards (80%), that also spent approximately five hours each day online (Hootsuite, 2018). This high penetration of mobile devices has led to an unprecedented irruption of shared mobility companies. Users usually access an interface with a city map in their applications and locate the closest vehicle to their location. Once the vehicle has been identified, they unlock it from the app and begin the journey. User data and bank information are saved when registering for the service in order to make payment for the use of their fleets. Once the user reaches their destination, they park and relock the vehicle from the app. As we can see, one of the most important reasons that has made it possible for these services to be extended in cities is that just by having a mobile, you can make a vehicle reservation, start and finish the trip (Monzón et al., 2019).

In general, shared mobility started in many cities with bike-sharing programs, but later on it expanded to car-sharing and more recently, to other micromobility modes as mopeds (also known as moped-style scooter-sharing or moto-sharing) or scooters (kick-style scooter-sharing) services. In addition to the different shared modes available, these services can also be differentiated in relation to their parking models in docked (also called station-based) or dockless services (also known as free-floating). Docked services have a fixed infrastructure called stations or bases where users pick or leave the vehicles at, while dockless services allow users to collect or return the vehicles at any point within a restricted geographic area (known as geofence). Most of the recent micromobility services are dockless, allowing greater flexibility and the possibility of door-to-

door trips. A critical issue from the operational point of view in both cases is the need to redistribute vehicles since there is often an imbalance between the origins and destinations of trips according to hours of the day. Thus, for example, in early morning hours, most trips originate from residential zones, while they end at employment areas and the contrary tends to occur in the afternoon (commuting patterns). This causes vehicles to be concentrated in some neighbourhoods and scarce in others, forcing operators to redistribute vehicles in vans, with the consequent increase of operation costs, congestion and pollution. In addition, dockless services require more operational logistics for maintenance and recharging tasks. In regard to the spatial distribution of these services, they are often offered mainly in the city centres, where operators find more profitability, as land uses are diverse, and a high concentration of public transport and activities offered. However, the concentration of shared services in the city centre may be competing with public transport and active mobility and hence, a more homogeneous distribution is desired reaching also peripheric areas, usually the most car-dependent ones, and where these services could be a solution to the last-mile trips.

Moreover, unlike the first public bike-sharing systems that were mostly financed or promoted by public organisations, the new shared mobility services are mostly incentivised by private initiatives. Large private companies are behind many of these initiatives (e.g., BMW with Car2Go, Renault with Zity or Kia with Wible). These services are usually implemented with hardly any limitations and at a relatively lower costs, since most of them are dockless and do not require any physical infrastructure. However, the lack of regulation has also caused many conflicts, especially when these vehicles are parked invading sidewalks. Since their irruption worldwide in the summer of 2017 and 2018, cities are now just beginning to react to this phenomenon with the introduction of regulations (Henderson, 2019). Despite the conflicts caused, the fact is that these services, such as BiciMAD in Madrid, Bicing in Barcelona, Valenbisi in Valencia, SEVICI in Seville, MálagaBici or BiZi in Zaragoza are becoming important forms of mobility in their cities. The success of these systems is helping to promote a more sustainable modal shift and increase policies oriented to extend the needed infrastructure to make them safer and more attractive. With the burst of shared mobility and more recently, of dockless micromobility services, there is a growing need to have all the mobility offer centralised in a single place, which has enabled the concept of Mobility as a Service (MaaS).

2.3. The umbrella concept: Mobility as a Service (MaaS)

The globalised, tech-driven, servicizing era has begun and it is enabling new concepts like Mobility as a Service (MaaS). Millennials are the first digital-native generation, accustomed to technology and more interested in services than in assets. With many shared mobility and micromobility options available, citizens are finding it difficult to navigate through the plethora of applications. MaaS is born from the idea of servicizing mobility by integrating all services into one unique app. The promise is to integrate both, the existing traditional public transport systems but also the new emergent shared mobility services (Fioreze et al., 2019). The result of this combination is precisely the “bet” on MaaS, as it could cover all transport needs required to substitute a private automobile. Instead of owning individual vehicles, MaaS customers will join a MaaS offer that includes different transport options (Gaudó Labarta, 2017).

This concept arose in 2006 when the entrepreneur Sampo Hietanen proposed, what he called *mobility packages*, and idea oriented to bundle our mobility services in a similar way as a mobile phone contract (Hietanen, 2014). In 2014, Hietanen described Maas as a distribution model that delivers users’ transport needs through one single interface of a service provider, combining different transport modes to offer tailored mobility packages (Hietanen, 2014). The concept appeared in scientific literature with Sonja Heikkilä’s master thesis, which was supervised by Sampo Hietanen, offering a definition of MaaS as “a system in which a comprehensive range of

mobility services are provided to customers by mobility operators” (Heikkilä, 2014). Since then, many researchers started addressing this topic and proposing their own definitions. For example, Sakai broadly considered MaaS as all the modes of transport other than private cars (Sakai, 2019). The definition offered by (Kamargianni & Goulding, 2018) described MaaS as a user-centric, intelligent mobility distribution model in which all mobility service providers’ offerings are aggregated by one sole mobility provider, the MaaS provider, and supplied to users through a single digital platform.

All these authors focused on the role of technology to enable MaaS through an application. Another frequent definition found in literature is provided by MaaS Alliance, as the integration of various forms of transport services into one single mobility service accessible on demand (MaaS Alliance, 2017) focusing primarily on the integration of transport services, similar to the definitions offered by (Matyas & Kamargianni, 2019; Sochor et al., 2015b). MaaS is often referenced as an intelligent, multimodal and completely user-oriented mobility distribution and management system, in which a provider integrates multiple transport operators (public and private) providing easy access to them, through a digital platform and allowing them to plan, pay and access their mobility services quickly and conveniently (Heikkilä, 2014; Hietanen, 2014; Ho et al., 2018; Kamargianni & Goulding, 2018; Mulley et al., 2019; Smith & Hensher, 2020; Wong et al., 2018). In general, the central idea of MaaS is to concentrate the entire mobility offer in a single application that allows users to navigate through all the options and to move within or outside their city, making it possible for them to obtain information, plan routes and make a payment for the services consumed, all quickly and conveniently (Kamargianni et al., 2016; Kamargianni, Yfantis, et al., 2018). As the concept is still recent, many contributions are being made. Hence, the results of an exhaustive scoping literature review will be described in the last chapter of the thesis, outlining the pathways towards a MaaS offering in Madrid.

2.4. Background conclusions

The background offers an overview of the concepts around the previously mentioned three stages of the mobility paradigm (past-shared mobility, present-micromobility and future-MaaS). As main conclusion of the revision of the concepts we can highlight that today, the mobility paradigm is oriented to increase the potential of micromobility as the efficient travel option for the first/last mile trips. The so-called last mile problem refers to the interconnection gap that usually exists between long and short distance transport services, which causes that the last (or first) mile of the trip is made by car or taxi (Dell’Asin et al., 2015). The implementation of new public transport system is highly expensive, and thus, it is mostly allocated in the main transport corridors with high demand, leaving some areas without coverage. In general, walking is the mode of access to these mass transit systems, however, some authors highlight that the distances that users are willing to walk to access a bus stop or a train station is short (around 400m) (Adjei, 2010). This is the void that micromobility can cover, functioning as a feeding mode of transport for those users who are located within an area that is more than 400m from the bus stop or station, but less than 5-7km (Adjei, 2010). By feeding public transport systems, micromobility could increase mass transit catchment areas by four times (ITDP, 2011) generating savings of up to 15 minutes (Martens, 2004). Therefore, the intermodality between mass transit and micromobility services could leverage the strengths of both systems creating a modal chain that is competitive with the private car in terms of time travel, comfort, and convenience. Consequently, intermodality represents the present time of the mobility paradigm and MaaS is promising to be the future stage by facilitating these interconnections with all services integrated in a single app. We have described the context in which the burst of micromobility services appeared: an urgent climate crisis, and the development of collaborative economy and technology advances as two of its main solutions oriented to achieve sustainability. This brief overview sets the theoretical framework of our research.

3. Madrid: a shared mobility living lab

This chapter¹ introduces the case of study, the municipality of Madrid. We describe its main characteristics and provide a geographical context to understand the different analysis performed and the results obtained. Next, we delve into the characteristics of BiciMAD, the main service to be analysed in the thesis as well as the existing cycling infrastructure. Finally, it ends by diagnosing Madrid's current shared mobility ecosystem and the current policies and plans towards sustainability.

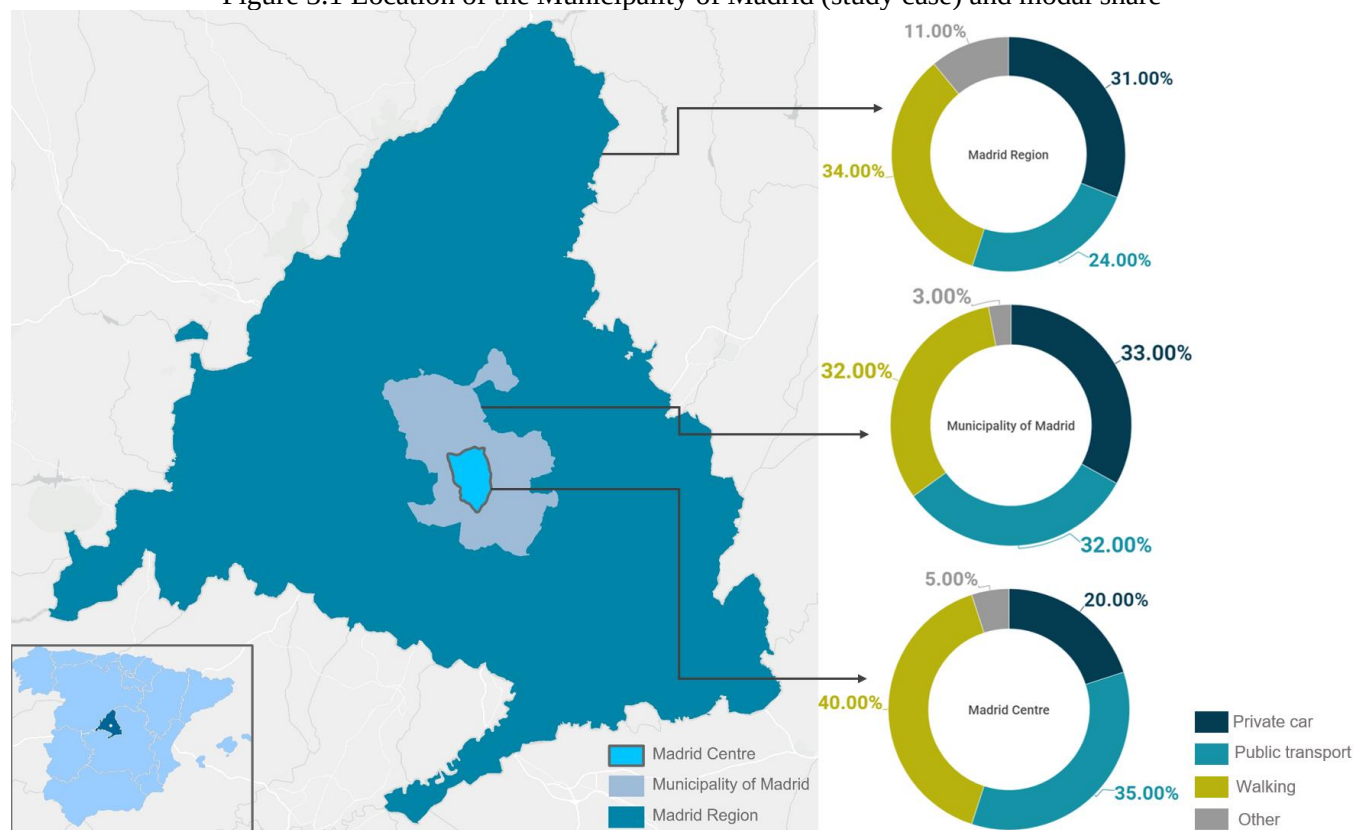
3.1. Madrid: breeding ground for shared mobility

Madrid municipality is the capital of Spain and the country's most populated urban area. It has a population of 3.3 million (INE, 2021), holding the second position in urban population terms within Europe (after Berlin), and with its metropolitan area reaching almost 6.8 million people. It has a relatively high population density, standing at 5.460 inhabitants per square kilometre on average and reaching 17.485 inhabitants per square kilometre, inside the M-30 highway urban area which is called *Almendra Central* and constitutes the city's centre (see Figure 3.1). Madrid concentrates 1.29 million jobs and has a great supply of social, educational and cultural facilities, offering various entertainment events and public activities. The weather varies quite dramatically throughout the year, with temperatures commonly over 30 °C in summer and close to 0 °C in winter, and it has a dry climate with one of the lowest precipitation levels in Europe (400 mm/year) (Asenjo, 2020). Another important characteristic of Madrid is its topography, with the presence of some hilly streets close to the river and the constant north-south positive slope (Romanillos, 2018).

The public transport network spreads through metro, suburban rail and city and inter-city buses. It mainly serves the municipal area of Madrid, although in recent years, it has been extended to several other towns in the region. Three ring motorways contour the city distributing a high number of trips between the nine radial roads. Madrid is one of Europe's cities with the highest level of public-transport use, as well as non-motorised transport, according to the (European Commission, 2014). The last Household Mobility Survey of Madrid Region conducted in 2018, showed that there are 15.8 million displacements occurring on a working day (approximately 2,32 trips per person) out of which 3.8 million employ public transport (24%), showing the important of the public transport system in the city (Comunidad de Madrid, 2018). The average trip in the region lasts 25 minutes and covers 6km. The modal share in the Municipality of Madrid is distributed in 33% of trips with private car, 32% in public transport, 32% walking and 3% in other modes, while the city centre shows a more sustainable pattern with a distribution of 40% of trips walking, 35% in public transport, 20% in private car and 5% in other modes. When zooming into the share of the category "other modes", we find that motorcycles are the most important in both the Municipality of Madrid and the city centre with 44% and 37% of the share respectively, followed by taxi and ride-hailing services (19% and 30%), bicycles (16% and 18%) and other modes (23% and 15%).

¹ The content of this chapter has been published in (Arias-Molinares & García-Palomares, 2020a)

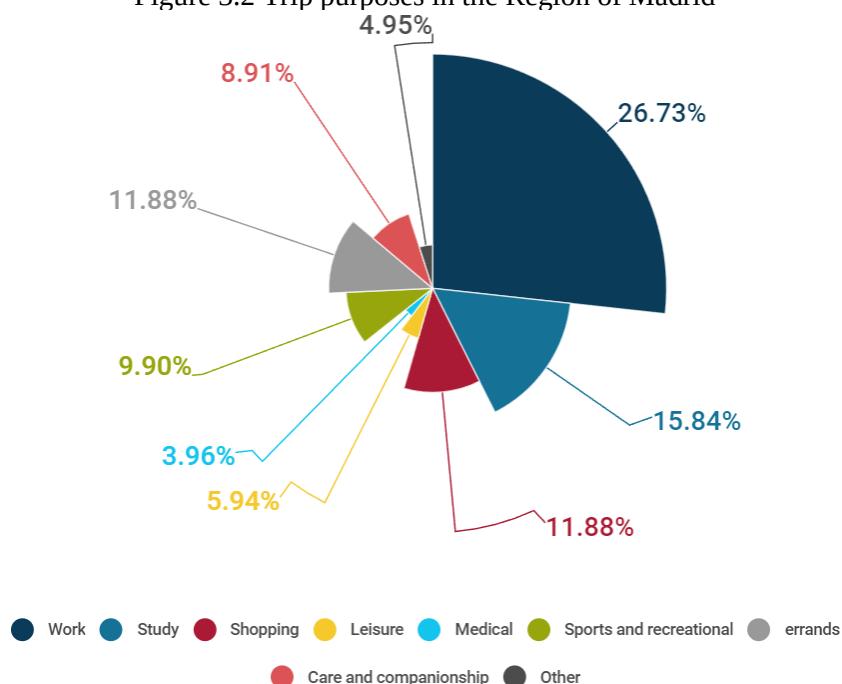
Figure 3.1 Location of the Municipality of Madrid (study case) and modal share



Source: own elaboration based on data given by (Comunidad de Madrid, 2018).

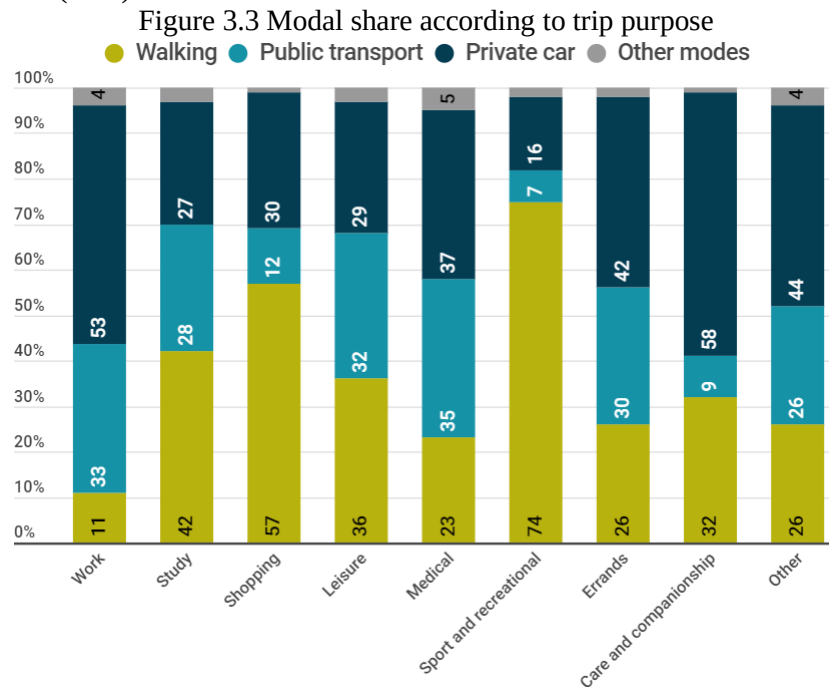
In general, occupational mobility (commuting) accounts for 43% of the trips, while non-occupational mobility holds the other 57%. The most important trip purposes in the region are work (approximately 27%), study (16%) and shopping and errands (12% each) (see Figure 3.2).

Figure 3.2 Trip purposes in the Region of Madrid



Source: own elaboration based on data given by (Comunidad de Madrid, 2018).

The modal share has variations according to the trip purpose (see Figure 3.3). The private car is the preferred mode for taking care and accompanying family (58%), work-related activities (53%), other motives (44%) as traveling outside Madrid, conducting errands (42%) and medical appointments (37%). On the other hand, public transport is preferred for medical appointments (35%), followed by work (33%), leisure (32%) and errands (30%). And finally, walking is preferred for sportive and recreative activities (74%), as well as shopping (57%), study (42%) and leisure activities (36%).



Source: own elaboration based on data given by (Comunidad de Madrid, 2018).

Madrid's Public Transport Authority is called Consorcio Regional de Transportes de Madrid (CRTM) and it coordinates all the public transport operators in the region. The subway and bus networks are the most important components of the public transport system. The subway network is the fifth largest in the world only surpassed by New York, Shanghai, Paris and London, with 294 km and 305 stations (Metro de Madrid, 2022). The municipal bus network is also very dense, with 218 lines, 2.081 buses and 10.367 bus stops (EMT, 2022). The great flexibility of the buses facilitates covering those areas of the city where the subway is not present. The public transport system has a relatively high degree of coverage; a GIS-approach study published in 2008 showed that roughly half the population of the Region of Madrid lived less than 600 m from a subway/railway station and in the case of the Municipality of Madrid, practically all the population have access to bus stops within a 300 m-distance threshold (Gutiérrez & García-Palomares, 2008). Another important aspect that promotes public transport usage relates to the offer of five well connected multimodal interchange stations within the city centre: Moncloa, Plaza Castilla, Plaza Elíptica, Avenida de América and Principe Pio. This infrastructure serves to facilitate connections between different transport modes promoting intermodality and also offering park and ride facilities, bike parking, commercial areas and other services.

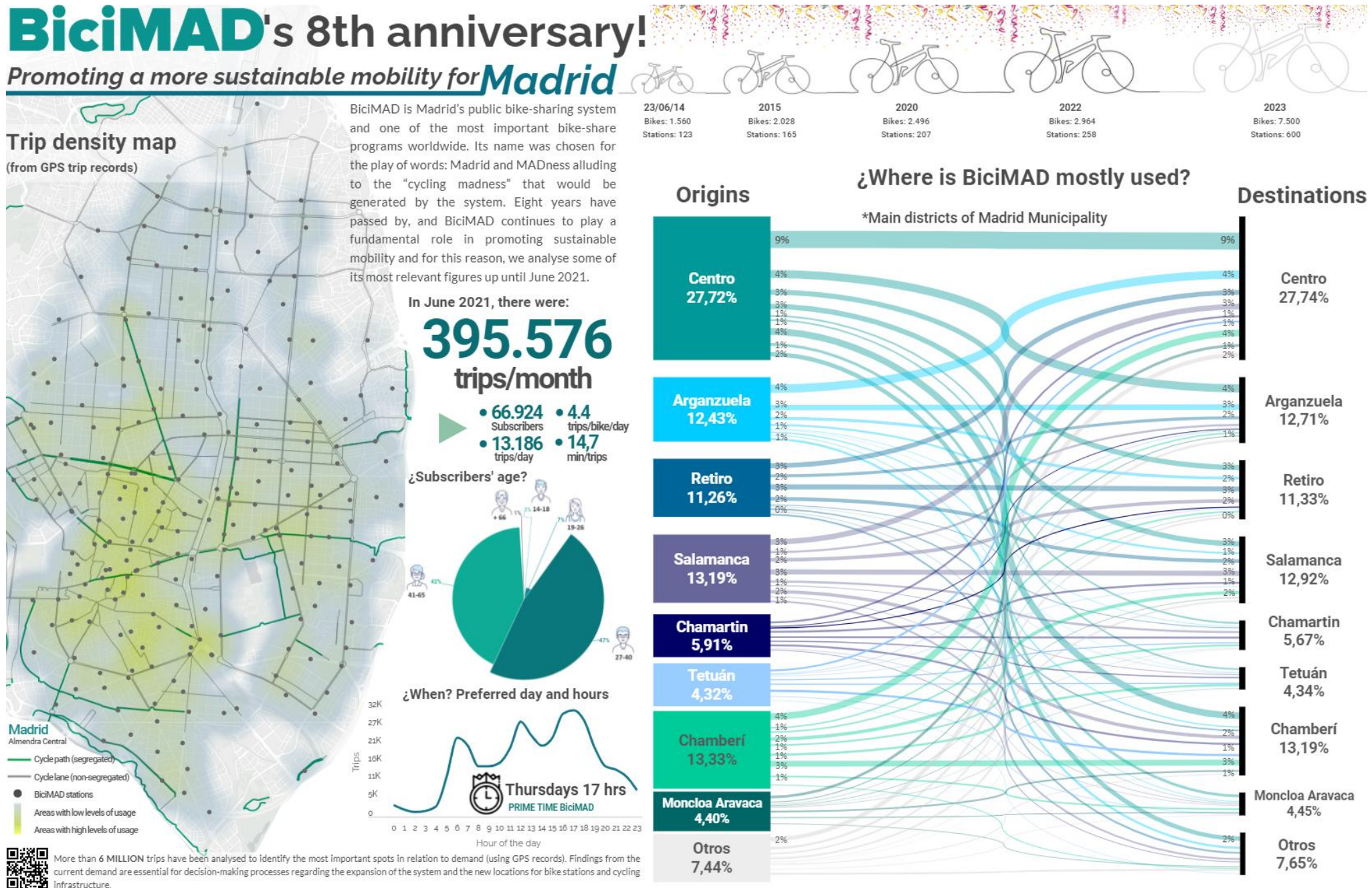
3.2. BiciMAD: Madrid's public and station-based bike-sharing system

This thesis focuses on BiciMAD, Madrid's bike-sharing system. BiciMAD was founded on June 23rd of 2014, and it is currently being managed by the Municipal Transport Company (EMT) reaching 58.397 (last data update: October 2022), which is less than the subscribers from June 2021 (Ayuntamiento de Madrid, 2022) (see Figure 3.4). Since its launch in 2014 there have been three expansions of the system, totalling 258 stations and 2.964 bicycles. The new expansion is

expected to be achieved by 2023 with 7.500 bikes and 611 stations (Ayuntamiento de Madrid, 2021). The latest data available for the system (June 2021) indicates that there were 395.576 trips/month and 4.4 trips/bike/day. As the infographic shows, the areas that have a high level of usage are mainly located in the city centre, with 27,72% of the trips being originated from the centre district and 13,33% from Chamberi district. We can also observe that subscribers are mostly aged between 27 and 40 years old and that their preferred time for travelling using BiciMAD is on Thursdays at 17hrs.

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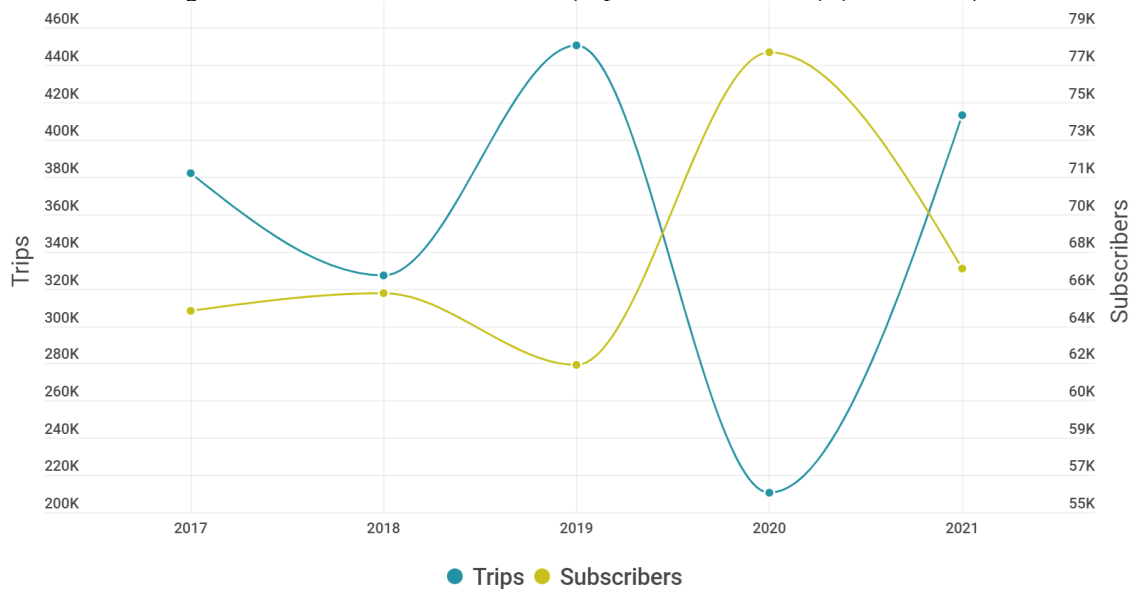
Figure 3.4 BiciMAD's infographic with its main figures (June 2021).



Source: own elaboration with BiciMAD open data portal (June 2021).

If we analyse the historical data of BiciMAD, we can also see some important patterns (see Figure 3.5). Trips increased from 2018 to 2019 and in 2020, we observe the dropdown due to COVID pandemic. However, up until June 2021 we can appreciate the good recovery of the system, with trips getting closer to pre pandemic levels. In regards with subscribers, we can observe a similar pattern from 2017-2019 and then a rise of subscriptions in 2020 as many people subscribed to the service during the pandemic (the so-called *boom of bicycles*), probably due to the fear of contagion using the public transport system. From 2021, we are seeing that the number of subscribers is returning to pre pandemic levels.

Figure 3.5 Evolution of BiciMAD (trips and subscribers) (2017-2021)



Source: own elaboration.

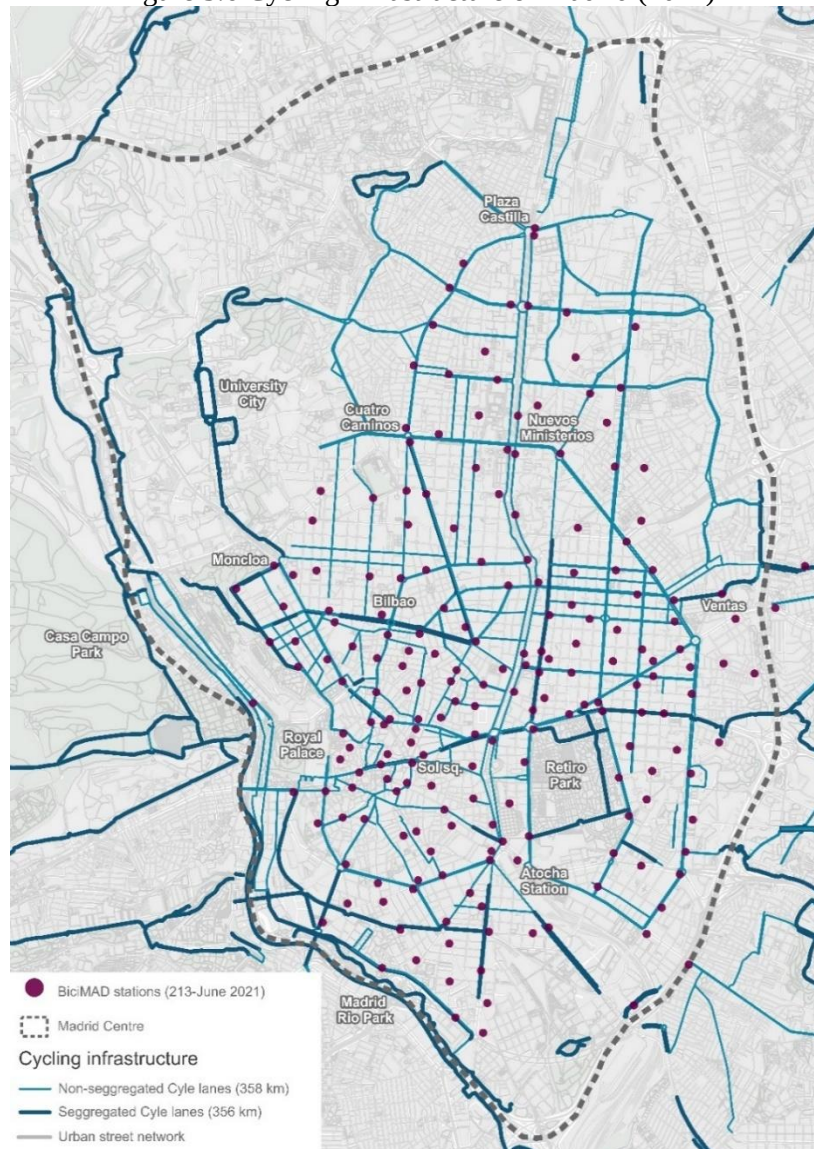
Regarding the characteristics of the bike-sharing system, we can highlight that the entire BiciMAD fleet is electric, and its bicycles have GPS devices that allow users to record their trips. BiciMAD is one of the first fully pedelec-based systems worldwide (a convenient feature in a city like Madrid, with some hilly streets that might be an obstacle for cyclists). Bike trips are anonymised and published in the open data portal of the EMT ([https://opendata.emtmadrid.es/Datos-estaticos/Datos-generales-\(1\)](https://opendata.emtmadrid.es/Datos-estaticos/Datos-generales-(1))). Currently, BiciMAD comprises almost all the characteristics and features of a fourth-generation scheme, such as: bicycle redistribution innovations (automated technologies, incentivising user-based redistribution, etc.), smart card integration with other transportation modes (public transport, carsharing, etc.) or no smart card (identification by mobile apps and QR codes), advanced pedalling technology, electric power-assisted bicycles (e-bikes or pedelecs, with an electric pedal assistance up to 25 km per hour in the case of BiciMAD), bicycle tracking (GPS, RFID), state-of-the-art docking stations (solar power, touchscreen kiosks) and online apps offering information such as real time availability of bikes at stations (Romanillos, 2018).

BiciMAD has an interesting pricing model, as its subscribers pay 0.5€ for all trips under 30 min (1st fraction), and 0.6€ for the next 30 minutes (2nd fraction). This pricing scheme is designed this way, to avoid bike-sharing trips substituting walking (really short distances). In any case, the annual fee of 25€ for registration is relatively low (considering also that for those with the transit monthly ticket is 15€), compared to other cities, such as London (120€), Budapest (45.8€), Barcelona (50€), Brussels (33.7€), Paris (37.2€) (Munkácsy, 2017). BiciMAD operates considering two types of BiciMAD subscribers: frequent and occasional ones. Frequent subscribers buy an annual membership (25€ in 2022), and then pay 0.50 € for trips with a duration of less than half an hour. Occasional subscribers can obtain a free card for 1, 3 or 5 days, and only

pay for the trips completed during these days. Occasional fees are higher with 2€ for the first fraction (under less than 30min rides) and 4€ for the second and consecutive fractions. Thus, the system's prices are designed with a specific target: Madrilenians as it tries to attract more frequent subscribers (residents of Madrid) instead of occasional ones (tourists).

Regarding the available cycling infrastructure, there are mainly two types: “Vía de uso compartido” (on road or non-segregated from traffic bike lanes) and “Vía exclusiva bici” (bike lanes partially or fully segregated from traffic, not necessarily with a physical barrier). According to the City of Madrid (Ayuntamiento de Madrid, 2019b), it holds a total of 406,43 km of cycling infrastructure, from which 238,78 km (58,75%) on road or non-segregated from traffic bike lanes while 167,65 km are somehow or fully segregated (41,25%) (see Figure 3.6).

Figure 3.6 Cycling infrastructure of Madrid (2022)



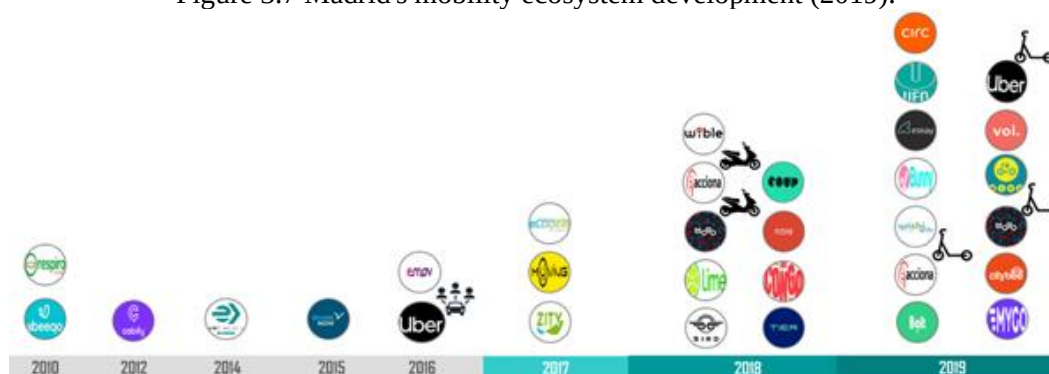
Source: own elaboration with information from (Ayuntamiento de Madrid, 2022).

The high concentration of a young and diverse population (the majority of them with bank accounts and smartphones), work/study areas, different social and cultural facilities and relatively good weather and topography are all important factors to create an adequate breeding ground for new shared mobility services to burst (Y. Li & Voegelé, 2017; Pangbourne et al., 2020).

3.3. BiciMAD and the complex and growing shared mobility ecosystem

Madrid's mobility ecosystem is rapidly growing. Since 2010, numerous companies have been joining the shared mobility sector (see Figure 3.7), especially since the summer of 2018 when micromobility companies started operating. In 2019, the city was a unique living lab for shared mobility and especially micromobility services, with a fleet size of around 30 thousand vehicles (Granda & Sobrino, 2019). The outbreak of the pandemic and the successive periods of confinement and restrictions have been a severe test for these companies, producing a restructuring process in the sector.

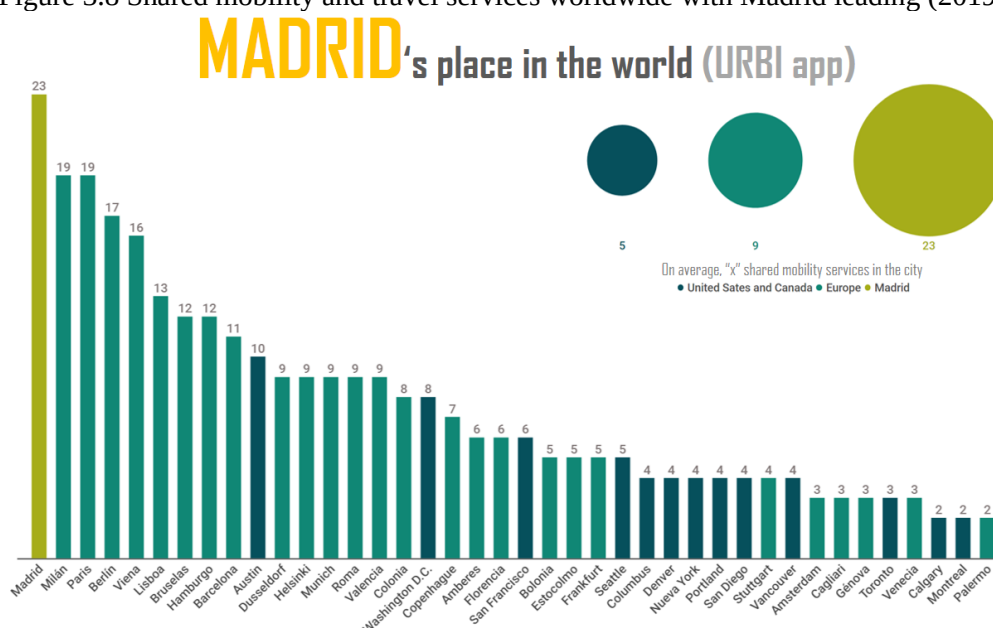
Figure 3.7 Madrid's mobility ecosystem development (2019).



Source: own elaboration.

In the beginning of the timeline (from 2010 until 2016), we can observe that the mobility ecosystem was dominated essentially by car-sharing and bike-sharing (BiciMAD). However, between 2017 and 2019, start-up ventures and other mobility operators became interested in micromobility, which resulted in shared mopeds and scooters bursting on the scene. According to the mobility aggregator URBI, operating globally in more than 47 cities, by 2019 Madrid concentrated the largest number of transport operators (public and private), with 23 companies, followed by Milan and Paris, with 19 operators (see Figure 3.8). A more detailed diagnose of the shared mobility ecosystem was conducted in Madrid during 2019, showing even more impressive results with at least 35 shared mobility services managed by 29 operators as listed in Table 3-1.

Figure 3.8 Shared mobility and travel services worldwide with Madrid leading (2019).



Source: own elaboration (based on URBI app data).

Table 3-1 Shared Mobility ecosystem of Madrid by 2019.

Sharing mode	Operator	Service Name	Type *	Mergers	Source ^a	Fleet	Source ^e	Companies behind	Source ^e	Schedule	Price (€/minute)	Entry fee	Operating in Madrid since
Car haring	1	Share Now	1	DriveNow + Car2Go	a	850	1	BMW Group + Daimler AG	I	24/7	0.19	9	2015
	2	Free2Move	1	Emov	b	605	1	PSA Peugeot-Citroën	b	24/7	0.25	9	2016
	3	Respiro	2			218	2	Seat	II	24/7	0.033	Free	2010
	4	Ubeeqo	2	Bluemove	c	344	2	Europcar Mobility Group	c	24/7	0.033	Free	2010
	5 and 6	Uber + Cabify	1			7.269	3	Uber + Cabify		24/7	No info	Free	2012 y 2016
	7	Wible	1			500	1	Repsol + Kia	III	24/7	0.28	Free	2018
	8	Wishilife	1			35	IV	EMC emobility Concept	IV	24/7	No info	Free	2019
	9	Zity	1			650	1	Ferrovial+ Renault	V	24/7	0.26	Free	2017
	Subtotal	9	9			10,471							
Moto sharing	10	Acciona	1			1,000	1	Acciona S.A.		24/7	0.19	Free	2018
	11	Coup	1			1,350	1	Bosch	VI	24/7	0.25	Free	2018
	12	E-cooltra	1			1,800	1	Cooltra Group	VII	24/7	0.26	Free	2017
	13	Muving	1	Iosccot (Motit4U)+ Muving	d	1,000	1	start up		6:00-3:00	0.25	Free	2017
	6	Movo	1	Movo + SJV Consulting	1	515	1	Cabify	VIII	24/7	0.2	Free	2018
	Subtotal	4	5			5,665							
Bike sharing	14	Bicimad	2			2,500	1	Empresa Municipal de Transportes (EMT)		24/7	0.017	15	2014
	15	Mobike	1			1,000	1	Mobike		24/7	0.05	Free	2018
	Subtotal	2	2			3,500							
Scooter sharing	10	Acciona	1			179	4	Acciona S.A.		8:00-23:00	0.23	Free	2019
	16	Alma	1			140	4	start up				Not yet operating	
	17	Buny (Ari Sharing)	1			420	4	start up			0.15	1	2019
	18	Bird	1	Bird + Sccot	g	1,106	4	Bird	XII	7:00-21:00	0.2	1	2018
	19	Citybee	1			246	4	Modus Group	XII	7:00-21:00	0.15	1	2019
	20	Eskay	1			64	4	start up		No info	0.15	1	2019
	21	Circ	1	Flash+Koko	e	2,296	4	start up		7:00-21:00	0.15	Free	2019
	5	Jump	1			566	4	Uber	IX	No info	0.12	1	2019
	22	Lime	1			641	4	Neutron Holdings	X	7:00-21:00	0.15	1	2018
	15	Mobike	1			170	4	Mobike				Not yet operating	
	13	Muving	1	Iosccot (Motit4U)+ Muving	d	36	4	start up				Not yet operating	
	6	Movo	1	Movo + SJV Consulting	1	1,440	4	Cabify	VIII	24/7	0.11	Free	2019
	23	MyGo	1			90	4	start up		7:00-21:00	0.15	1	2019
	24	Ride Conga	1			403	4	start up		No info	0.11	Free	2018
	25	Bolt	1	Bolt+Taxify	f	750	4	start up		No info	0.15	1	2019
	26	Tier	1			484	4	Tier	XII	7:00-22:00	0.15	1	2018
	27	Ufo	1			530	4	Seat	XI	No info	0.15	1	2019
	28	Voi	1			162	4	start up		No info	0.15	1	2019
	29	Wind	1			136	4	start up		6:00-22:00	0.15	1	2019
	Subtotal	14	19			9,859							
Total		29	35			29,495		11 start-ups /24 consolidated					

- 1) (Granda and Sobrino, 2019)
- 2) (Monzón et al., 2019)
- 3) (Sanz, 2019)
- 4) (Ayuntamiento de Madrid, 2019b)

- c) (Jaen, 2019)
- d) (ABC, 2019)
- e) (El Español, 2019b)
- f) (De Aragón, 2019)
- g) (El Español, 2019a)

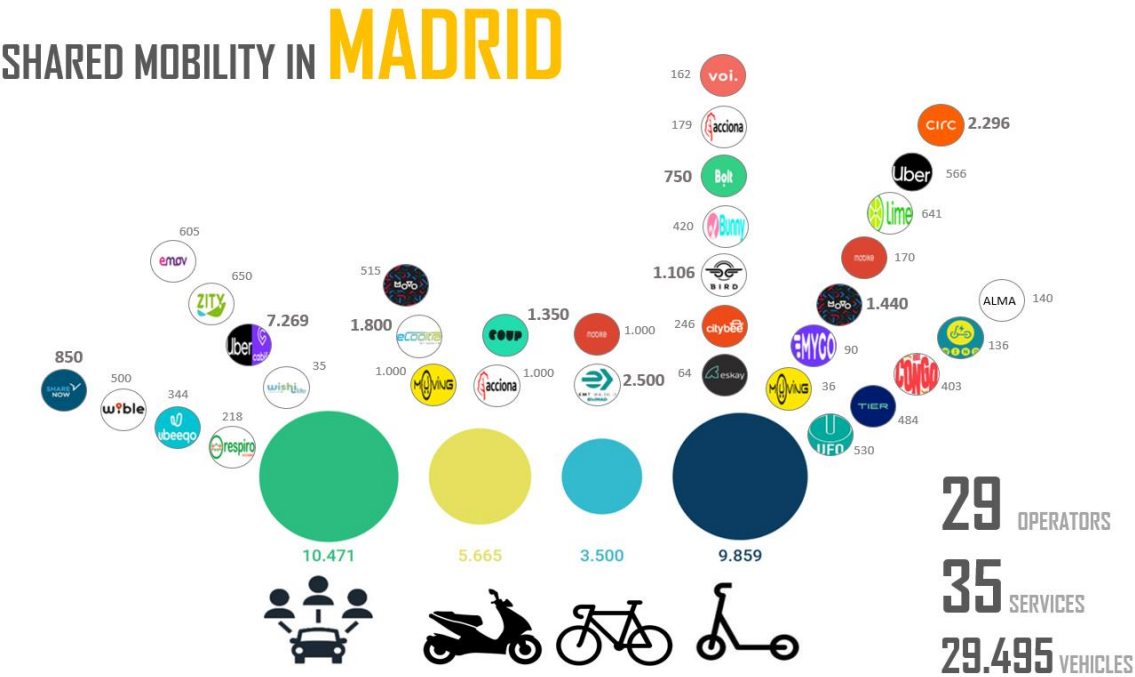
- a) (Hlubi and Seftel, n.d.)
- b) (Eadiccico, 2019)

- VII. (Daimler AG, 2019)
- VIII. (Espinós, 2018)
- IX. (San Esteban, 2019)
- X. (Sánchez Criado, 2018)
- XI. (Merino, 2019)
- XII. (Castells, 2018)

- I. (Torné, 2018)
- II. (Barciela, 2019)
- III. (Domínguez, 2019b)
- IV. (Revista GQ, 2018)
- V. (Domínguez, 2019c)
- VI. (Asenjo, 2019)

The largest share of the fleet was oriented to car-sharing services with 10.471 vehicles, followed by scooter sharing with 9.859 units (see Figure 3.9). The approximate fleet of 29.495 vehicles only accounts for 1.5% of the total automobile fleet of the Municipality of Madrid (1.919.036 as of 2017) (Comunidad de Madrid, 2018). Even though it could be seen as a relatively low percentage, it is a considerable large fleet of vehicles introduced into the city in such a short period of time, creating the general perception that the urban landscape, for good or bad, completely changed (Martínez, 2018).

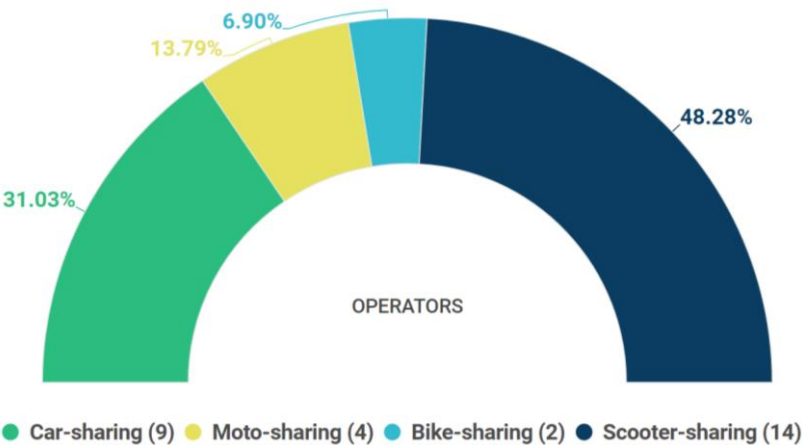
Figure 3.9 Shared mobility ecosystem of Madrid (2019)



Source: own elaboration.

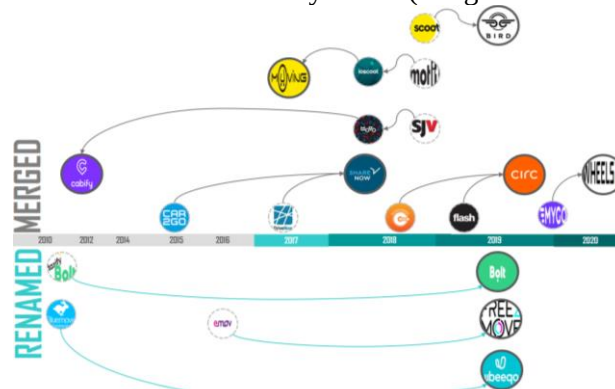
Almost half of operators are scooter-sharing services (48,28%) (see Figure 3.10), being the most developed and youngest market (Monzón et al., 2019). Shared moped services showed great dynamism as well, with 13,79% of the share of companies. Although these modes were the last ones to be introduced, they quickly showed a process of atomisation with many operators trying to get licences to operate in the city. This was followed by different processes of merges and/or ceased of operations after 2020 (see Figure 3.11).

Figure 3.10 Share of operators by type of mode (2019)



Source: own elaboration.

Figure 3.11 Dynamics in the shared mobility sector (merges and renaming) (2019-2020).

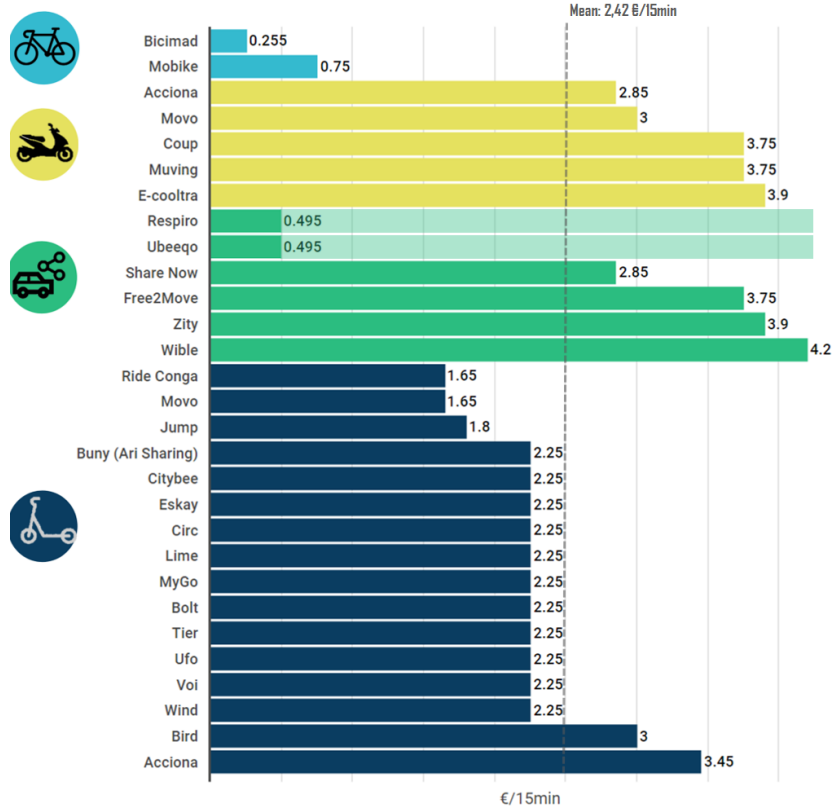


Source: own elaboration.

Many of the start-ups have been closed or acquired by large companies. The need for capital in the sector and the possibility of restructuring its business models towards the future of shared mobility and electric mobility has encouraged large companies in the automotive sector or logistics and industrial sectors to invest in recent years in these new mobility models. Hence, many of these start-ups in micromobility were backed by consolidated/large firms (24 companies), while only 11 were individual initiatives. The majority of services offer dockless or free-floating mobility, allowing users to park the vehicles anywhere, which is convenient for subscribers, but has also raised controversy, since the vehicles are occupying sidewalks (removing space for pedestrian circulation) (Hendersen, 2019; Martínez, 2018).

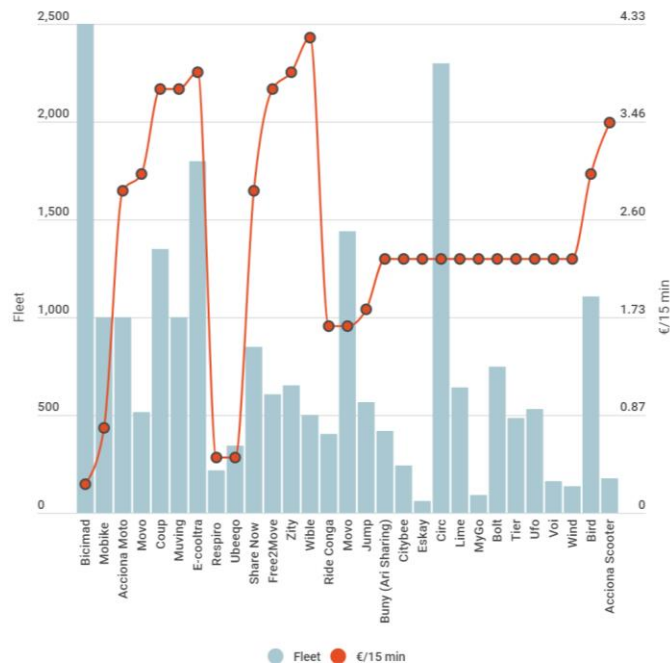
When analysing their fees, the shared mobility ecosystem is quite heterogeneous (see Figure 3.12). By choosing the services that offered price information per minute on their websites/apps, we calculated the fee for a 15-minute ride to allow comparisons. Our results showed that bike-sharing, especially the public system BiciMAD, was the most price-convenient. The average price for Madrid's micromobility services in a 15-minute ride was calculated in approximately 3 euros, with scooters and bikes being all under the average price and mopeds and cars being above it. The prices of different services in Madrid have a positive aspect: modes that occupy less space are cheaper (bicycles and scooters), incentivising their usage. When considering price and fleet, in general the rule seems to be that as the fleet size increases, so do the prices (apart from BiciMAD which is a public service and a few exceptions) (see Figure 3.13). Increasing the fleet makes a micromobility operator more competitive as people actually find more vehicles spread in different parts of the city, while in the case of low-size companies, they usually concentrate their offer in the city centre being a relevant limitation.

Figure 3.12 Fees for shared mobility in Madrid (2019).



Source: own elaboration.

Figure 3.13 Fleet size and 15-minute ride price in Madrid (2019).



Source: own elaboration.

This limitation is what also causes the different services to have varying coverage areas, also known as geofences. All the services offer their fleets in the core city centre (inside the Almendra Central), while they become scarcer in the suburbs and basically inexistent in the borders of the Madrid Region (see Figure 3.14). This spatial limitation reduces the services' accessibility as many residents of peripheral areas of the city are not allowed to use them for their last mile trips.

Figure 3.14 Different geofences shown in the service's apps (2019).



Source: own elaboration.

BiciMAD's service is available 24 hours and 365 days/year, as recharging/maintenance tasks are conducted in the station. Other micromobility services as mopeds and scooters are usually not available during early morning hours (00-04 am) as they are collected to be stored in operational hubs for maintenance and recharge. This creates additional logistical costs for the operator and inconvenience for customers who may need to use one of these services after midnight, when the subway is closed, and the bus frequency is low (especially for nightlife purposes). To tackle this problem, many micromobility operators are starting to conduct operational tasks (changing the battery) where the vehicles are parked, especially shared moped services.

Despite these mentioned limitations, shared mobility continues to grow and attract more subscribers in Madrid. In the case of bike-sharing, BiciMAD has around 75.000 subscribers, that have made more than 3 million trips according to their open data (Ayuntamiento de Madrid, 2019a). As stated by (Romanillos, 2018), the cycling modal share in recent years reveals this intense growth, going from 0.22% in 2008 to 1.20% in 2015. In the case of car-sharing services, ShareNow has reported 237.000 subscribers in Spain, compared with Free2Move with 200.000, Zity with 157.000 or Wible with 100.000 (Ruiz-hidalgo, 2019). In the case of shared mopeds, information found in the grey literature suggest E-cooltra as the most popular service, with 750.000 users in Spain (López-Redondo, 2019) or Muving with 350.000 users (de las Heras,

2019). Therefore, based on the city's main characteristics we can highlight Madrid as one of Europe's most important shared mobility labs and thus, an important city for MaaS initiatives.

3.4. Current policies and plans for BiciMAD and micromobility services

With the recent and disruptive introduction of micromobility services in Madrid, authorities have reacted by trying to regulate accordingly these services. The new City Ordinance (Comunidad de Madrid, 2019) is an effort to exhort BiciMAD and micromobility subscribers to circulate on the road at no more than 30 km/hr. It states that micromobility users may use bike infrastructure (non or segregated ones). Additionally, it restricts the use of micromobility in bus lanes and pedestrian space. An exception is made in the cycling infrastructure inside parks where users can reach up to 5km/hr circulating using BiciMAD and other dockless micromobility services. It also recommends the city and operators to work together to provide adequate public spaces for parking. Some companies have started to introduce the concept of *virtual stations* (see Figure 3.15), which are designated areas for parking micromobility vehicles. These designated areas are located usually in sidewalks when they are wide and offer adequate circulation for pedestrian and micromobility users and/or on the road substituting previous parking spots. The services' apps let the subscriber know that he/she must pick the vehicle at these designated areas. In the case of parking after making the ride, the app indicates the customer where to leave the vehicle and he/she must take a picture of it well parked or else, the app will continue to charge them for the current ride. Some private initiatives are also relevant, because they offer free helmets, restrict speed of vehicles according to GPS location when crossing pedestrian areas (or for example, 5km/hr in public parks) or offering insurance and free courses for users to learn safety driving (Domínguez, 2019; Portaltic, 2018).

Figure 3.15 Virtual stations for micromobility (painted sidewalks)



Source: <https://mobile.twitter.com/Menrodriguez/status/1535632051453497345>.

In order to comply with acceptable air quality levels, in 2015 the local government established an air-quality protocol to respond to high NO₂ pollution episodes. This protocol implemented restrictions on the use of private vehicles, on-street parking and an odd-even license plate control scheme. In 2018, a low emission zone, called *Madrid Central*, of 4.7 km² was established in the city centre. In September 2019, the city Hall introduced the “Madrid 360 Strategic Plan” which stated that traffic flow decreased from 2010 to 2018 in 15%, while the share of mopeds increased for the same period in 28% (Ayuntamiento de Madrid, 2019b). Regarding the cycling and micromobility policies proposed to promote sustainability, we can highlight from this Plan the following:

- Pedestrianisation of the main city's square Sol: five streets will become pedestrian areas and traffic flow is planned to be redistributed to other arteries as well as logistic traffic

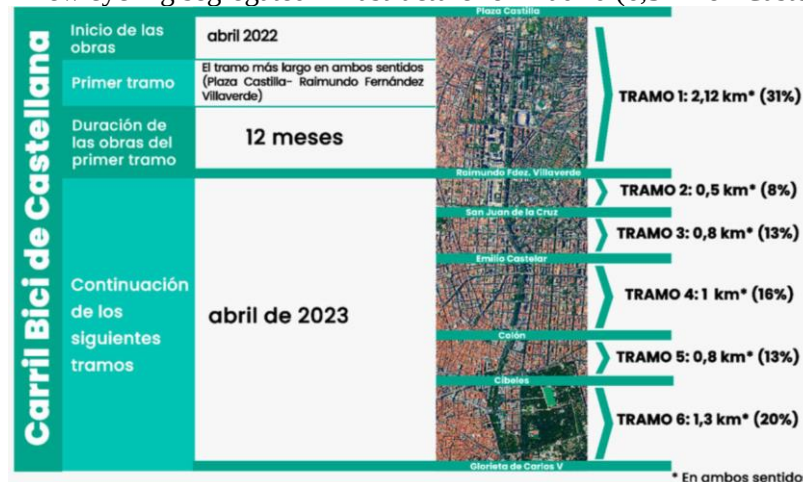
and public transport routes. The project is expected to be ready by spring of 2023 (see Figure 3.16).



Source: (Ayuntamiento de Madrid, 2019b; Viejo et al., 2022). Figure 3.16

- New segregated cycling infrastructure for the Castellana north-south axe: a new cycling infrastructure totalling 6,5km will be installed and ready in spring 2023 reaching the 200 km of segregated cycling street for Madrid. The visuals of the project are offered through this link: <https://www.youtube.com/watch?v=7IVDUo6CIQM>

Figure 3.17 New cycling segregated infrastructure for Madrid (6,5km on Castellana road).



Source: (Ayuntamiento de Madrid, 2019b; García-García, 2022).

- The introduction of a new MaaS app for Madrid: this project will be discussed furtherly in the last chapter regarding initiatives of MaaS in Madrid.

3.5. Conclusions on the case of study

Our characterisation of Madrid shows that the city is experiencing a burst of shared mobility and especially, micromobility services since 2010. The dynamics of its mobility ecosystem is facilitating MaaS, as users begin to find it difficult when navigating through all the different applications. As stated by (Y. Li & Voegelé, 2017), in order to implement MaaS two conditions need to be in place: a robust and consolidated public transport system and a multiple and varied shared mobility offer. Based on our review of the case of study, Madrid has them both. And more specifically, the city has a plan considering the development of a MaaS offer. All these characteristics and current policies are oriented to the promotion of micromobility and MaaS being an excellent case of study for the thesis.

4. BiciMAD and dockless micromobility user profiles and preferences

4.1. Introduction ²

As was mentioned in the background chapter, collaborative economy and the irruption of technological advances in social media and Information and Communication Technologies (ICT) are rapidly changing people's lifestyles and thus, their mobility behaviour. In the Transport Arena, shared mobility has been described as one of the three revolutions in urban passenger travel (Fulton, 2018), becoming a topical subject. Shared mobility has been defined as the short-term access to shared vehicles according to the user's needs and convenience, instead of requiring vehicle ownership (Shaheen et al., 2016). On the other hand, the term "micromobility" has been coined as the shared use of a bicycles, mopeds, scooters or other low-speed modes on an as-needed basis (Shaheen & Cohen, 2019). These services include different transport modes, and they can be station-based or dockless services. Most studies focus on station-based services as they have been operating for more than a decade, while only few efforts are found regarding dockless ones, as they have gained attention more recently (Degele et al., 2018; Hardt & Bogenberger, 2019; McKenzie, 2019b; Reiss & Bogenberger, 2015). Consequently, their impact on urban mobility dynamics is yet to be determined, offering a burgeoning new sub-field with numerous avenues of exploration. One of them is the exploration of its subscribers' opinions and perceptions regarding the different models and more importantly, those particular users subscribed to both models (station-based and dockless) as they can offer interesting insights when comparing the services. Hence, from the point of view of BiciMAD users (Madrid's public and station-based bike-sharing system), we explore opinions and preferences for other dockless services available. Therefore, with this study we aim to answer the following three questions: 1) To what extent have BiciMAD subscribers also adopted other dockless services? 2) Are there any differences with respect to socio-demographic characteristics, mobility behaviour or preferences between users that are only subscribed to BiciMAD and those also subscribed to other dockless services? 3) Is the relationship between both models complementary or competitive?

Responses from a BiciMAD satisfaction survey are analysed. This is an annual questionnaire that explores opinions related to the service's performance and users' satisfaction levels. The BiciMAD survey constitutes a great data source as we support (Felleson & Friman, 2012) when stating that customer satisfaction highlights the link between what a company does (in terms of the service offered) and how its customers react, making this link a key concern. We think analysing this link is of great importance, and especially for the recently introduced micromobility services. Consequently, we take the perspective of service dimension used by previous studies related to public transport (Felleson & Friman, 2012; Hensher & Stanley, 2003) and apply it to recently introduced micromobility services, analysing and comparing BiciMAD subscribers' opinions regarding station-based and dockless services. We consider five service dimensions which are demand patterns, price, comfort of ride, ease of use and spatial availability. By comparing BiciMAD users' satisfaction levels and preferences for station-based and dockless services simultaneously, we could offer insights to policymakers about what they consider important, as well as the perception about how the existing services are performing in these dimensions. The rest of the study is organized into four sections. Section 2 provides background. Next, we present in section 3 a brief overview of the study area and methodology used. Section 4 describes the main results and finally in section 5 we offer discussion and conclusions.

² The content of this chapter has been published in (Arias-Molinares, Julio, et al., 2021)

4.2. Background

When analysing the shared mobility literature available, station-based bike-sharing is by far, the most studied shared mobility service (Fishman, 2015; Pucher et al., 2010). Some authors have explored users' demographics (LDA Consulting, 2012; K. Wang et al., 2018), others have visualised their dynamics identifying trends (Borgnat et al., 2013; Romanillos, 2018; Zaltz Austwick et al., 2013), usage rates, demand models and the location of bases (García-Palomares et al., 2012; Goodman & Cheshire, 2014; Rojas-Rueda et al., 2011). A study made by (Munkácsy, 2017) analysed BiciMAD's users' profiles and intentions to adopt the service, finding that users were usually young, well-educated males. More recently, (Velázquez Romera, 2019) studied the factors that impact on the adoption of mobility solutions, one being bike-sharing systems, finding that user's satisfaction influenced the most. In a robust literature review on ride-hailing services, (Tirachini, 2020) highlights that most studies have found the service adopters usually among a relatively young, well-educated and wealthier population. The author also revised studies that found that built environment (mixed use, auto accessibility) and personal characteristics (using social media and smart apps, being tech-lover and having environmental awareness) play a key role in adopting these kinds of services. Nevertheless, compared to bike-sharing or ride-hailing, the research body related to dockless services is relatively smaller, which is understandable as dockless micromobility gained unprecedented popularity only in the last years. As a result, even though dockless services have been rapidly deployed in different cities, and only in the US, they went "from being virtually non-existent in 2017 to facilitating over 38.5 million trips in 2018" (Younes et al., 2020, p. 308), its specialised bibliography is still in its nascent stage and their usage in many cities is timidly growing.

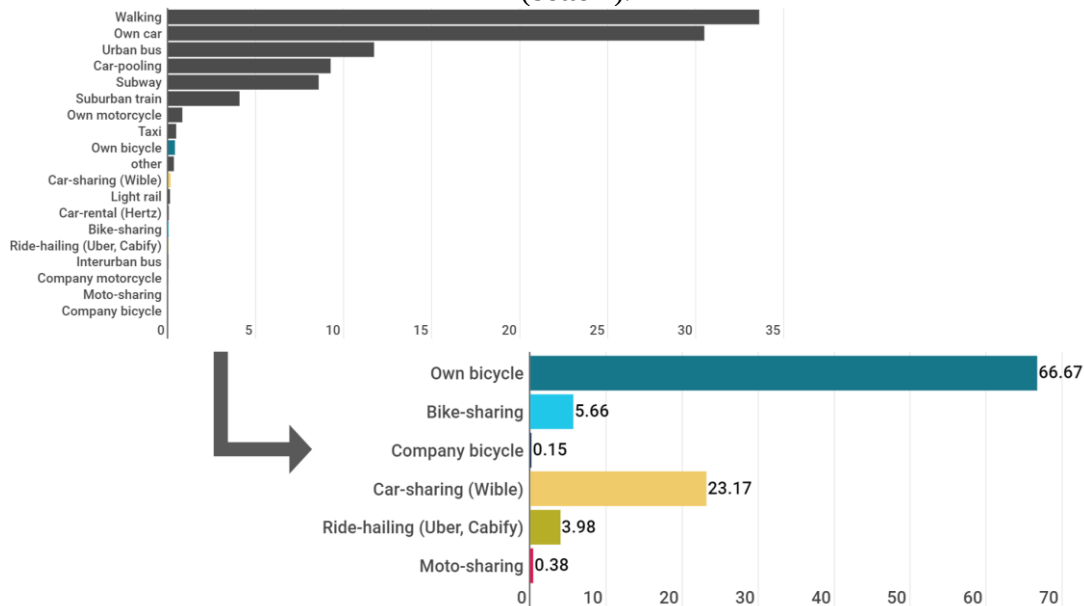
In general, studies related to dockless services could be classified in three main groups. The first one related to definitions and guidelines as made by (Shaheen & Cohen, 2019). A second group of studies are those entirely devoted to analysing a certain mode, especially scooter-sharing as in (Jiao & Bai, 2020; Zhu et al., 2020), but also dockless bike-sharing as in (Paul et al., 2016; Paul & Bogenberger, 2014; Reiss & Bogenberger, 2015, 2016, 2017). In the case of (Reiss & Bogenberger, 2017) they studied Munich's dockless bike-sharing service travel patterns and urban dynamics using GPS datasets, in order to propose vehicle relocation strategies that make the system more efficient. We can highlight that one of their main results was a demand model that considered different factors like seasons, weather conditions, time of the day and holidays/weekends, fleet distribution by area and time slots. And lastly, the third group of studies are those few that focus on comparing docked and dockless services simultaneously, which is the path we intend to follow in this research. In this group we could mention the work conducted by (Lazarus et al., 2020), that compared station-based and dockless bike-sharing systems and found that station-based bike-sharing trips tended to be short, flat commute trips, mostly connecting to/from major public transit stations, while dockless bike-sharing trips were longer, more spatially distributed and more heavily servicing lower-density neighbourhoods. Similarly, (Zhu et al., 2020) compared dockless bike-sharing and scooter-sharing services and found that scooters have spatially compact and quantitatively denser distribution compared with bicycles, and that their high demands were associated with places such as attractions, metros, and the dormitory. All these mentioned references analysed travel patterns based on GPS datasets, without considering the profiles and preferences of micromobility users. We focus on users' opinions (not their travel behaviour) and our results are based upon survey's responses (not GPS datasets). Our contribution to research literature is made by analysing how docked and dockless services interact from the point of view of its customers.

4.3. Study case and methods

4.3.1. Study case

The selection of Madrid is of special interest as the city has been known as one of Europe's top living labs for shared mobility, as we described previously in the Chapter 3. This varied mobility offer allows its residents to become familiar with the emerging mobility options. According to the last mobility report, 66,67% of Madrilenians have their own bike, 23,17% and 5,66% use car-sharing and bike-sharing services respectively (Comunidad de Madrid, 2018), supporting the idea that these shared services are gaining importance and popularity in the city (see Figure 4.1).

Figure 4.1 Prior transport mode in general (top) and when considering only certain modes (bottom).



Source: own elaboration based on (Comunidad de Madrid, 2018).

In addition to BiciMAD, which main characteristics are also summarised in chapter 3, the conducted survey for this research also addresses the preferences and characteristics of the subscribers to other dockless services, like Mobike or the varied scooter-sharing companies. Mobike is a Chinese private and dockless bike-sharing system that operated in Madrid from 2016 to 2019, with a fleet size of around 1.000 bikes. With respect to scooter-sharing companies, the survey did not address any particular service, as there were many companies operating by the time it was conducted. All the micromobility services analysed (docked and dockless) in this study, enjoy the privilege of free on-street parking and are allowed to circulate anywhere in the city (including the city centre which has been partly restricted to vehicles with the Madrid Central low emission zone).

4.3.2. Methods

The research workflow included two main stages. The first one related to obtaining and processing the survey responses and offering the socio-demographics descriptive results. A second stage involves comparing both models (station-based and dockless) based on two approaches: 1) conducting statistical analysis of the two user groups (Group 1- only BiciMAD subscribers and Group 2- BiciMAD+ other dockless services subscribers) and 2) identifying similarities and differences in the five service dimensions.

4.3.2.1. BiciMAD survey

The BiciMAD Survey is a yearly questionnaire made by EMT and sent to all BiciMAD subscribers to evaluate the service's performance based on their opinions. We have used the last survey conducted in 2019, that intended to explore users' characteristics and revealed preferences for station-based and dockless services. Our objective was to identify the extent to which BiciMAD users have also adopted dockless models, to evaluate differences/similarities between those only subscribed to BiciMAD (we called them Group1- BiciMAD only users) and those also subscribed to other services (called Group 2- BiciMAD+ other users) and finally to define the type of relationship between both models. Our hypothesis is that BiciMAD (a public and efficient micromobility service) is becoming crucial for the transformation in urban mobility dynamics. The system is prompting the use of other micromobility programs and thus it is enabling new concepts like Mobility as a Service to emerge in the city. Hence, we hypothesised that a considerable amount of BiciMAD users is also trying new modes and that their preferences (Group 2) probably differ from those in Group 1. With respect to the type of relationship, our hypothesis is that the systems complement each other as micromobility services are just beginning to operate. In the questionnaire, individuals are asked about:

- General socioeconomic and demographic information: gender, age, education level, occupancy, monthly income, environmental consciousness and zip code of residence and work/study.
- Mobility and travel-related variables: subscriptions to bike-sharing/dockless bike-sharing/ scooter-sharing services, trip frequency in different modes of transport, mobility patterns in weekdays/weekends.
- BiciMAD usage: trip frequency, trip purpose, trip time, previous mode used before BiciMAD, mode that they will use if BiciMAD is not available, satisfaction levels with BiciMAD and cycling infrastructure.
- Perceptions and use of dockless services: trip frequency, trip purpose (only for scooter-sharing and BiciMAD), proximity to user, satisfaction with service and best attributes for adoption.

A 5-point Likert-type scale was used on the questionnaire for all items to measure satisfaction levels, frequency of use, changes in travel behaviour and environmental consciousness. From March to August of 2019, 5.540 responses were received. Answers were codified to process information more efficiently and after the cleaning process (uncompleted forms or typo errors), we obtained 5.218 valid responses. We then processed the survey counting and coding responses in categorical data. After valid responses were obtained, a descriptive analysis of results was made, summarising users' main characteristics, travel behaviour and preferences for BiciMAD and dockless services.

4.3.2.2. Station-based and dockless services: comparison analysis

The second stage of the study involved analysing the two groups (Group 1 and 2), by using two approaches: statistical tests and service dimensions. When analysing them statistically, we used the statistical method called the Chi-square test, as it is the most appropriate when evaluating categorical data. The chi-square test is intended to test how likely it is that an observed distribution is due to chance. It is also called a "goodness of fit" statistic because it measures how well the observed distribution of data fits with the distribution that is expected if the variables are independent (Ling, 2008). The null hypothesis (H0) is that there is no variation between both groups, while the alternative is the contrary. With a 95% confidence (p-values under 0,05)

indicator we can reject or accept the null hypothesis evaluating whether the two groups present significant variations. Based on the two sample groups, we used this method to compare user's characteristics and other variables regarding preferences and mobility behaviour. Moreover, we compared them using the service dimension perspective, we identified five dimensions: demand patterns (how do their demand behave?), price (what's the cost?), comfort of ride (how comfortable it is?), ease of use (how easy it is to ride one?) and spatial availability (how easy it is to find a vehicle?). All these dimensions were evaluated through each survey question allowing us to conduct better comparison analysis. Lastly, the spatial dimension is analysed with the home/activity location of station and dockless services' users, using the zip code information given by respondents. These maps were based on a subset of 3.851 people (73,80% of the sample), that accepted to give information regarding the home/work-study zip code questions.

4.4. Results

4.4.1. Socio-demographic characterisation of BiciMAD subscribers

Table 4-1 shows respondents according to their subscriptions. As it can be observed, 11,92% of BiciMAD subscribers (622 out of 5.218) have subscriptions to other dockless micromobility services. This figure is relatively low however, it does reflect a considerable amount of people who are trying dockless services once they have tried BiciMAD. Thus, their experience with the bike-sharing service could be making them keener to use other micromobility services. Interestingly, there are more users subscribed to scooter-sharing rather than Mobike, which could be related to users finding it redundant to have two bike-sharing subscriptions (even though Mobike differs from BiciMAD as it is dockless) and thus they are more attracted to a scooter-sharing service.

Table 4-1 Percentage of BiciMAD subscribers with subscription to other dockless micromobility services.

Subscribed to BiciMAD since	Respondents (Total)	BiciMAD + Mobike	BiciMAD + scooters	BiciMAD + Mobike + scooters
2014	901	63	66	13
2015	921	53	53	12
2016	885	48	51	7
2017	1.036	61	72	13
2018	1.041	80	87	19
2019	434	26	33	7
Total	5.218	331	362	71
BiciMAD customers subscribed to other services (%)		11,92% (331 + 362 - 71 = 622)		

Source: own elaboration.

Once we measure to what extent are BiciMAD customers subscribed to other services, we can also highlight some of their main socio-demographic characteristics (see Table 4-2). We have included the Mobility Survey (EDM2018) survey results (Comunidad de Madrid, 2018) for some variables, to clarify that BiciMAD is a very targeted and specific survey, having low representativeness of the general population of Madrid. As we see, and supporting all the previous similar studies, most respondents were male (64,3%). Regarding age groups, most respondents are 35 to 49 years old (45%). When further analysing normalised values, a higher rate of dockless micromobility customers is found in the age group "under 26": for every user on this age group that only has subscription to BiciMAD, there are 0,21 users that subscribed to other dockless services. Moreover, most of the sample (91,5%) acquired a bachelor's degree or higher education level, but in the case of those subscribed to dockless services, a higher rate is observed in undergraduates, which could mean that this mode is more attractive for younger population.

Mostly, respondents are employees (86,5%), followed by unemployed (4,7%) but interestingly, when contrasted, a higher rate of house keepers and students are subscribed to dockless micromobility services. The chi-square results point at significant differences between Group 1 and 2 with respect to genre, age, occupation, and monthly income. We noticed for Group 2 less females than expected, younger population and more students. In relation to monthly income, most respondents reported to earn between 1.300 to 2.000 €/month. Nevertheless, in the case of Group 2, rates and chi square results show the same trend: dockless micromobility subscribers seem to earn more or be more parent/couple-dependent than those only subscribed to BiciMAD. Furthermore, 86,28% of respondents reported that environmental consciousness is important or extremely important, however, a higher rate of dockless service users is found in the “indifferent” group.

Table 4-2 Comparison of socio-demographic characteristics for Group 1 and 2.

Characteristics		Group 1- BiciMAD only		Group 2- BiciMAD + dockless services		Total		EDM2018	For each BiciMAD only user...there is “x” BiciMAD + other services user	
Genre	Female	1.704	37,10%	161	26,00%	1.865	35,70%	45,86%	1	0,09
	Male	2.892	62,90%	461	74,00%	3.353	64,30%	54,14%	1	0,16
<i>Chi-square test</i>										Value 29,9 (p=0,000)
Age	Under 26	286	6,20%	59	9,00%	345	6,60%	22,73%	1	0,21
	From 26 to 34	1.367	29,70%	191	31,00%	1.558	29,90%	7,54%	1	0,14
	From 35 to 49	2.058	44,80%	288	46,00%	2.346	45,00%	22,66%	1	0,14
	Above 49	885	19,30%	84	14,00%	969	18,60%	47,08%	1	0,09
<i>Chi-square test</i>										Value 19,0 (p=0,000)
Education Level	Non-university	383	8,30%	63	10,00%	446	8,50%	62,28%	1	0,16
	University	4.213	91,70%	559	90,00%	4.772	91,50%	37,72%	1	0,13
<i>Chi-square test</i>										Value 2,3 (p=0,132)
Occupancy	Employee	3.976	86,50%	536	86,00%	4.512	86,50%	44,61%	1	0,13
	Unemployed	224	4,90%	23	4,00%	247	4,70%	7,93%	1	0,1
	Retired	93	2,00%	6	1,00%	99	1,90%	20,07%	1	0,06
	Student	289	6,30%	54	9,00%	343	6,60%	20,59%	1	0,19
	House keeping	14	0,30%	3	0,00%	17	0,30%	6,79%	1	0,21
<i>Chi-square test</i>										Value 10,2 (p=0,0379)
Environmental consciousness	Not at all important	85	1,85%	12	1,93%	97	1,86%		1	0,14
	Slightly important	327	7,11%	42	6,75%	369	7,07%		1	0,13
	Indifferent	216	4,70%	34	5,47%	250	4,79%		1	0,16
	Very important	2229	48,50%	305	49,04%	2534	48,56%		1	0,14
	Extremely important	1739	37,84%	229	36,82%	1968	37,72%		1	0,13
<i>Chi-square test</i>										Value 1,0 (p=0,913)
Monthly Income	Not declared	48	1,00%	8	1,00%	56	1,10%		1	0,17
	Less than 800€/month	343	7,50%	39	6,00%	382	7,30%		1	0,11
	800-1.300 €/month	871	19,00%	111	18,00%	982	18,80%		1	0,13
	1.300-2.000 €/month	1.580	34,40%	179	29,00%	1.759	33,70%		1	0,11
	2.000-3.200€/month	1.191	25,90%	176	28,00%	1.367	26,20%		1	0,15
	More than 3.200 €/month	414	9,00%	85	14,00%	499	9,60%		1	0,21
	Dependent (parents or couple)	149	3,20%	24	4,00%	173	3,30%		1	0,16
<i>Chi-square test</i>										Value 21,1 (p=0,001)
Total		4.596		622		5.218				

Source: own elaboration.

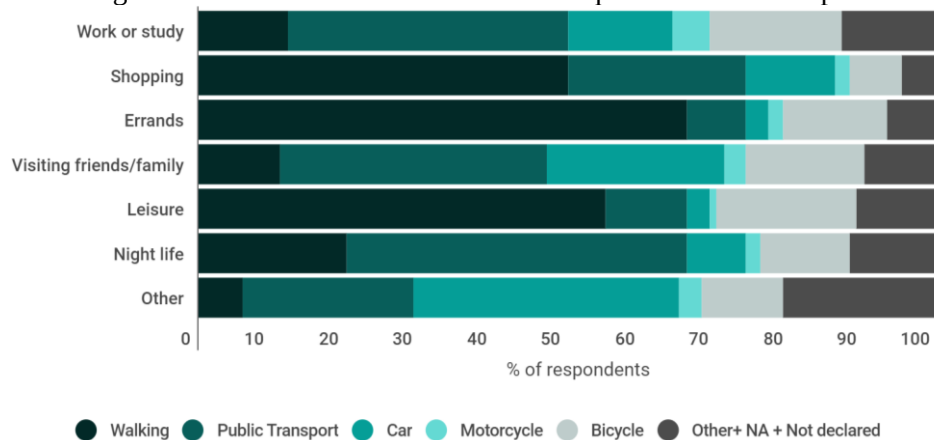
These results suggest that BiciMAD and dockless micromobility customers share similar socio-demographic characteristics: they are mostly males, from 35 to 49 years old, with high education level, employed with medium monthly incomes and environmentally conscious. Some slight differences point at dockless micromobility services attracting younger (under-26) males, ungraduated students or high-income employees with an indifferent attitude towards environmental issues.

4.4.2. BiciMAD and other dockless micromobility subscribers' preferences

4.4.2.1. The first service dimension: travel demand patterns

When comparing their travel demand patterns, Group 1 and 2 share similarities. On average, all respondents travel 12 times in weekdays (Monday-Friday) (2,4 trips per day) and five on weekends (Saturday and Sunday) (2,5 trips per day). The average trip duration reported resulted in 29 minutes in line with Madrid's Mobility Survey findings (25 minutes) (Comunidad de Madrid, 2018). In the case of dockless micromobility subscribers exclusively, on average, they travel 11, 5 (dockless bikes-Mobike) and 13 (scooter-sharing services) times in weekdays and 4,5 and 5,1 times on weekends respectively, showing a similar pattern to the whole sample. The most frequent mode used for work/study purposes is public transport (38%), followed by bicycle (18%) and car (14%) (see Figure 4.2), being quite different from the EDM2018 survey results (1-walking, 2-own car and 3-urban bus). Walking is the preferred mode for shopping (50%), errands (66%) and leisure (55%) activities, whereas public transport is preferred for night life with 46% of the trips. The car is mostly preferred for visiting friends and other long trips (24 and 36% respectively).

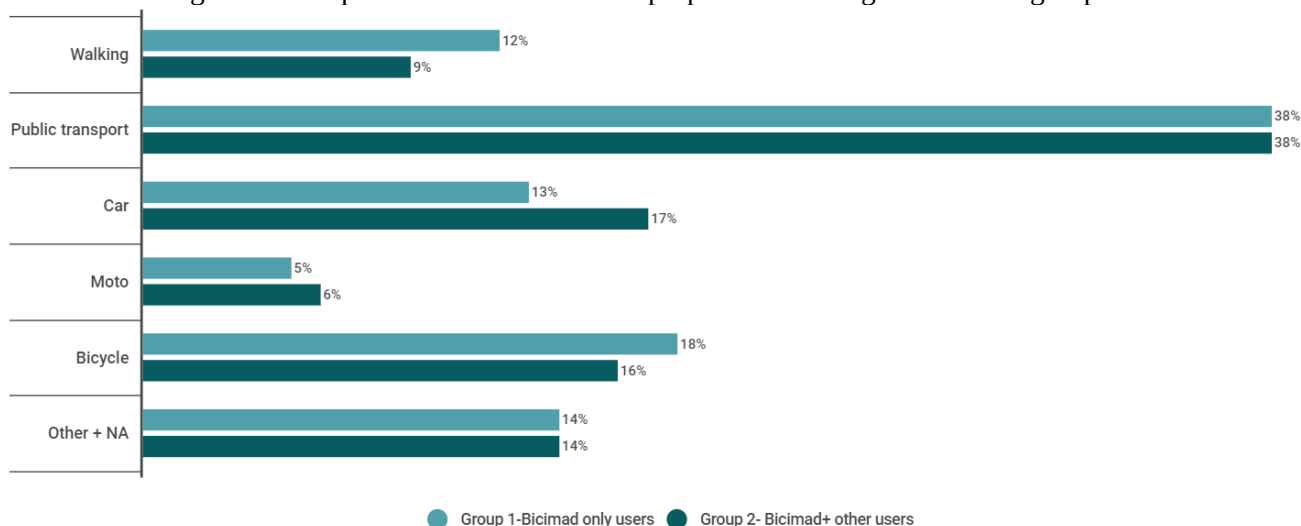
Figure 4.2 BiciMAD subscribers' most frequent mode of transport.



Source: own elaboration.

When further analysed according to the two groups of the sample, chi-square test results show differences regarding the most frequent mode for work purpose (value: 11,6 and p-value 0,04) (see Figure 4.3). They both seem to use public transport, but Group 2 uses more cars and mopeds (related also with higher income population), whereas BiciMAD only users use more walking and bicycles.

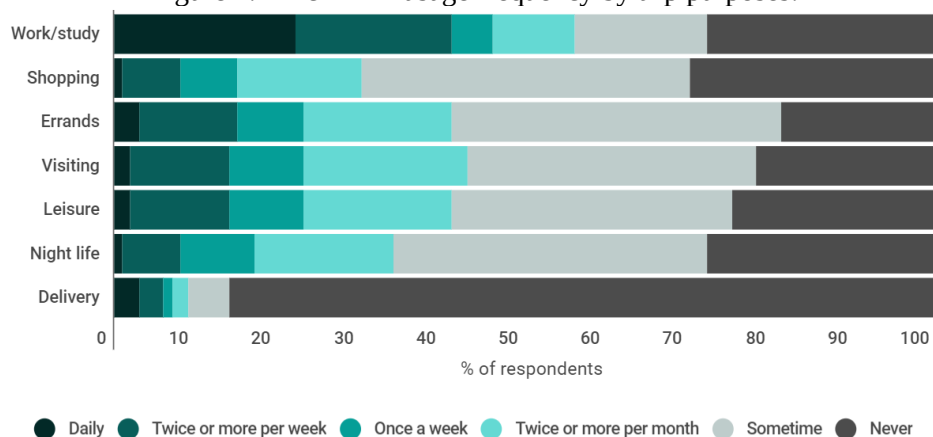
Figure 4.3 Frequent mode used for work purposes according to each user group.



Source: own elaboration.

In the case of BiciMAD-only users the average BiciMAD trip duration reported by respondents was calculated in 18 minutes, similar to the 17,15 minutes found by (Romanillos, 2018). In relation to the frequency of use and purposes (see Figure 4.4), findings show that at least once a week or more, 46% of respondents use BiciMAD for work/study purposes (of which 22% use it on a daily basis). Visiting, errands and leisure activities are also important purposes, whereas shopping is the least important, which could be related to the need for carrying heavy objects and bags which is less comfortable in bicycles. Interestingly, 14% of BiciMAD users reported using it for delivery activities (of which 3% use it daily). This is quite a considerable figure reflecting the increasing number of riders and delivery services in the city, a phenomenon also captured by (Romanillos, 2018).

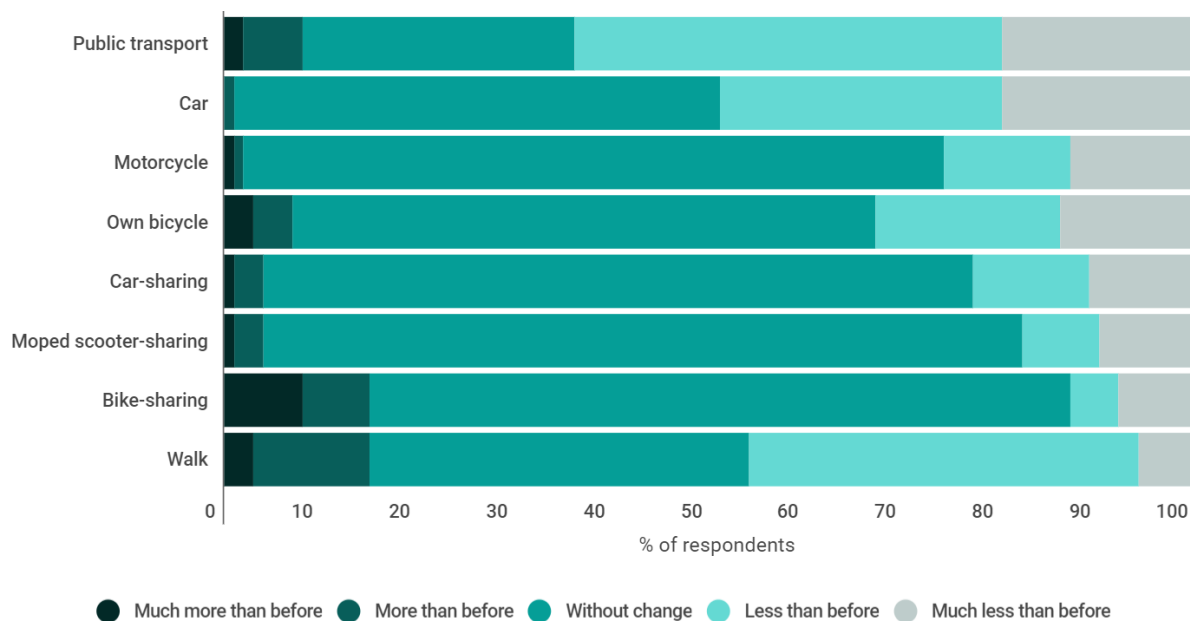
Figure 4.4 BiciMAD usage frequency by trip purposes.



Source: own elaboration.

Around 70% of respondents reported to notice no change in travel behaviour after using BiciMAD, while around 20% of them reported an increased usage of walking and bike-sharing, as well as new dockless services (around 10%) (see Figure 4.5). On the contrary, a vast number of users reported to be using less public transport (64%) or walking (46%), but also fewer private cars (49%). Hence, although BiciMAD could be competing with public transport and walking, results suggests that it is being an alternative to the private car as well.

Figure 4.5 Travel behaviour change with BiciMAD for general sample.



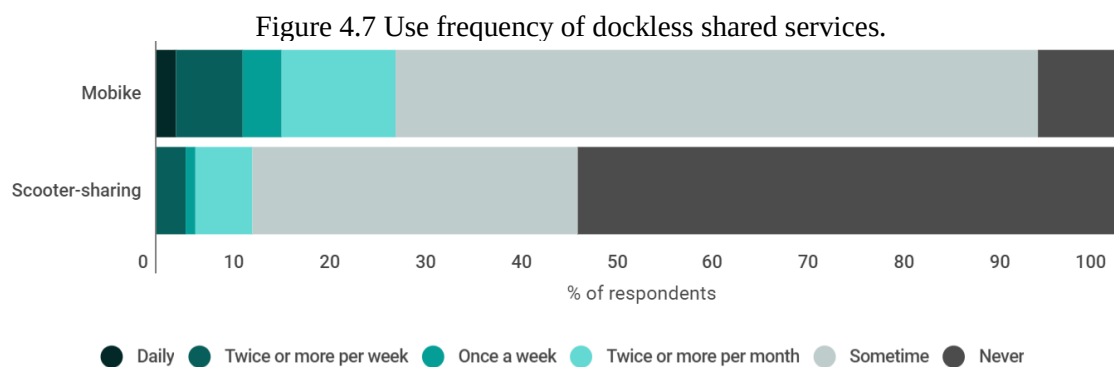
When analysed according to Group 1 and 2, significant variations are noticed in travel behaviour changes after using BiciMAD for walking, bike-sharing, cars, car-sharing and moped-style scooter-sharing (see Figure 4.6). Group 2 seems to be walking more (17% vs 14% in Group 1), cycling more (20% vs 14% in Group 1), and using moto-sharing (7% vs 4% in Group 1), while cars' usage is reported to be reduced (58% vs 48% in Group 1).

Figure 4.6 Changes in travel behaviour after using BiciMAD according to each user group.

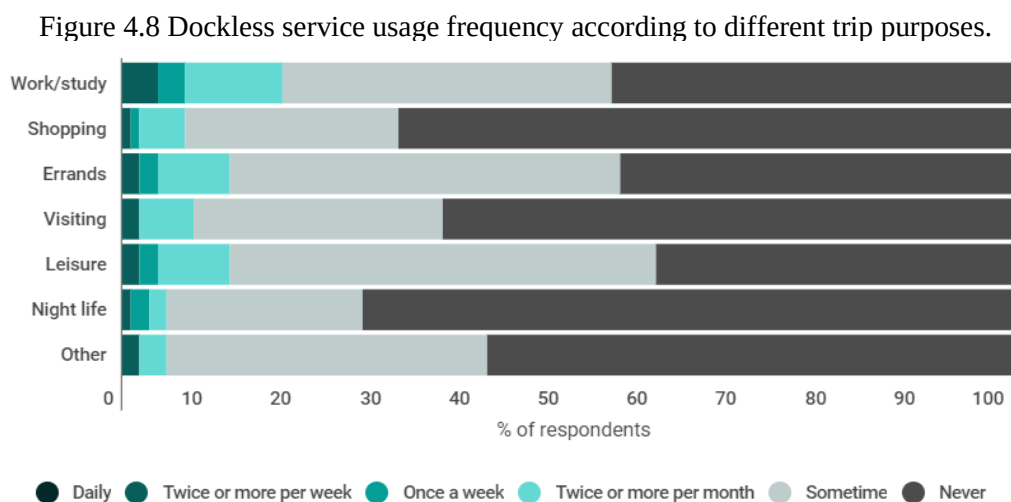


Source: own elaboration.

In the case of Group 2, Figure 4.7 shows that respondents are more familiar with Mobike, as 92% reported using it at least once (of which 7% use it twice or more per week and 2% on a daily basis), whereas this figure drops down to 44% in the case of scooter-sharing services. This result is understandable, as Mobike arrived first at Madrid (around 2016) in comparison with the most recent implemented scooter-sharing companies that arrived mostly in the summer of 2018. Work/study and leisure activities were the most common purposes for using a dockless mode, while nightlife and shopping the least common (see Figure 4.8).



Source: own elaboration.

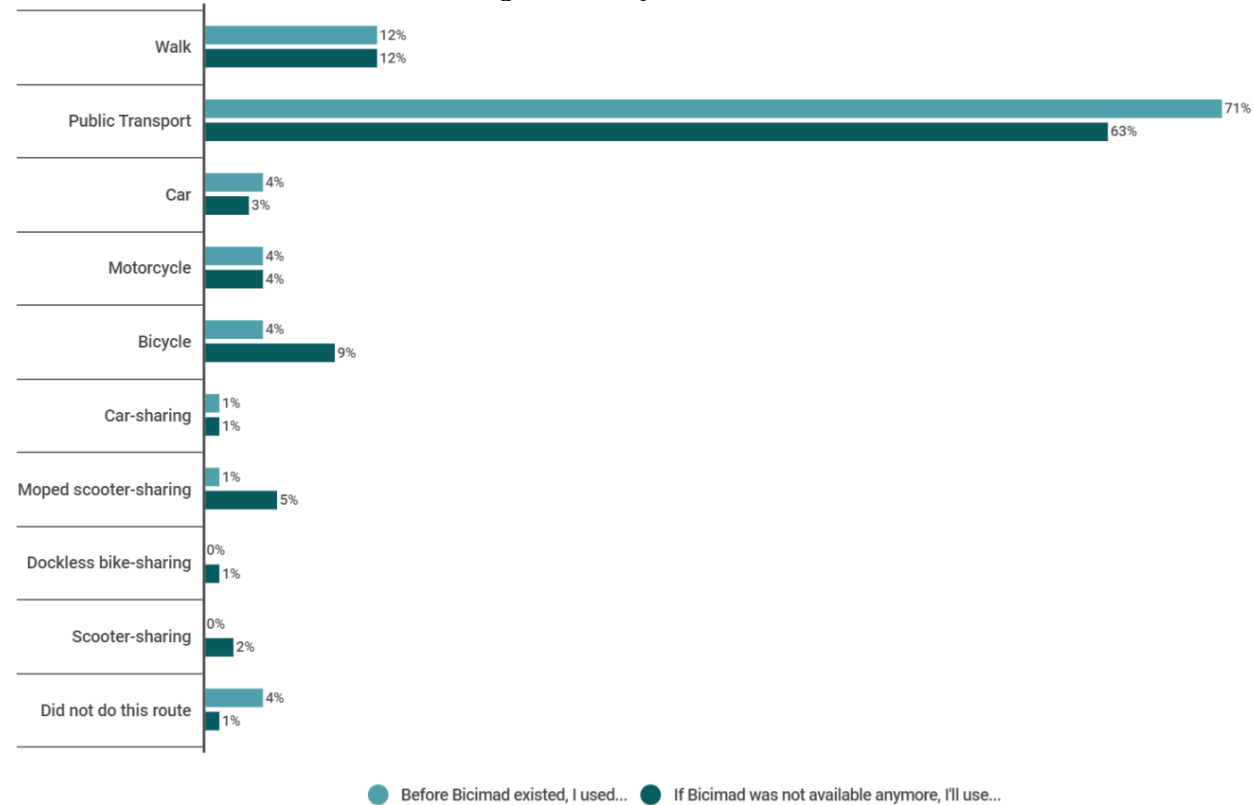


Source: own elaboration.

Moreover, a key concern in micromobility research has been to explore the extent to which it could substitute car trips, which is the main objective of sustainability-oriented policies. In other words, the ideal situation is that micromobility could attract car drivers to use more active modes. Nevertheless, some studies show that sometimes, the contrary happens, with car drivers maintaining or even increasing car usage and instead, micromobility stealing users from public transit, cycling or walking (Henderson, 2019; Tirachini, 2018, 2019). In order to analyse this issue, we asked the question “*before using BiciMAD, what mode did you use to do the same trip?*” We found 71% of respondents reported to use public transport previously, followed by 12% that walked. Other users used their private car, moped, bicycle or did not make the same route with 4% respectively. Hence, we may infer that BiciMAD is competing with public transport and walking, which is not a sustainable pattern to follow, as it will be if BiciMAD took most of its trips from motorised private modes (cars/mopeds). However, if we consider that achieving a

sustainable shift is progressive challenge, we could appreciate that BiciMAD, in its nascent stage, is substituting 8% of previously motorised trips (private cars and mopeds with 4% respectively). When asked “*if BiciMAD is not available anymore, which other mode would you use?*”, an even clearer sustainable pattern is found. Only 3% would take their cars, reducing car trips by 1% in comparison with the pre-BiciMAD choice (see Figure 4.9). Choosing a bicycle increases from 4% (pre-BiciMAD) to 9%, showing that previous experience with the bike-sharing system increases the usage of bikes. And more interestingly, 9% of respondents would now choose a dockless service, of which moped scooters were the most preferred (5%). Thus, BiciMAD could be allowing users to experience with micromobility and trying new modes, which was also supported by (Aguilera-García et al., 2020).

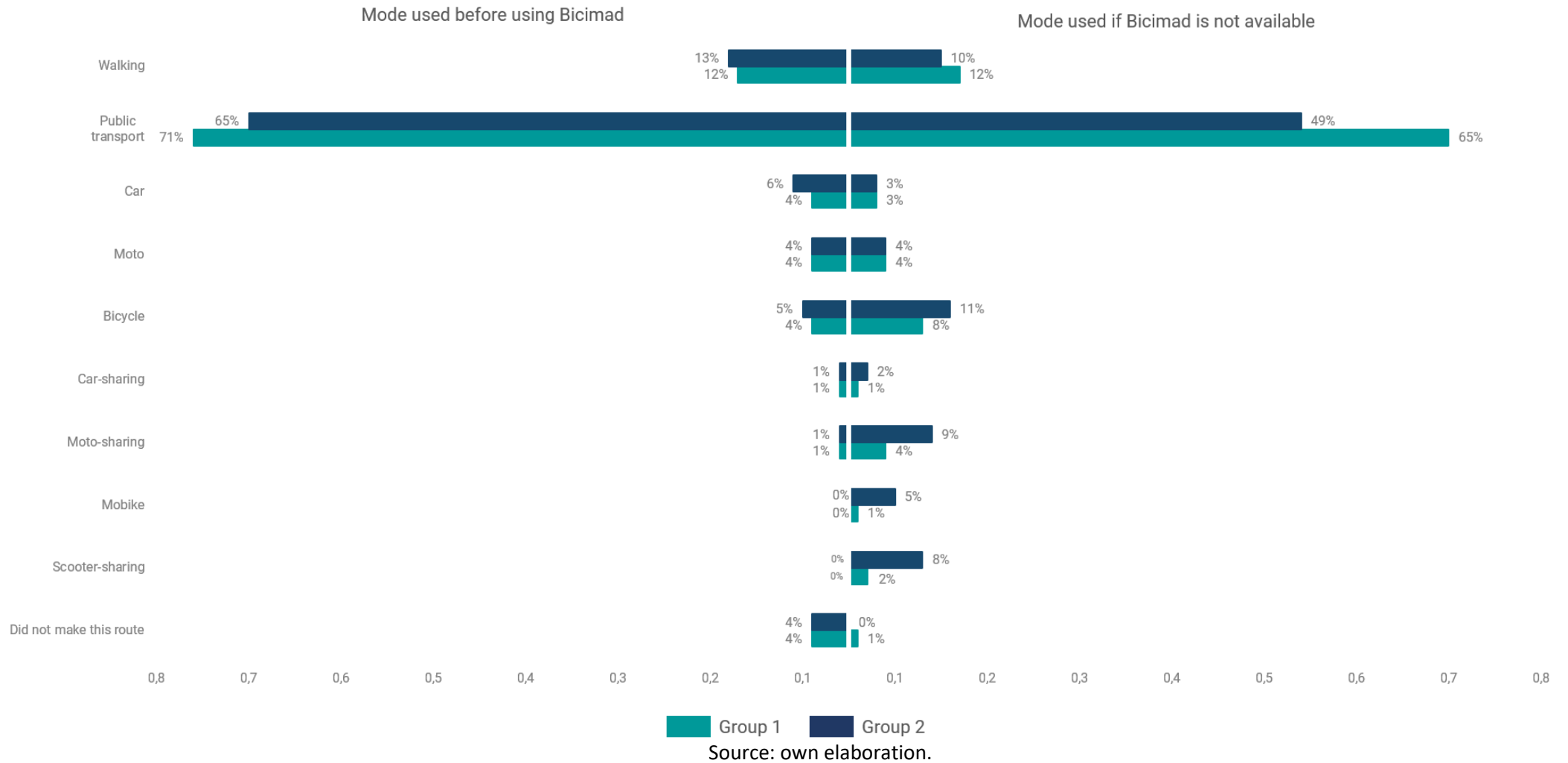
Figure 4.9 Modal choice before BiciMAD and modal choice if BiciMAD stops being available for general sample.



Source: own elaboration.

When we analyse these responses by each group of users (Group 1 and 2), we noticed some differences (see Figure 4.10). Group 1 mostly used public transport and walking before using BiciMAD, and they will mostly go back to public transport, walk or using their own bicycle if BiciMAD become inoperative. On the other hand, Group 2 has a considerable amount of people also coming from private cars and a relatively bigger reduction of 3% (from 6 to 3%) in their willingness to go back to driving their cars. Additionally, Group 2 also shows a higher willingness to go back to using different dockless shared mobility modes if BiciMAD was not available (bike-sharing 11%, moped-style scooter-sharing 9% and scooter-sharing 8%). From this figure we could infer that BiciMAD is becoming crucial to promote the use of other dockless micromobility services.

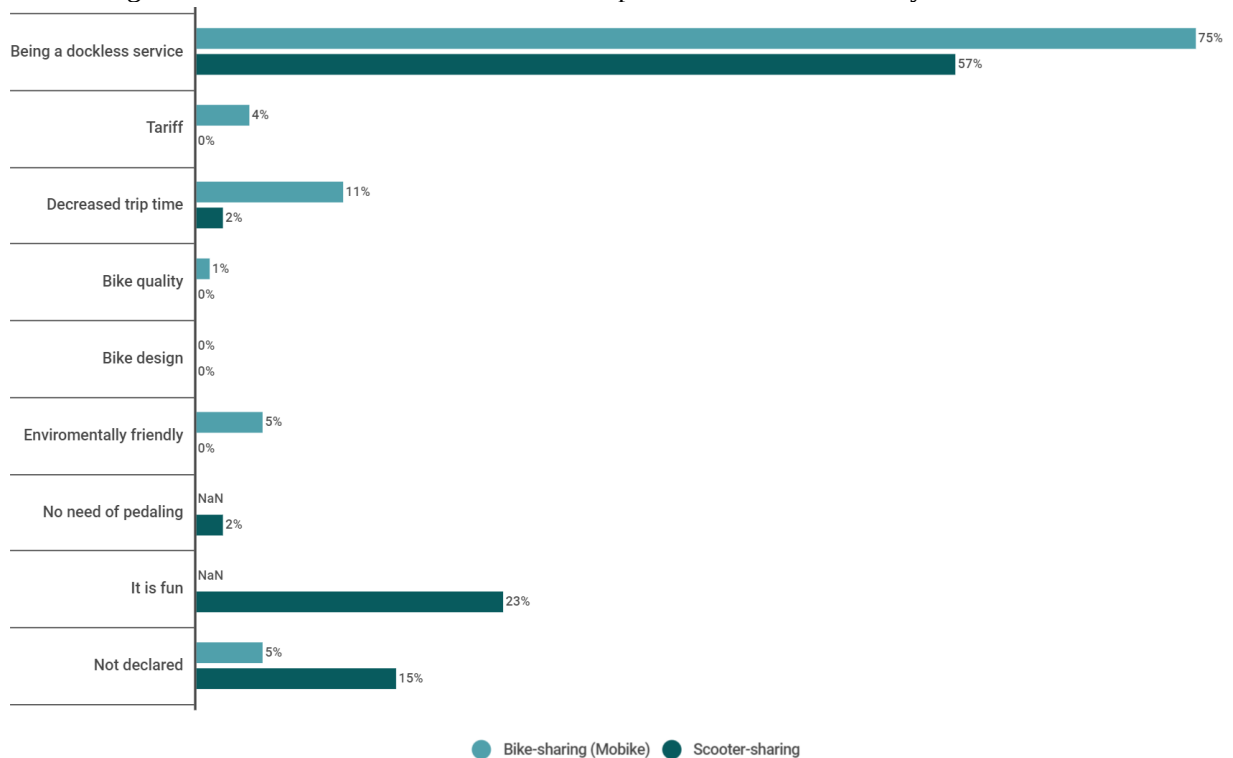
Figure 4.10 Modal choice before and after using BiciMAD according to each group.



4.4.2.2. The following three service dimensions: price, comfort of ride and ease of use

In order to better understand why customers could be interested in trying new micromobility modes, we asked “*which of the following attributes you find more attractive about the service (dockless bikes and scooters)?*”. In both cases the majority of respondents (dockless bikes with 75% and scooter-sharing with 57%), answered the fact that it was a “dockless service” as the most attractive attribute (see Figure 4.11). This important insight yields that many customers find as an advantage dockless modes because they do not have to worry about knowing where to find or leave a vehicle (ease of use), allowing them to have a more seamless door-to-door experience in their trips. In the case of Mobike dockless bikes, the second most attractive attribute was the decreased trip time (11%) which could be related to the convenience of ending a trip at the actual destination rather than a nearby docking station, also reported by (Younes et al., 2020). Interestingly, in the case of scooters, the second most attractive attribute was “*it is fun*” to ride one (comfort of ride), in tune with findings in socio-demographics about the predominance of younger people and study or work being one of the most common purposes to use them. On the other hand, service fares (price) were declared unattractive for all the dockless micromobility services, which could mean that they may be finding the service too expensive.

Figure 4.11 Most attractive attributes to adopt dockless micromobility services.

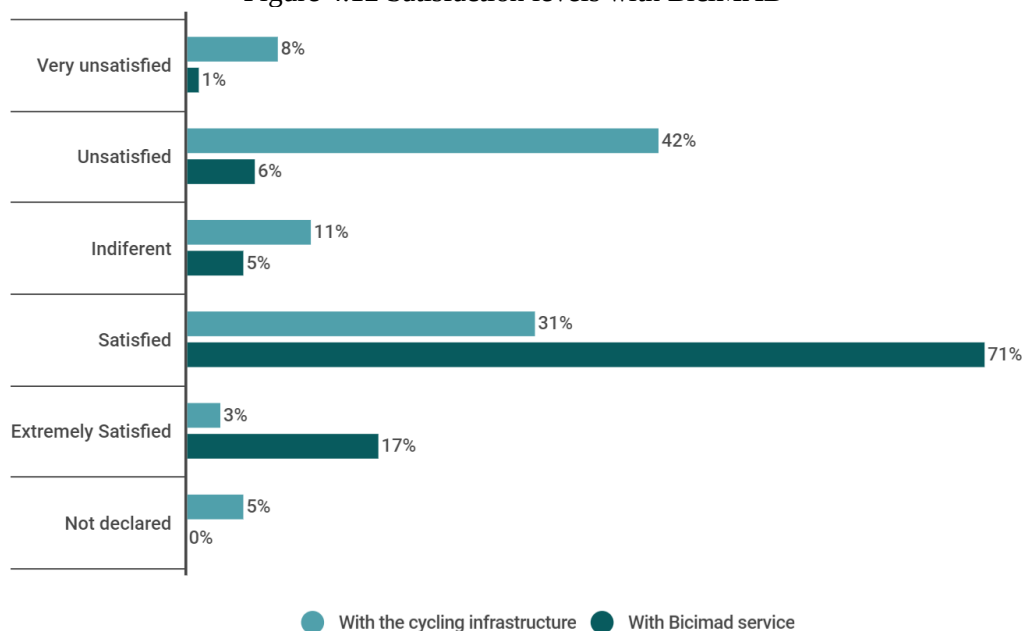


Source: own elaboration.

In regard to satisfaction levels, Group 1 (BiciMAD-only users) show higher levels, but low ones with respect to cycling infrastructure quality as shown in Figure 4.12. Results show that 88% of respondents are satisfied or extremely satisfied with BiciMAD, while this figure drops down to 34% in the case of the cycling infrastructure. Most of the sample (50%) is unsatisfied or extremely unsatisfied with the infrastructure reporting the need to have more cycling infrastructure (especially segregated bike lanes) and better connections. In the case of dockless micromobility services (see Figure 4.13), Mobike stands out as a slightly better service with 40% of respondents

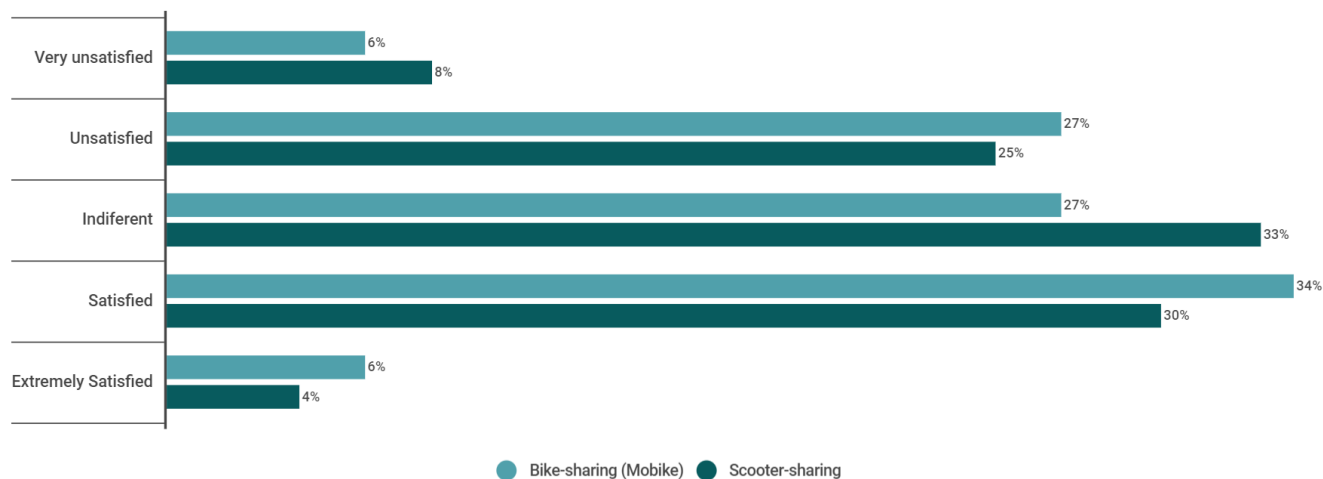
reporting to be satisfied or extremely satisfied, whereas this same figure drops to 34% in the case of scooter-sharing services. The “indifferent” category is higher in the case of scooter-sharing with 33%, which could be related to younger generations being predominant in this group.

Figure 4.12 Satisfaction levels with BiciMAD



Source: own elaboration.

Figure 4.13 Satisfaction levels with dockless shared services.



Source: own elaboration.

4.4.2.3. The last service dimension: spatial patterns

At last, this section analyses the home/work or study location of respondents based on 73% of the sample that completed the zip code information in the questionnaire (n=3.851 out of 5.218 responses). In general, we found that the majority respondents live and work/study inside the M-30 urban zone (71%) as summarised in Table 4-3, which was expected as the survey was conducted to BiciMAD customers, and the service is mostly available inside M-30 highway. This area also represents the space where most jobs, commercial zones and public facilities are concentrated offering a great supply of social, educational and cultural places, various entertainment events and public activities (Comunidad de Madrid, 2018).

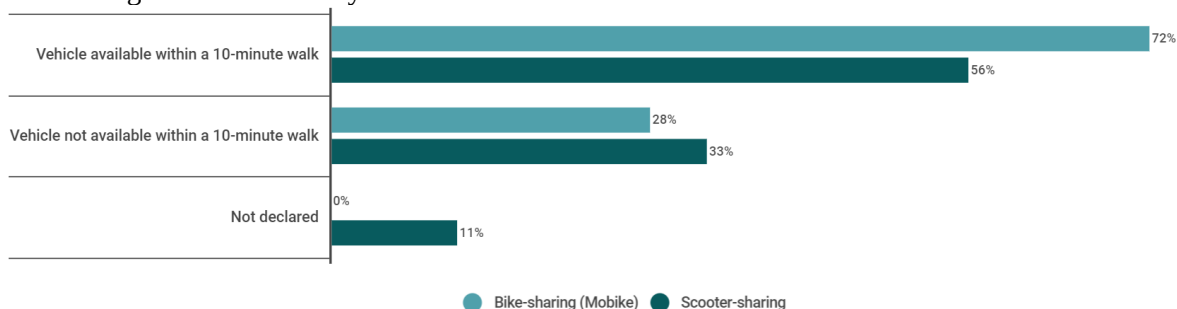
Table 4-3 Home and work location of respondents (n=3.851).

	BiciMAD-only		BiciMAD-other		Total	
	Users	%	Users	%	Users	%
Lives within M-30	2780	82,5	369	76,4	3149	81,8
Lives outside M-30	588	17,5	114	23,6	702	18,2
Subtotal	3368	100,0	483	100,0	3851	100,0
Works within M-30	2916	86,0	387	83,8	3303	85,8
Works outside M-30	473	14,0	75	16,2	548	14,2
Subtotal	3389	100,0	462	100,0	3851	100,0
Lives and works within M-30					2.745	71%
Lives and works outside M-30					144	4%
Lives within M-30 and works outside M-30					404	10%
Lives outside M-30 and works within M-30					558	14%

Source: own elaboration.

Moreover, other findings regarding proximity to other dockless micromobility vehicles, show that 72% of Mobike users reported that it was easy to find a dockless bicycle within a 10-minute walk from home, whereas in the case of scooters this percentage drops to 56% (spatial availability) (see Figure 4.14). This is understandable with most respondents living inside M-30 urban zone, where most shared vehicles are deployed.

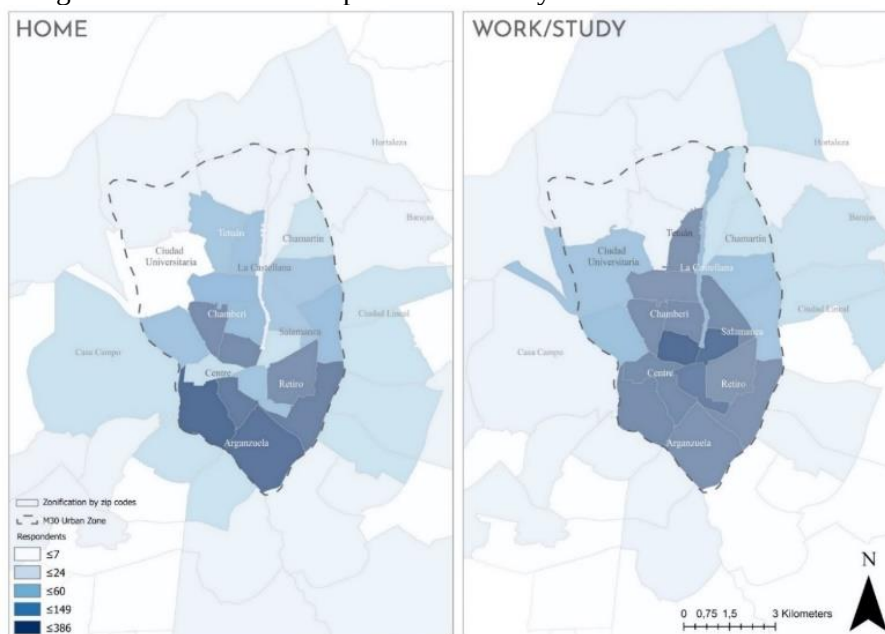
Figure 4.14 Proximity to dockless shared vehicles in a 10-min walk from home.



Source: own elaboration.

When analysing the zip locations of respondents' home and work/study places (see Figure 4.15) it is noted that many of them live around the city centre and Arganzuela district, while work/study areas are concentrated along the Castellana road where most office buildings are located. We can also observe the importance of "Ciudad Universitaria" (University City) as main destination for BiciMAD users, being an attractive mode of transport for university students.

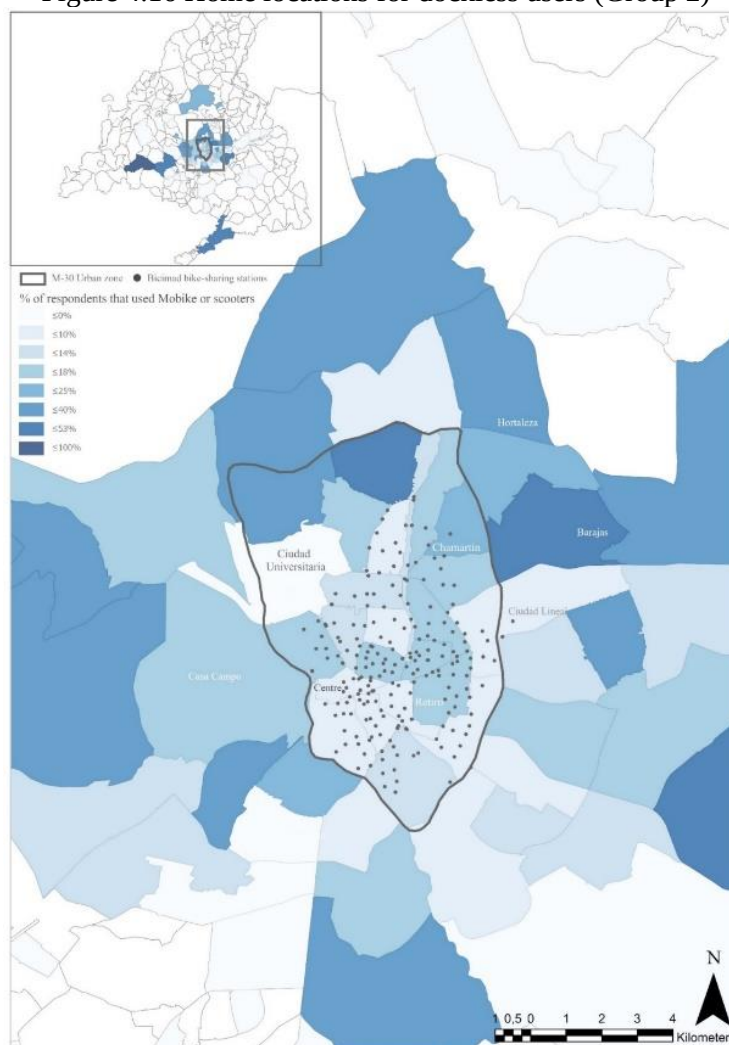
Figure 4.15 Home/work zip location density from BiciMAD customers.



Source: own elaboration.

When analysing dockless micromobility customers exclusively (Group 2), Figure 4.16 shows that as the distance from the city centre increases, the proportion of dockless service users is higher. This may be due to the fact that most shared mobility services are concentrated inside M-30 highway, including BiciMAD, increasing the transport supply. In the peripheries though, with less options and BiciMAD not available, users are more captive of dockless services. These results may suggest that station-based and dockless systems in Madrid are, rather than competing, complementing each other, as the case of San Francisco described by (Lazarus et al., 2020). Hence, dockless services could be most attractive and needed in the peripheries. Micromobility regulations could promote dockless services to be deployed in suburban areas where there are no BiciMAD stations and public transport routes are less frequent, making Mobike and scooters more convenient to cover the first/last mile of the trip.

Figure 4.16 Home locations for dockless users (Group 2)



Source: own elaboration.

4.5. Discussion and conclusions

This study explored the opinions and preferences of BiciMAD customers in relation to other dockless micromobility services. Our two sample groups (Group 1 and 2) are socio-demographically similar; however, some slight differences are observed. When contrasting the normalised values and analysing chi-square results, we observe that different socio-demographic characteristics apply for those that use dockless services: they seem to be mostly young men, especially university students or high-income employees, with neutral/indifferent environmental consciousness. Group 2 of users reported “fun” as one of the most important attributes to subscribe to the dockless service. All these insights could better inform public policy designing targeted campaigns knowing that dockless micromobility services (especially scooters) attract younger generations compared with BiciMAD.

In its nascent stage, we found that only 11,92% of BiciMAD subscribers have also subscription to other dockless micromobility services. However, this result along with the increased preference for dockless services if BiciMAD stopped being available, suggests that the BiciMAD is actually making users keener to try new options, which is similar to what other authors have found regarding users’ experience as a prompter for adopting different travel modes (Matyas & Kamargianni, 2018a; Strömberg et al., 2018). Furthermore, it was found that even though

BiciMAD is mostly used by people who previously travel on public transport or walking, which is not a desirable path, it could be also substituting 8% of previously motorised trips (cars and mopeds).

Regarding satisfaction levels, we find that BiciMAD stands as the better service, which also is related to a more familiar option due to its eight years of operation in Madrid, compared to other dockless services that are more recent (2016 for Mobike and 2018 for scooter companies). However, the levels of satisfaction with cycling infrastructure were found low, which means that users are satisfied with the public bike-sharing system, but rather unsatisfied with cycling infrastructure. In terms of management, we could say that the public company EMT stands out as a good operator for the system. Secondly, this largest quality gap shows that more cycling infrastructure is needed, and thus transport planners and authorities should plan to extent segregated bike lanes, to create bicycle parking and other infrastructure. A good path to follow is the planned and currently under construction cycling infrastructure in Castellana road. In regard to dockless services satisfaction, we could conclude that proportions are very similar, with Mobike slightly standing as a better service.

When comparing trip purposes, we found some trends. In the case of station-based service, it seems like the predominant profile is an employee who uses it for work purposes as they may already be familiar with the stations near their home/work locations. Instead, in the case of dockless services, the profile points to a young student that uses the scooter/bicycle mostly for leisure activities or study purposes. Thus, BiciMAD seems to respond to routine trips like work where users already have identified the stations to plug/unplug bicycles, whereas dockless services seem to be used mostly for recreation trips where not much trip pre-planning is needed.

Finally, spatial analyses showed important insights. On one hand, a proximity to dockless vehicles was predominant (72% Mobike and 56% scooter-sharing), however this could be influenced by the fact that most respondents live within M-30 urban zone (71%) where all micromobility options are concentrated. On the other hand, respondents' homes were mostly located around southern Madrid inside M-30 highway, whereas work/study densities were more homogeneously distributed to the north of the city. These patterns follow the expected distribution of vehicles according to land uses, with work/study areas being mostly around the north-south axis of La Castellana and residential zones located in the north or south surroundings of M-30 highway. We have also found that a higher proportion of subscribers to dockless shared services lived outside M-30 zone, which supports that docked and dockless systems in Madrid may have a complementary relationship, especially in peripheral areas; users in outer areas with no BiciMAD, are keener to use dockless services (they are more captive). These insights are of great importance to better inform public policy, as dockless vehicle supply could improve by offering more vehicles in the city's peripheral areas where no BiciMAD station is available yet. Based on the survey's responses, 1% of BiciMAD users were previously driving their cars, and in the case of Group 2, these percentage increases to 3%. Although these results are not conclusive yet, they point to the potential of these services to replace car trips, which is a line of research that should be better explored.

As main conclusions we have that our exploration serves to better understand the relationship between BiciMAD and dockless services in Madrid. We found that a considerable amount of BiciMAD users is also subscribed to other services (12%) and identified some differences and similarities between both groups. In the context of new emerging concepts like Mobility as a Service (MaaS), the relationship of different modes will have an important impact. If pre-existing

bike-sharing programs contribute to promote the use of other dockless modes, this will be positive in future MaaS applications where all services are displayed and available in one single platform.

As main limitations of the study, we can highlight the fact that results cannot be generalised, as some groups of the population are unrepresented (women for example) as well as the population living outside M-30 highway. This is mostly due to BiciMAD being offered inside M-30 highway ring, especially in 2019 when the survey was conducted (in 2020 a new expansion of the system has taken place). With future expansions of BiciMAD to outer peripheral areas (outside M-30), it will be possible to capture a more representative picture of the city. Service expansions may reach areas that are now being poorly served with travel options and where users may be more captive of dockless services. Additionally, by analysing results based on a nested survey of BiciMAD users conducted in 2019, we could have misrepresented the preferences of those users that only use dockless services. Future studies could address this limitation by conducting a survey exclusively to dockless service users and by making panel research that considers multiple years to see if preferences change over time. Other future studies may also be oriented to increase the sample size and conduct regression analysis to model responses and predict willingness to use certain modes in a future MaaS context. An evaluation of preferences based on services' fares (total travel cost) is also recommended, as this was found to be relevant in the survey.

5. Visualising the spatiotemporal travel patterns of BiciMAD

5.1. Introduction and background ³

Since their introduction in Amsterdam (1965), Bike-Sharing Systems (BSS) have been rapidly growing around the world, to a reported number of 1.286 schemes with more than 3 million bicycles in over 50 countries and 500 cities (Pucher & Buehler, 2017). Several factors have helped, including changes in legislation, the implementation of policies and cycling infrastructure, and technological advances in batteries that allow cheap electric powered bicycles (e-bikes) that provide a broader range of movement and more comfortable usage in hot weather and changing topography (Weinert et al., 2007). With the spread of these BSSs, the scientific literature has also raised a wide variety of topics, such as the use of cycling infrastructure, safety issues, modelling frameworks, the analysis of demand and cycling flow, bicycle modal integration, public policy and cycling behaviour, preferences and travel patterns.

One of the most well-developed research lines has focused on the analysis of travel times and the length of cyclists' routes in BSSs. Some findings have shown that cycling movements are not well balanced and different behaviours are associated with the length of trips (Moncayo-Martínez & Ramirez-Nafarrate, 2016). Shorter trips tend to be concentrated in the city centre and seem to better complement public transport, while longer trips are more focused on streets with cycle tracks, decreasing their complementarity effect with other modes (Levy et al., 2019).

Another research line has analysed the cycling flow generated by Bike-Sharing Systems, with different approaches. Some studies have examined the activity over time with the aim of identifying trends (Borgnat et al., 2013; O'Brien et al., 2014; Zaltz Austwick et al., 2013). A similar study carried out by (Purnama, 2018) analysed bicycle travel patterns in New York and London and observed that there were differences as well as similarities in temporal correlation level between the riding behaviour of BSS users and the hour of the day, day of the week, season, and local weather. Other research has analysed the imbalances produced by the different levels of attraction and generation of trips at the BSS stations (Goodman & Cheshire, 2014), recommending additional redistribution approaches (Raviv et al., 2013; Shu et al., 2013).

Furthermore, a recently explored topic is studying the spatial dimension of cycling mobility, especially now that BSS have collected a great amount of time and location data, which enables the study of travel behaviour and mobility at an individual level (Beecham & Wood, 2014). The research carried out by (Romanillos & Zaltz Austwick, 2016) gathered, visualised and analysed volunteer cyclists' routes and the distribution of cycling flow across Madrid's urban street network. Another example is the research carried out by (Romanillos et al., 2018), whose results revealed the different spatial cycling patterns of frequent and occasional users. Factors related to street network properties (such as slope, motor traffic speed or density of traffic lights and intersections), to the trip (such as the purpose of the journey) or the cyclist (such as gender or age) were shown to have great impact on cyclists' speed, in a later study based on a detailed analysis of the GPS tracks (Romanillos & Gutiérrez, 2019). Even a comparative analysis of different transport modes was carried out, showing that cycling was the most competitive transport mode for small-medium distances (under 21 minutes in length for Madrid).

Building upon this previous literature, the study aims to bring together a spatial and a temporal analysis of the cycling flow of BiciMAD, the Madrid Bike-Sharing System. The study analyses

³ The content of this chapter has been published in (Talavera-Garcia et al., 2021)

cycling flow at three different temporal scales: over the course of the day (trips aggregated per hour), during weekdays or weekends as well as over the course of a whole year, to provide a better understanding of the different demand according to the different seasons, which is relevant in a city like Madrid where the weather varies considerably during the year. Moreover, this research visualises the cycling flow between stations during weekdays and over the weekend, highlighting the most important flows between origin-destination pairs. Finally, all these analyses have been carried out considering two types of users: frequent and occasional users. The study reveals the radically different spatiotemporal travel patterns of both groups. The study intends to increase the understanding of BSS travel behaviour and to provide information for planners and decision-making actors to respond efficiently to this growing cycling demand.

5.2. Data and methods

The data for this study has been obtained from BiciMAD open-data website. Each bicycle is equipped with a GPS tracker that records its location every 75 seconds on average. The data set was gathered for one year from September 2017 to September 2018. In this period, 21.460.814 GPS records were collected for a total of 3.737.173 routes, of which 308.695 routes were identified as redistribution tasks of bicycles by the system management. Each of these records contains information on both the origin and the destination stations and docks, type of users (*frequent user*, *occasional user*, *employee* and *unknown user*), age (aggregated in ranges, for anonymisation), the duration of the journey and the timestamp of the beginning of the journey (at one-hour intervals).

The location and description of the BSS stations, again provided by the open-data portal, has also been incorporated to the analysis. From the total number of stations that make up the BSS (173 in the period of time studied), those having different IDs but a similar location (side-by-side) have been grouped together as one, then all the corresponding information has been added accordingly. Thus, a total of 163 stations are included in the analysis. Additionally, the Map includes a grayscale background from the latest available orthophotography (2018) of the National Plan of Aerial Orthophotography (PNOA), provided by the Spanish National Centre for Geographic Information.

The methodology included three phases: data recollection, process and analysis and lastly presenting results. Firstly, the JSON files were downloaded from the open data website of EMT (<https://opendata.emtmadrid.es/Home>). These files were processed with Python to disaggregate timestamp information into new attributes: year, month, week number, day of week and time of day, and then imported into MongoDB (a free and open non-relational database software). Once the BSS data for all the research period was stored in MongoDB, the information at node level (stations) was exported into multiple GEOJSON files to make the information manageable. Then, using the open GIS software QGIS, GEOJSON files were exported to PostgreSQL (a relational database) in order to apply location queries through the spatial database extender PostGIS.

Two different scenarios were set according to the information provided in each record. The first scenario corresponds to the trips that take place on a weekday, from Monday to Thursday, but excluding public holidays. The second scenario covers weekend trips and trips that take place on public holidays. Trips made on Fridays are excluded as they are considered days of transition whose spatiotemporal dynamics could distort the dynamics of the rest of the days as also described in (Romanillos, 2018). Additionally, we focus on the analysis of the two provided profiles, frequent users and occasional users.

Taken together, these two profiles and two scenarios allow us to analyse comparatively the spatial and temporal patterns of BiciMAD subscribers. To this aim, we first grouped BSS records by

months to analyse the annual distribution of trips according to the different types of users and scenarios. Secondly, BSS records were grouped by the time of day to show temporal distribution of trips over the course of the day. Finally, the records were grouped according to the origin and destination stations in order to obtain the spatial dynamics of the types of users and scenarios. Then, to illustrate the existing spatial dynamic between origins and destinations on the Main Map, we created the flow lines using a SQL query that joins geographic information of BSS stations and the flow weights (average number of trips per day) based on the BSS station ID. In this case, to avoid zero-length lines, the flow line was only drawn when the station ID of origin and destination were different. The flow maps, illustrated in the Main Map, allow us to see the most frequent trips according to type of users and scenarios. In addition, we include the number of arrivals and departures for each station, which shows the relevance of each station over the whole BSS and, in consequence, a better understanding of the BiciMAD users' travel patterns.

5.3. Results

The results obtained show the different temporal and spatial dynamics in the use of BiciMAD according to the type of user (frequent or occasional) and scenarios (weekday and, weekend and holiday). Table 5-1 shows remarkable differences in the average time of use of BSS between frequent users and occasional users.

Table 5-1 General statistics about trips per type of user and scenario.

Trips	Avg. time (s)	Avg. time (min)	Count
Total trips	938	15,63	3.428.402
User type: frequent	902	15,03	3.324.181
User type: occasional	2.568	42,81	60.098
Weekday trips (Friday exc.)	889	14,82	2.079.704
Weekday frequent users	866	14,43	2.031.780
Weekday occasional users	2.485	41,42	22.917
Weekend and holidays	1.068	17,80	835.999
Weekend frequent users	998	16,63	792.360
Weekend occasional users	2.645	44,08	29.763

Source: own elaboration.

The distribution of trips for occasional users is irregular throughout the year (Figure 5.1), taking its maximum values in summer months (July to September) whereas occasional user trips are less relevant in autumn and winter months. The use of the system by potential tourists during these months could be an explanation. When it comes to the trips of frequent users, we can identify a clear seasonality, with higher demand between April and October, during the warm seasons, and a decrease during autumn and winter. August is an outlier in this trend due to the fact that a large percentage of local residents leave the city to spend their holidays abroad.

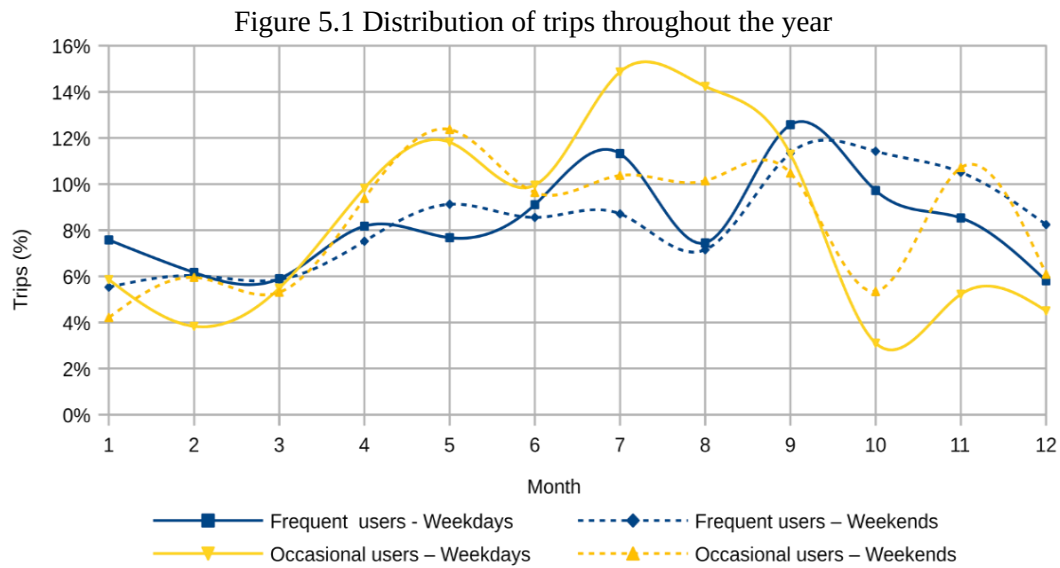
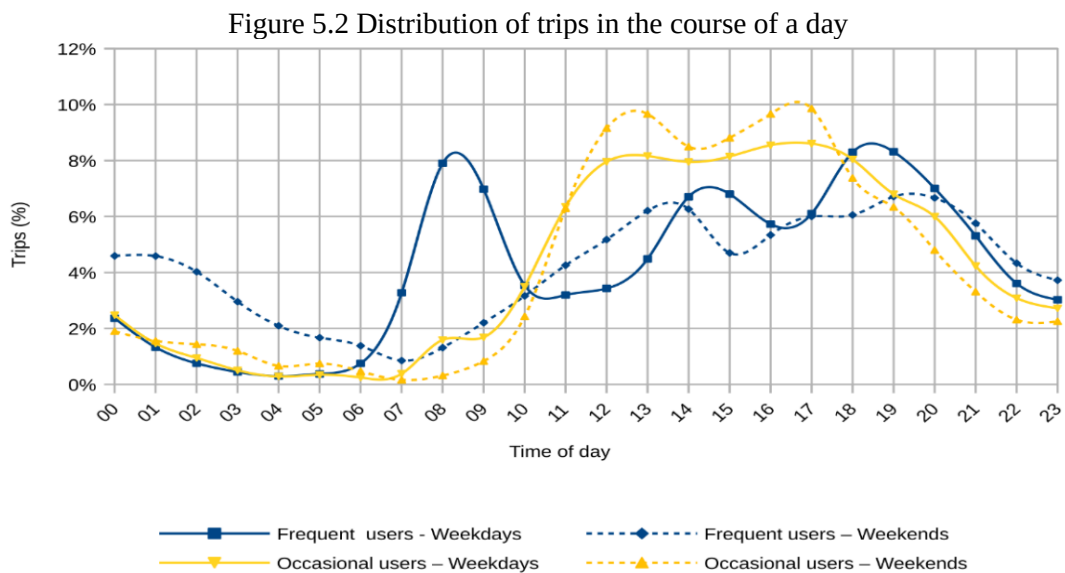


Figure 5.2 shows the distribution of trips over the course of a day. The figure reveals different patterns according to the type of users and type of day. Occasional users maintain a similar distribution of trips, with a peak in the noon and afternoon (11 am to 6 pm). Nevertheless, the distribution of trips for frequent users shows clear differences. In weekdays, there are three peaks with high percentage of trips: in the morning, in the afternoon and in the evening. These peaks correspond to commuting trips. On weekends and holidays, the distribution changes, showing no peak hour in the morning but with a remarkable increase of trips at midnight, probably associated to nightlife leisure activities and the fact that certain public transport services shut down at night, such as the metro.



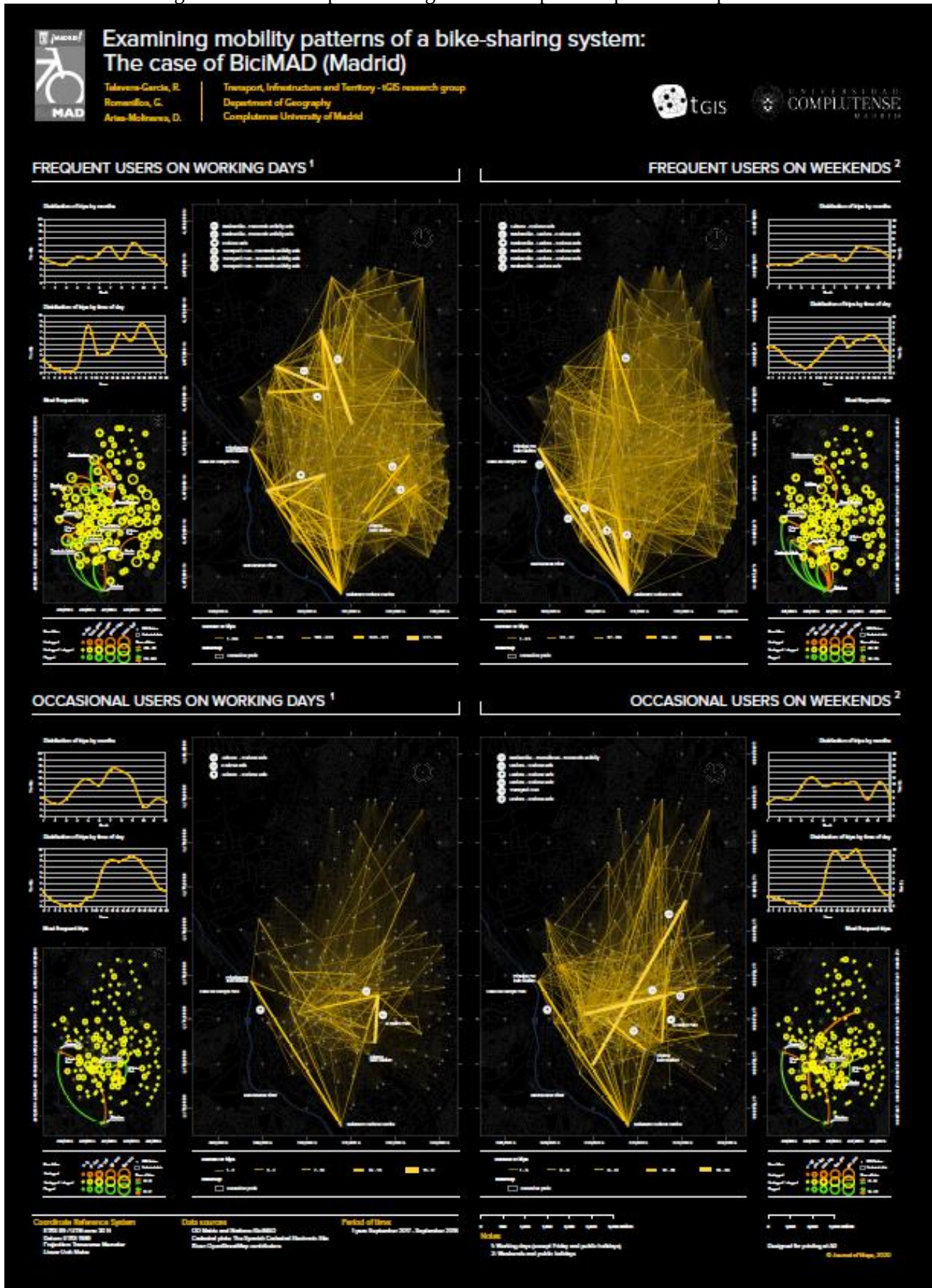
The Main Map illustrates the OD cycling trips from the activity of Madrid BSS (see Figure 5.3), providing an overall view of the cycling footprint and its extension across the city. At a first glance, frequent users' cycling flow is sprawled, covering more areas than that of occasional users who usually concentrate their trips in the more touristic zones (e.g. the city centre with the Royal Palace, Gran Vía, Puerta del Sol, Puerta de Alcalá and Retiro Park, and other surroundings).

Another general difference is that on weekdays, BiciMAD trips are more equally distributed as people travel for different purposes (work, study, shopping, recreation, etc.) while on weekends, they tend to visit specific places (mostly recreational and leisure), which is why certain axes appear more clearly highlighted, like the north-south axis (Bravo Murillo and San Bernardo streets) or the east-west axis (Mayor and Alcalá streets). In all scenarios, the east-west axis is highlighted, showing its importance for cyclists, especially nowadays with the Madrid Central public policy (low emission area restricting private automobiles to circulate), which is greatly promoting active modes in the city centre.

Regarding frequent users, it is noticed that cycling flow grows on weekdays around the north districts of Madrid, which are prominently work sites. Instead, on weekends they tend to travel more in the north-south axis, which connects northern residential zones with southern entertainment and touristic places (city centre). Another tendency shown is that frequent users on weekends mostly travel to mid-central Madrid, instead of the city centre, which is more attractive for tourists (occasional users). The mid-central zones are covered with specialised retail and restaurants are abundant. Most frequent users' trips on weekdays are made in the late spring-beginning of summer season (July) and September, with a decreased number around the winter months. The time of the day with the highest number of cyclists are peak hours from 8-9 hours and from 18-19 hours. On weekends most trips are made in September and October (autumn season) with a downsized number of trips in August, which could be related to the summer period, when most Madrilenians go on vacations out of the city. When comparing the graphs of weekdays and weekends, there is an increase in the use of bicycles for the early hours (from 23-2 hours) at weekends, which could be related to night life activities.

As regards occasional users, we can notice, at a first glance, that movements are concentrated in the city centre where the most visited places are located (e.g. the Royal Palace, Puerta del Sol, etc.). Additionally, bike trips at weekends cover a more extended area than on weekdays, with users traveling up to more northern zones (e.g. Santiago Bernabeu Stadium). Moreover, a strong connection between important green recreational spaces is observed between Casa Campo (northwest area) and Matadero Hub-Madrid Río (southeast area) on both weekdays and weekends, which supports (Zhou, 2015) who also reported that people are willing to bike longer if the urban environment is safe and encouraging. Occasional users mostly travel on BiciMAD from July to September (as expected for the summer season). On weekdays, most trips are made from 12-18 hours decreasing at night. May and summer season (warm periods) are the most attractive for occasional users, and time periods are similar to the weekdays scenario, with peaks in the afternoon from 12-18 hours. Unlike frequent users, occasional users do not tend to use bikes as much in the early morning hours (nightlife) and this may be caused by the fact that they do not know the city well enough to take the risk of cycling at night.

Figure 5.3 Main Map illustrating BiciMAD spatiotemporal travel patterns



Source: Elaborated by Rubén Talavera-García (Talavera-Garcia et al., 2021).

5.4. Conclusions

This chapter explored the spatial and temporal travel behaviour of frequent and occasional cyclists in BiciMAD. Our analysis considers BiciMAD, as it is the public bike-sharing system in Madrid, and the one that has been operating for more time (most consolidated system). BiciMAD is also the most important micromobility service in the city with more than 75.000 subscribers. Results show that attractive visiting spots and OD trip matrices drastically change according to the type of user and to the time, day or season, specifically. Some of the most important findings show that frequent users have more sprawled travel patterns than occasional users, due to diverse travel purposes (frequent users mostly for study/work purposes and occasional users mostly for recreational ones). The use of the system by both frequent and occasional users reveals a clear seasonality, with a higher demand in the warmer months, between April and September. In the case of occasional users, seasonality is more dramatic probably because an important percentage of them are tourists. This changing and dynamic behaviour suggests the need to specifically consider every time period and location, when implementing new public policies.

6. Analysing spatiotemporal travel patterns of micromobility

6.1. Introduction ⁴

As was previously mentioned, shared mobility and micromobility services has grown in many cities around the world. They offer multiple benefits and in the particular case of mopeds, they provide faster speeds than bikes and scooters, and they are very attractive for non-flat cities (Aguilera-García et al., 2020). These known benefits are making mopeds an attractive mode to move around cities. In Madrid alone, the number of owned motorcycles increased in 28% from 2010 to 2018 (Ayuntamiento de Madrid, 2019b; Comunidad de Madrid, 2018). Most of the previous studies regarding shared mopeds are related to accidents and safety issues (Aare & von Holst, 2003; R. A. Blackman & Haworth, 2013; Haworth, 2012; Q. Huang & Wong, 2015) or riders' attributes, but they only consider those who own a motorcycle (R. Blackman & Haworth, 2010; Jamson & Chorlton, 2009; Rose & Delbosc, 2016; Yannis et al., 2007). The few studies that exist on shared mopeds focus on user characteristics and preferences (Aguilera-García et al., 2020; Degele et al., 2018).

Our study will focus not on moped users, but rather of their trips. Our objective is to analyse and visualise mopeds' spatiotemporal footprint and compare its dynamics in different cities. Taking the example of mopeds as a relevant case of a growing and fast-developing micromobility mode, we analyse if its travel patterns and dynamics change according to different geographical areas. We aim to evaluate whether micromobility could behave differently according to the particular urban area context. To that end, we propose a methodology that uses spatial autocorrelation tools to analyse travel patterns and visualise spatiotemporal behaviour over time, identifying the spots where most trips begin or end, and assessing to which extent the system is self-balanced, obtaining insights from different dynamics. We based our analysis on a dataset provided by Muving (shared mopeds), which is an operator present throughout Spain in seven different urban areas. Our findings are useful for authorities to understand micromobility behaviour (taking the example of mopeds) according to different contexts which could help to plan and offer adequate strategies to promote it. They are also important for shared mobility operators, adding value to their trip data and using insights to improve everyday operational tasks (maintenance, recharging, and distribution of vehicles).

6.2. Background

Shared mobility and micromobility are still relatively recent topics because the technology that allowed them to arise in many cities only took place about a decade ago. Nevertheless, many studies related to bike-sharing (Eren & Uz, 2019; Ricci, 2015) have been published. This is not the case for the scooter-sharing sector (kick or moped-style), which is understandable, since it mostly started running operations only a few years back (in the case of Spanish cities, around 2018). Given the recent nature of their worldwide expansion, to our knowledge, only two studies have been found regarding moped-style scooter sharing. With the data provided by a German operator, (Degele et al., 2018) developed a cluster analysis to segment users according to their age, time between rides, distance driven, and revenue per customer. They identified four types of moped users (power users, generation-X casual users, generation-Y casual users, and one-time users), analysed which type provided the most revenue, and proposed strategies to retain and promote their usage. On the other hand, (Aguilera-García et al., 2020) conducted a generalised ordered logit model to identify the key drivers determining the adoption and frequency of use of mopeds in Spanish urban areas. They found that both personal socioeconomic characteristics and trip-related attributes played a major role in explaining the adoption of scooter-sharing services. Young and highly educated people proved to be the segment of the population with the highest

⁴ The content of this chapter has been published in (Arias-Molinares, Romanillos, et al., 2021)

probability of using mopeds, but they also found a considerable amount of people in middle-aged groups.

None of the previously mentioned studies examined the spatial distribution patterns of moped trips. However, bikeshare-related studies can offer some lessons on travel behaviour associated with these systems. Temporal usage patterns show a morning and an evening peak, especially for commuting (K. Wang et al., 2018). Spatial analyses show that bikes are commonly taken from residential areas to travel to commercial zones, central business districts (CBDs), employment centres, and train stations in the morning, and back to residential areas during evenings (Caspi et al., 2020). In addition, it has been found that the temporal and spatial concentrations of dockless bikes are mainly influenced by the built environment, particularly density and street connectivity (Xu et al., 2019) and that most riders cycle short distances in urban centres (X. Li et al., 2018). Bike travel times are especially competitive compared to other transport modes for short trips in the city centre during peak periods (Romanillos & Gutiérrez, 2019).

Studies regarding micromobility and the analysis of spatial patterns using spatial autocorrelation tools are particularly scarce. An exception is the study on shared scooters by (Jiao & Bai, 2020) which uses univariate LISA to identify areas of high demand (hot spots) as a preliminary step before applying regression models. We elaborate on this research line and by considering shared mopeds trip data, we use the most common spatial autocorrelation tools to explore micromobility trips, making use of univariate and bivariate Global Moran's I and LISA statistics and including the temporal component (time bands) in order to capture the dynamics of the system. Univariate analysis allows us to answer the questions of when and where demand is more clustered, and bivariate analysis allows us to answer the question of when and where demand is more self-balanced. Both issues (demand concentration and self-balance potential) are key elements for good management and planning of micromobility services.

6.3. Study case, data and methods

Our study takes as cases of study seven Spanish urban areas, where the shared moped operator Muving was present by 2019. Spanish city centres are generally characterised by old historic urban structures, with narrow streets and recurrent congestion problems, which could positively influence the use of shared mopeds. This research was conducted using trip data from Muving for the following urban areas: Madrid, Valencia, Seville, Saragossa, Malaga, Cordova, and Cadiz. Table 6-1 summarises some of their relevant characteristics for the study. As can be seen, Madrid and Valencia are the most important cities in terms of population; however, Saragossa, Seville, and Cadiz also show high density (Inh/km²) which is an important factor influencing the adoption of shared services (Munkácsy, 2017; Velázquez Romera, 2019). Three of them are coastal cities, which usually have higher tourist activities promoting the use of mopeds. Warmer cities are mostly within the Andalusia Region in the south of Spain (Seville, Malaga, and Cadiz). Annual precipitation level is low in the seven cities analysed, which is also important to consider, as rainfall may reduce the use of micromobility in general.

Table 6-1 Summarised characteristics of the seven cities analysed.

Attribute		Madrid	Valencia	Seville	Saragossa	Malaga	Cordova	Cadiz
Population (municipality)		3,174,000	791,413	688,711	666,880	571,026	325,701	116,027
Average annual temperature (°C)		15.0	18.3	19.2	15.5	18.5	18.2	18.6
Average annual precipitation (mm)		421	475	539	322	534	605	523
Coastal city		No	Yes	No	No	Yes	No	Yes
Modal split (%)	Public transport	24	21.8	26.2	24	13.2	12.04	7
	Car	39	21.5	35	28	37	44.15	48
	Active**	37	56.7	38.8	48	49.8	43.81	45
Moped-style scooter-sharing operators	Number of operators	4	3	2	2	1	1	1
	Name of companies	Acciona, Movo, Ecooltra, Muving	Acciona, Ecooltra, Muving	Acciona, Muving	Acciona, Muving	Muving	Muving	Muving
Topography		Hilly	Flat	Flat	Flat	Flat	Flat	Flat

Source: own elaboration with data from (Greenpeace, 2019). *Updated with results from the last Mobility Survey in 2018 (Comunidad de Madrid, 2018)** Active = walk + bicycle + other low-speed mode. Data for Cordova and Cadiz was extracted from official reports (ETRALUX, 2011; Junta de Andalucía, 2018).

Only Valencia and Madrid had three or more moped-style scooter sharing operators by 2019. In the case of Madrid alone, some studies point to its role as one of the most important shared mobility labs in Europe, with an estimated fleet of more than 20 thousand vehicles (Arias-Molinares & García-Palomares, 2020a; Granda & Sobrino, 2019). These operators usually manage and maintain a fleet offered through an application where individuals access and subscribe to their service. Users pay a fee every time they use a vehicle, while operators are in charge of energy consumption and maintenance. In Spain, electric vehicles (including shared modes) do not have parking restrictions in city centres and generally benefit from free on-street parking, providing an attractive alternative for inner districts (for example, in the case of Madrid, within the M-30 highway).

Regarding the data used for the research, we consider trip records (GPS data) provided by Muving with all their trips between 13 February and 31 December 2019, with the following information:

- Id_vehicle: an identification number for each motorcycle.
- Id_customer: an identification number for each user.
- Start_time: trip starting timestamp (format: yy-mm-dd hh:mm:ss).
- Start_latitude and longitude: xy coordinates where the motorcycle was picked up.
- End_time: trip ending timestamp (format: yy-mm-dd hh:mm:ss)
- End_latitude and longitude: xy coordinates where the motorcycle was left.
- Trip time: trip duration in minutes.
- Travelled distance: travelled distance in km of the real trajectory by the street network.

The data workflow covered entering, cleaning, transforming, describing, analysing, and visualising data. Given the size of the dataset (almost two million entries), we processed it using Python (vs 3.8) programming language. A script performing all steps was created: to load the CSV files, extract the day and hour of the trip in the timestamp information, and obtain a new output table. This output table was then imported to a GIS environment (ArcGIS Pro vs. 2.5.2) to display coordinates, geolocate points, and create a new column with the city name. An outlier cleaning process followed, using travelled distances, which in some cases went unrealistically higher than average. In order to discard these outliers, boxplots were made for each city and the final valid dataset included 1.797.228 trips (see Table 6-2).

Table 6-2 Dataset without outliers

City	Trips with outliers	Distance (km) from which outliers were identified (boxplot)	Trips without outliers
Madrid	307.876	9,3	298.031
Valencia	437.795	8,1	425.683
Seville	477.424	8,4	463.825
Saragossa	201.294	8,6	195.942
Malaga	135.626	9,8	131.940
Cordova	126.061	6,4	121.034
Cadiz	163.616	6,7	160.773
Total	1.849.692		1.797.228

Source: own elaboration.

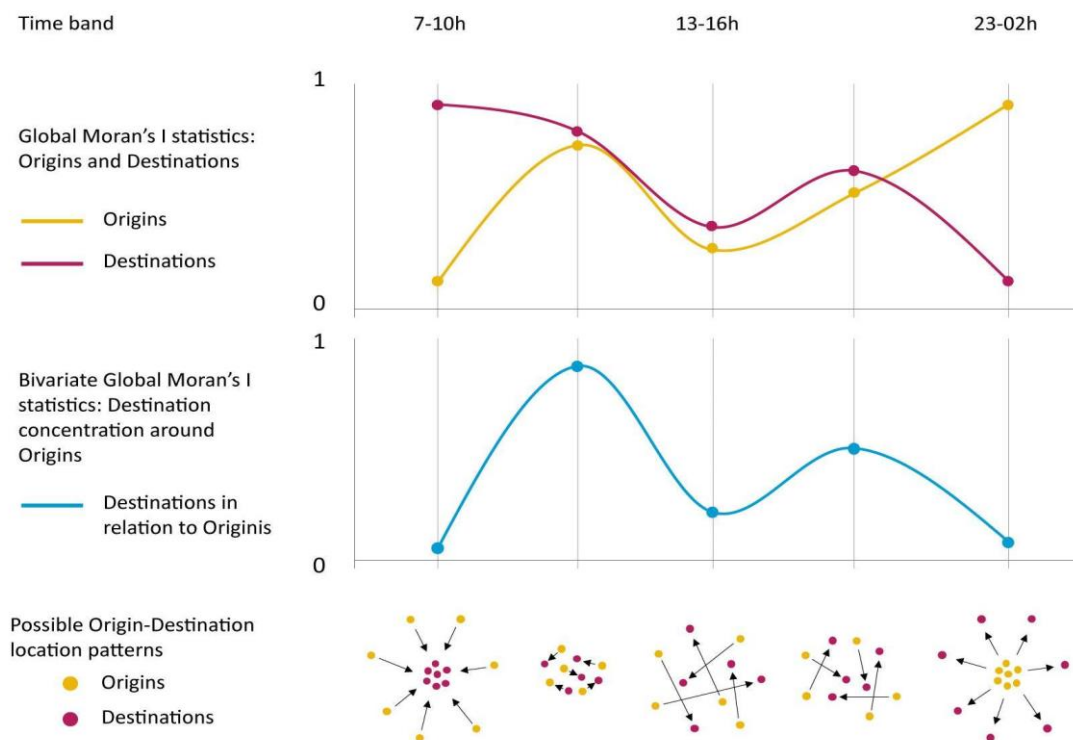
Since time and distance travelled were provided, we calculated average speed, as well as some other indicators, like average usage (trips/customers) and average vehicle rotation per day (trips/vehicles/365days per year). Consequently, a model builder was created in ArcGIS to split the dataset by city, day of the week, and time band. We decided to aggregate the days of the week into two groups: working days (from Monday through Thursday) and weekends (Saturday and Sunday). We excluded Friday from working days because in Spain, as described by (Romanillos, 2018; Talavera-Garcia et al., 2021), it is common to finish work earlier on Fridays, with particular travel patterns that could distort the normal working-day dynamic.

Regarding time bands, we selected four different hour periods: from 07 to 10 to evaluate the morning peak, especially for obligatory trips (commuting to work/study), 13 to 16 to analyse midday behaviour (lunchtime or midday activities), then 19 to 22 for after-work activities and/or return-to-home trips, and finally, from 23 to 02 hours to evaluate nightlife patterns. After splitting the dataset by time bands, the different layers according to each scenario (city, day of the week, and time band) were spatially aggregated into a hexagonal grid, obtaining the number of starting/ending trips by hexagon. Studies focusing specifically on walking distances to pick up shared mopeds were not found, but (Aguilera-García et al., 2020) found that users were willing to walk up to 500m. Hence, we determined 200 meter-sided hexagons as it appears to be an acceptable walking distance to pick up a motorcycle based on previous findings (Gilibert & Weymar, 2022; Song et al., 2022).

Lastly, the hexagonal grids were used to perform location patterns analysis using Exploratory Spatial Data Analysis (ESDA) tools. ESDA comprises a set of methods to describe and visualize spatial distributions which focus on distinguishing characteristics of geographical data and, specifically, on spatial autocorrelation and spatial heterogeneity (Anselin, 1995). To this end, we used GeoDa software (vs 1.16.0.16) to calculate two different Global Moran's Indices. The first one was univariate Global Moran's I statistics for origins and destinations separately. This helped us to study the level of concentration or dispersion of the origins and destinations of moped trips, and their variation over the course of the day. This insight could be of interest to inform operators as to the most optimal time and location to carry out operational tasks, like vehicle redistribution, recharging, and maintenance, and to know when/where demand is coming from. In addition, bivariate Global Moran's I was calculated to measure the spatial association between the destinations and origins of trips. Insights from this statistic served to analyse whether the system is self-balanced throughout the day by answering the question: "are users ending their trips near where others are starting theirs?" If the system is balancing itself, then the locations where users are arriving at a certain time are also the locations where other users are starting their trips, allowing for higher vehicle rotation. Both univariate and bivariate Global Moran's I statistics were calculated using a contiguity weight matrix of 1st order. The resulting univariate and bivariate Global Moran Indices and their z-score were graphed, and symbology was applied to the hexagonal grids, generating maps by time bands.

Figure 6.1 illustrates the conceptual framework of the different Global Moran's Indices calculated, in relation to expected origin-destination location patterns. Our hypothesis predicts that origins are more dispersed than destinations in the early morning band (predominance of trips from residential areas to the city centre), while the opposite should occur in the last bands of the day (predominance of return-to-home trips). It also expected that the system will tend to balance itself during the middle bands, since, at those hours, the population tends to be concentrated in the city centre, which produces a greater proximity between origins and destinations.

Figure 6.1 Conceptual framework of the different Global Moran's Indices calculated.



Source: own elaboration.

In addition, univariate Anselin Local Moran's I (LISA statistic) was used in order to identify and map local tendencies (clusters and outliers) related to the location of origins and destinations by time bands. With LISA statistics, it is possible to distinguish High-High clusters (a high value surrounded primarily by high values), Low-Low clusters (a low value surrounded primarily by low values), and spatial outliers, either High-Low (high values surrounded primarily by low values) or Low-High (low values surrounded primarily by high values) (Anselin, 1995). Lastly, bivariate LISA cluster maps for origins and destinations, by time bands, and on working days, were graphed in order to identify areas with a high concentration of both origins and destinations (HH clusters) in which the system self-balances, or other areas with imbalances between origins and destinations (HL and LH outliers).

6.4. Results

6.4.1. Service characteristics and performance

Table 6-3 shows the descriptive characteristics of the dataset analysed. Seville and Valencia generated the greatest number of trips during 2019, with 463.825 and 425.683 trips respectively, while Madrid, the most populated city, generated 298.031. In relation to this fact, it is important to consider that large metropolitan areas usually have more operators, so competition is a crucial

factor that determines their market share. In addition, Madrid is one of the cities with the highest shared mobility fleet, not only of mopeds, but also of other modes like bikes, cars, scooters, etc. This context could also explain why, although Madrid has more deployed vehicles, Valencia and Seville show a higher number of trips and more trips per customer throughout the year, with 13,87 and 12,92 respectively, in comparison with Madrid, with 9,33 trips per customer. The average vehicle rotation per day results in 2,04. Cities above this average, like Cadiz, Saragossa, Seville, and Valencia, are more attractive for companies (as the system is more profitable) than, for instance, Madrid, which bears the minimum value with just 1,08 vehicle rotations per day.

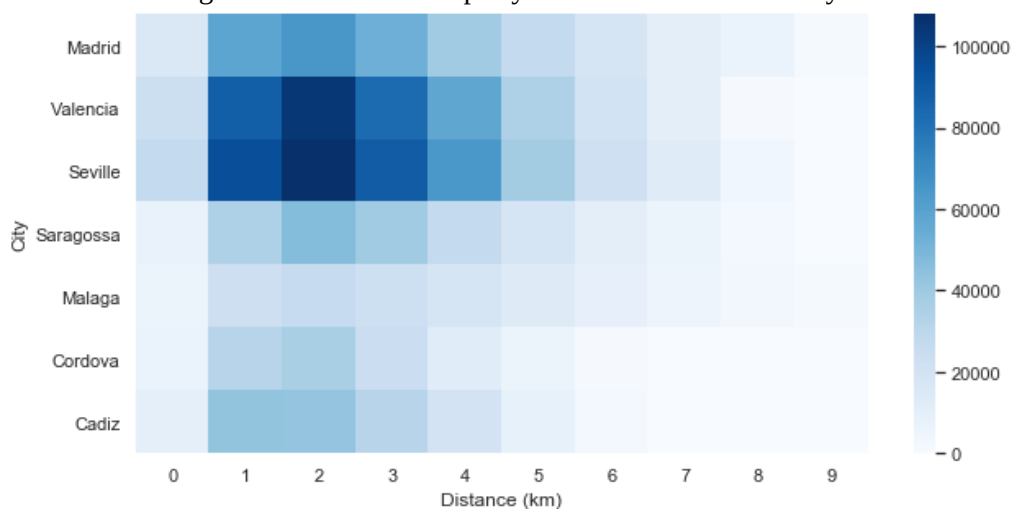
Table 6-3 Descriptive characteristics of the dataset analysed.

City	Trips	Vehicles	Customers	Usage (trips/ customers)	Veh. rotation/day (trips/vehicles/365 days)	Average trip time (min)	Average trip distance (km)	Average Speed (km/hr)
Madrid	298.031	755	31.934	9,33	1,08	11,48	3,49	18,24
Valencia	425.683	578	30.692	13,87	2,02	10,28	3,18	18,56
Seville	463.825	591	35.902	12,92	2,15	10,40	3,23	18,63
Saragossa	195.942	240	15.313	12,80	2,24	10,53	3,42	19,49
Malaga	131.940	196	12.613	10,46	1,84	10,86	3,68	20,33
Cordova	121.034	184	9.715	12,46	1,80	9,06	2,67	17,68
Cadiz	160.773	186	10.755	14,95	2,37	9,05	2,73	18,1
		2.414	129.384					
Total	1.797.228	(316 vehicles duplicated in different cities)	(17.540 users duplicated in different cities)	13,89	2,04	10,24	3,20	18,72

Source: own elaboration.

Average trip time, distance, and speed prove relatively homogenous across the different cities, with a trip time of around 10 minutes, a 3 km distance, and an 18km/hr speed. The city with the highest trip time is Madrid (11,48 minutes), which could be expected since it is the capital of Spain and is a more congested urban area. However, this 12-minute ride is still relatively fast compared to other services, such as bike-sharing, which displays trip times of 15 minutes or more (Romanillos, 2018). In any case, travel time and distance may be highly influenced by the size of the company's service area. Certainly, future expansions of these areas could allow users to travel longer distances. Regarding distances travelled, mopeds are mostly used for short urban trips between 1 and 3 km (see Figure 6.2). Madrid, Valencia, and Seville, which are large metropolitan areas, display a considerable number of trips with longer distances.

Figure 6.2 Number of trips by distance travelled and city.



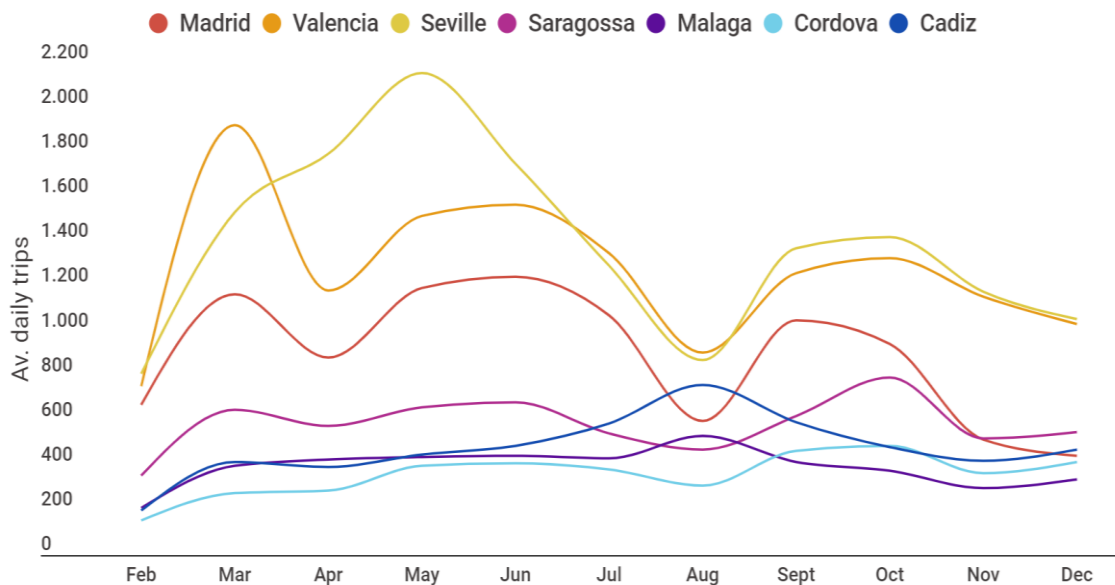
Source: own elaboration.

In addition to this comparative analysis between cities, when it comes to general fleet and customers, we found that 2.414 mopeds were operating in Spain during 2019 and almost 130.000 clients used one (of which 17.540 made trips in more than one city). The fact that some customers use the app in different cities could demonstrate their intention to use this kind of platform when travelling to different areas, which is an important insight, especially with the introduction of new concepts like Mobility as a Service (MaaS) (Arias-Molinares & García-Palomares, 2020b; Jittrapirom et al., 2017).

6.4.2. Temporal patterns

When analysing average daily trips by month, we identify a general trend for Spanish cities, with high peaks in March, May and October, and valleys in April and August (see Figure 6.3). Peaks are related to the beginning of spring season, when the temperatures rise, and shared mobility becomes more attractive. High trip counts in September and October correspond to the return from summer holidays when users begin their daily routines again. The valley seasons (April and August) concentrate most holidays (especially the summer season), when most Spaniards travel for holiday; this is very notorious in the case of Madrid, where the trip count drops considerably. Cities that follow a different trend are, for example Seville, which shows a high peak in April. This is probably due to the increase in tourist and local activity during the Holy Week and Seville's Fair. Other cities that follow different patterns are Malaga and Cadiz, which display high number in August, possibly related to the fact that these cities are summer tourist destinations. In these latter cities, trip counts are homogenous throughout the year, increasing notoriously only during the summer season, from which we might infer that many of the moped users during those months are tourists.

Figure 6.3 Average daily trips by month (2019).



Source: own elaboration.

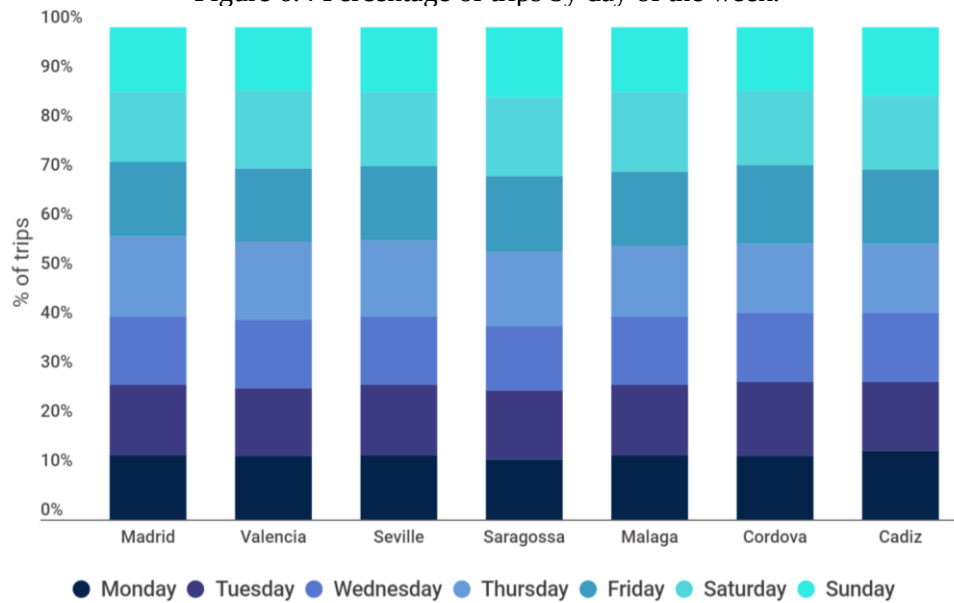
When aggregating data by day of the week, Table 6-4 shows that in general, 72% of the trips are made on working days and 28% over weekends. These results lead us to infer that mopeds are not only used for recreational trips, but also for other purposes, like commuting or running errands. Figure 6.4 shows that the distribution of trips is quite homogeneous throughout the week in greater detail.

Table 6-4 Trips by day of the week.

City	Working days (M-T)	Friday	Weekends (S +D)	Total
Madrid	169,425	45,773	82,833	298,031
Valencia	240,681	62,587	122,415	425,683
Seville	262,801	71,843	129,181	463,825
Saragossa	107,846	29,684	58,412	195,942
Malaga	73,771	20,030	38,139	131,940
Cordova	67,629	18,869	34,536	121,034
Cadiz	90,363	24,037	46,373	160,773
Total	1,012,516	272,823	511,889	1,797,228

Source: own elaboration.

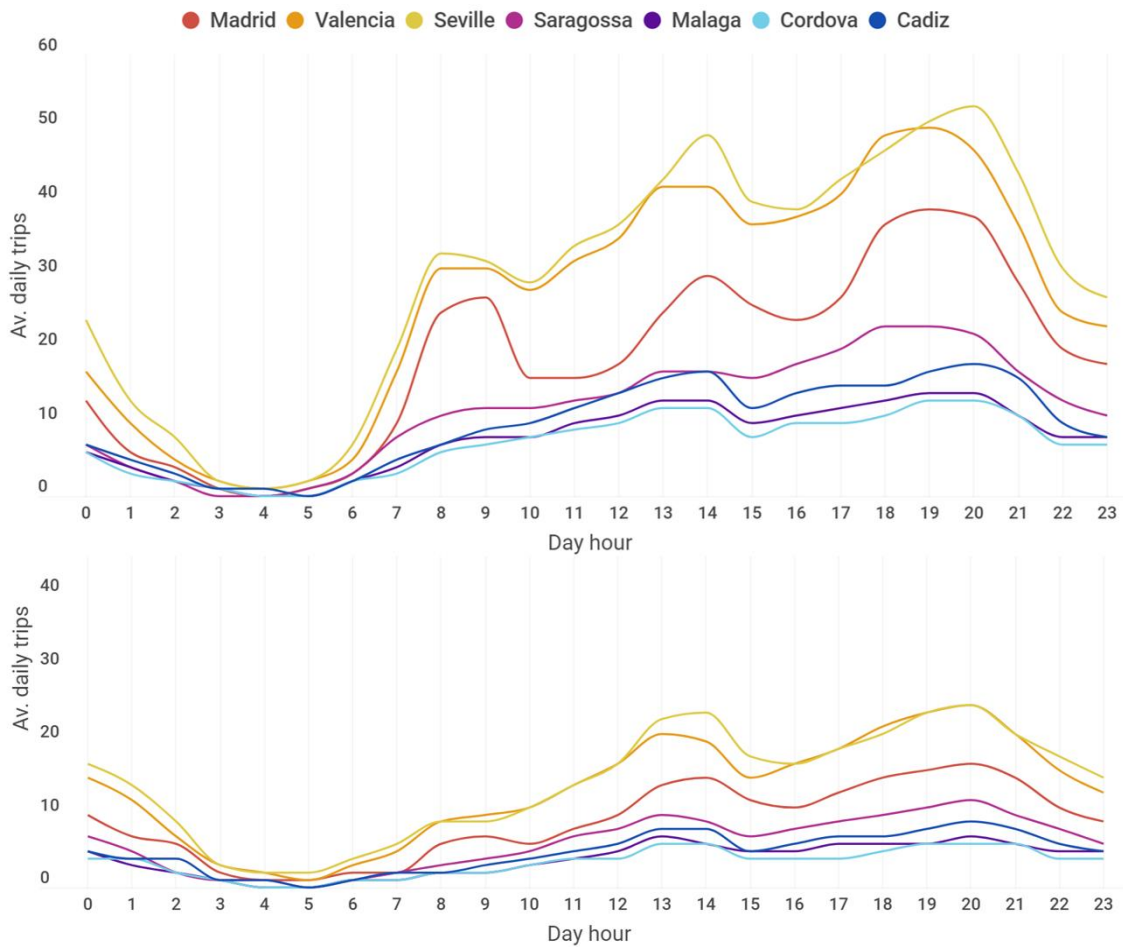
Figure 6.4 Percentage of trips by day of the week.



Source: own elaboration.

When exploring hourly patterns, Figure 6.5 shows the average daily trips on working days and weekends. Relatively homogeneous temporal behaviour is revealed with trips increasing toward the afternoon. We noticed three different peaks: the smallest one from 8 to 9 for commuting, a medium one from 13 to 14 related to midday activities (i.e., lunchtime), and the greatest one from 18 to 20 related to after-work activities and/or returning home. On the other hand, over weekends, the early morning rush hour disappears, and the midday peak (13-14 hrs) becomes as great as the night-time period (19-20 hrs), since many people start doing their activities from late morning onward. And lastly, over weekends, a significant percentage of trips is observed in the early hours (dawn), when customers use mopeds to return home from their night-life activities, given that the subways or public transport options are more limited. Given the lower usage over the weekend and the greater diversity in purpose, the spatial analysis was performed only for working days.

Figure 6.5 Average daily trips by hour of the day (top: working days, bottom: weekends).



Source: own elaboration.

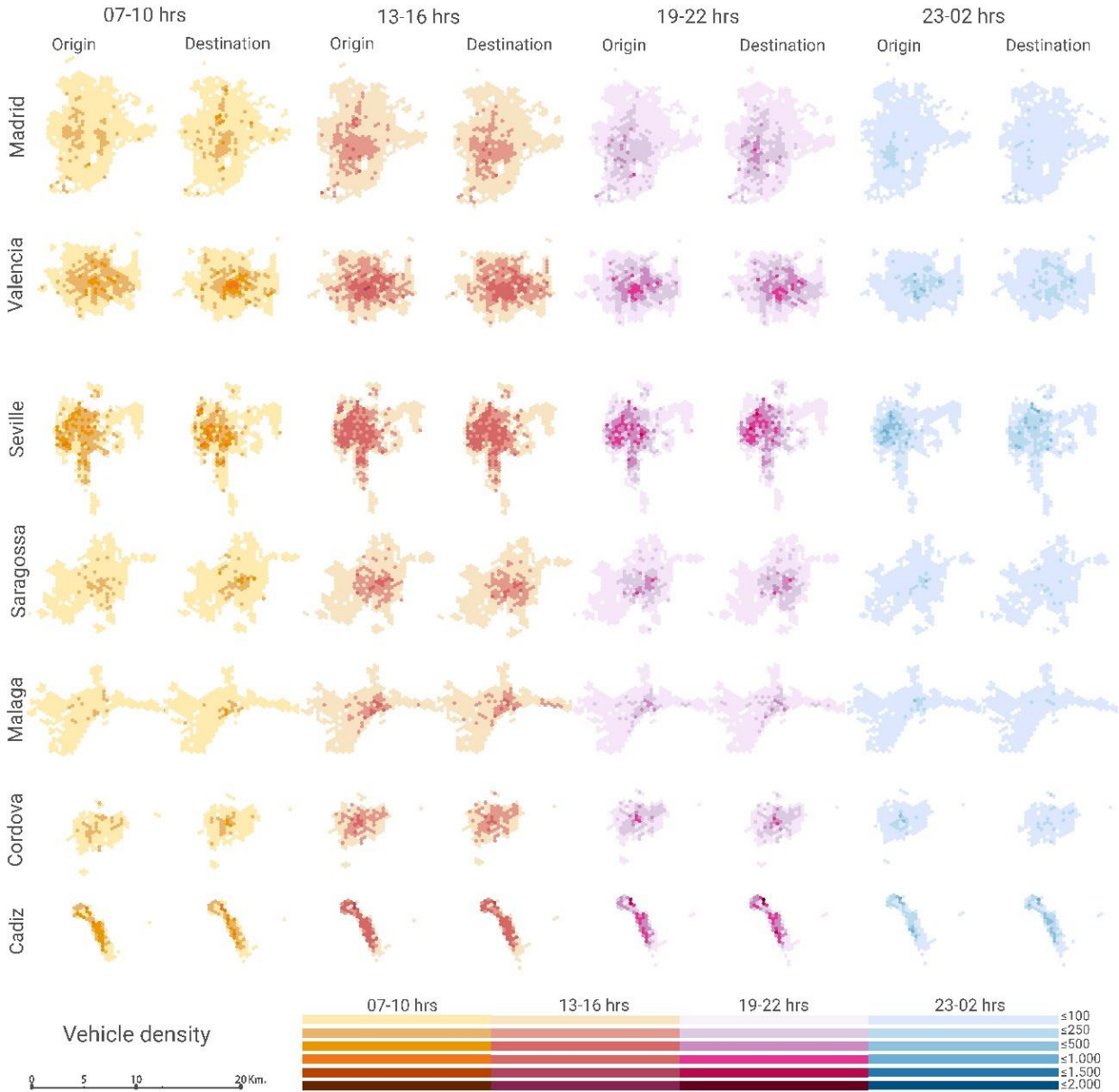
6.4.3. Mapping origins and destinations of trips over time

Visualisation of the spatial distribution of trip origins and destinations over the course of a working day is shown in Figure 6.6. In general terms, it reveals that, in the first band (07-10), origins are more dispersed than destinations, while in the last time band (23-02), the opposite occurs. This pattern follows the hypothesis outlined in the initial conceptual framework, as morning users usually come from different residential zones and commute to (mostly) specific clustered workplaces. In the late hours, users do the opposite, coming from clustered after-work locations and returning to those dispersed residences. In some cases, these residential areas may match, meaning that late-night users are leaving mopeds at the same or near the same areas where morning users will take them, which will make the system self-balanced. However, in most cases, the ending spots do not match the starting ones, which requires vehicle redistribution by the operator to cover demand areas in mornings.

On the other hand, band 2 (13-16) and 3 (19-22) have more similar dynamics since origins and destinations are homogeneously distributed, with a slight difference in band 3 when destinations appear to be a bit more concentrated. In these two bands, trips are coming and arriving at similar areas, enabling a higher vehicle rotation. This time period of the day responds to midday-activities, like having lunch, running errands, and doing after-work activities, which usually take place at public facilities, restaurants, bars, gyms, and entertainment locations that are very spread

throughout the city. This contributes to a less marked difference between origins and destinations. Hence, this is the period of time when the system’s self-balance potential is more visible, in comparison with bands 1 and 4. These results illustrate that the different spatiotemporal dynamics for shared mopeds in cities are closely related to their land-use distribution. For each city, we can identify the most important origins and destinations by time of the day, which informs operators where to allocate their resources at each time to cover a greater demand, and also for public authorities to know where to allocate infrastructure like parking facilities. The results obtained in the particular case of Cadiz, for this analysis and subsequent analyses, must be carefully interpreted, considering its particular location and shape: the city of Cadiz is located on a narrow slice of land surrounded by the sea. All results and maps are affected by this spatial singularity.

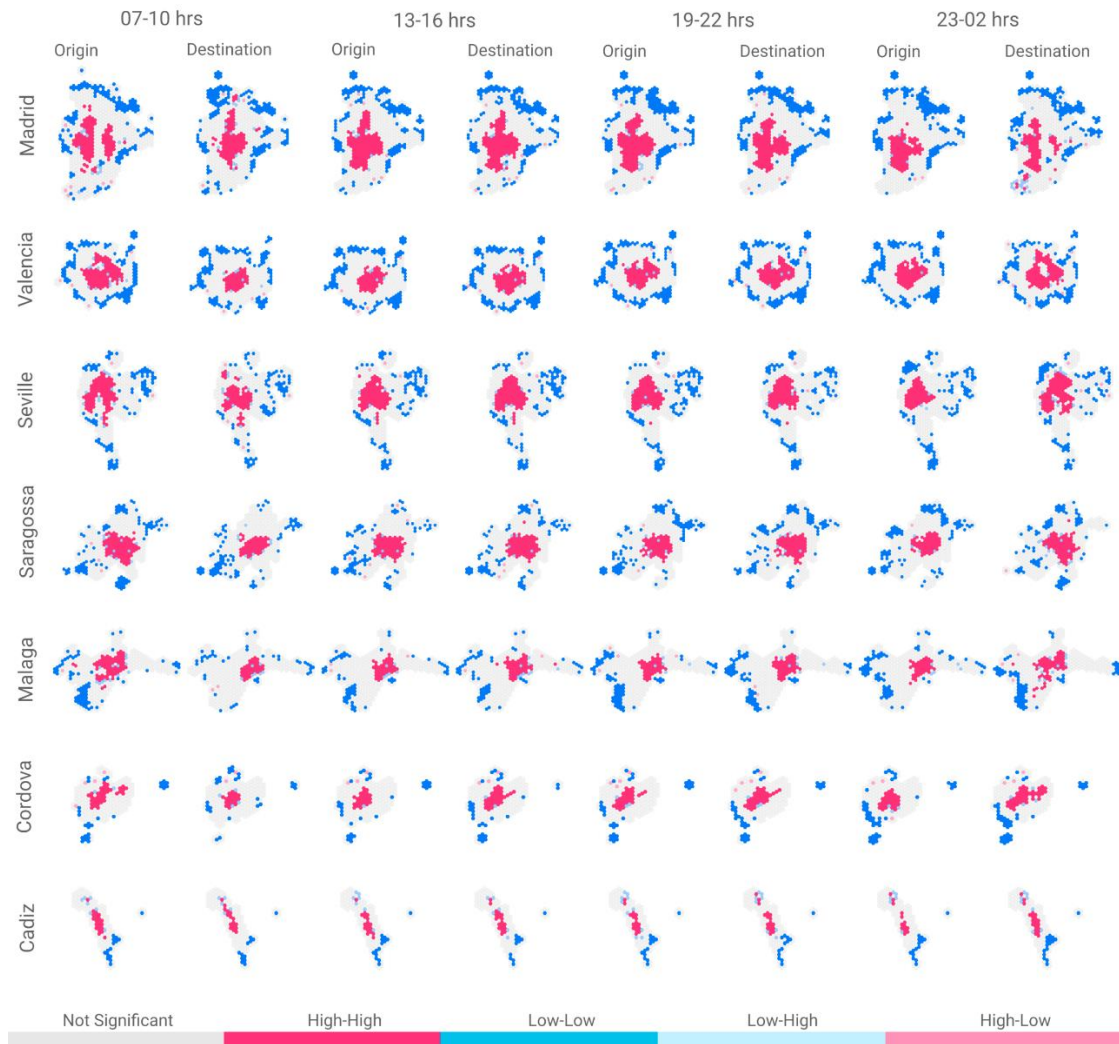
Figure 6.6 Spatiotemporal dynamics of mopeds during working days.



6.4.4. Spatial autocorrelation analysis: local trends

As described in the methodology, in addition to map visualisations, we performed a series of spatial statistical analyses in order to further explore and quantify the trends previously identified. Firstly, Anselin Local Moran's I statistic was calculated in order to map the presence of origin and destination clusters at local level. The maps illustrated in Figure 6.7 show the marked differences between High-High clusters in bands 1 and 4, due to the location of residential zones and workplaces, especially in Valencia and Madrid, whereas HH clusters in bands 2 and 3 are located quite similarly. In all cases, there is a clear concentration of HH clusters in the city centre and LL on the periphery. Interestingly, the HH cluster maps of destinations in each time band are very similar to the HH cluster maps of origins in the following time band, which proves that the availability of vehicles near the users' location clearly influences increased usage. Moreover, interesting results are obtained from observing spatial outliers, especially in the first band, which is mostly for commuting trips. In Madrid, for example, an HL spatial outlier for origins is located at Ciudad Universitaria, which is Madrid's main higher-education hub, meaning that from 07 to 10 AM, many trips begin on these university campuses.

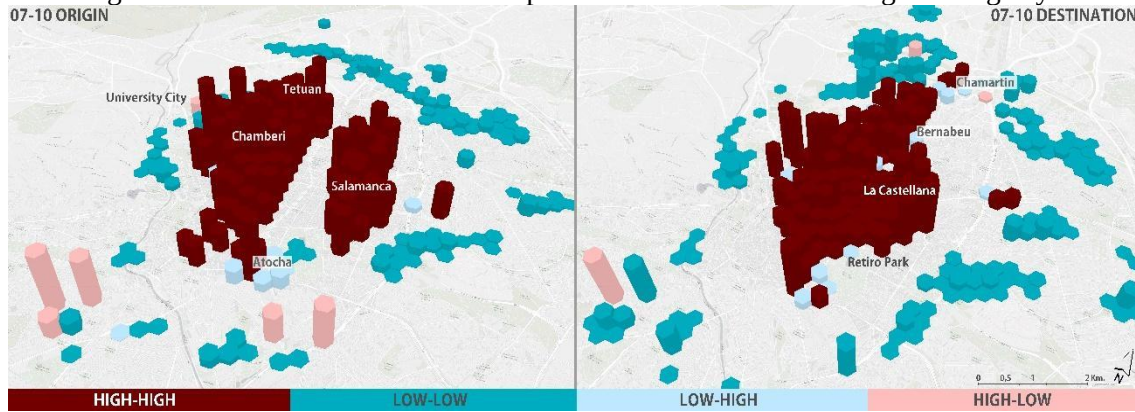
Figure 6.7 Univariate LISA cluster maps for origins and destinations by time bands and working days.



Source: own elaboration.

When considering Madrid as an example case to zoom closer, we differentiate certain dynamics throughout the day, especially during band 1 (see Figure 6.8). In the morning hours, demand mostly comes from districts that concentrate residential zones with a medium-high income population (Chamberi, Salamanca, and the east area of Tetuan) and mostly arrives at workplaces and offices located over the north-south axis of Paseo de la Castellana. The geolocation of demand is consistent with results obtained by (Aguilera-García et al., 2020), which revealed that most moped users had relatively high incomes.

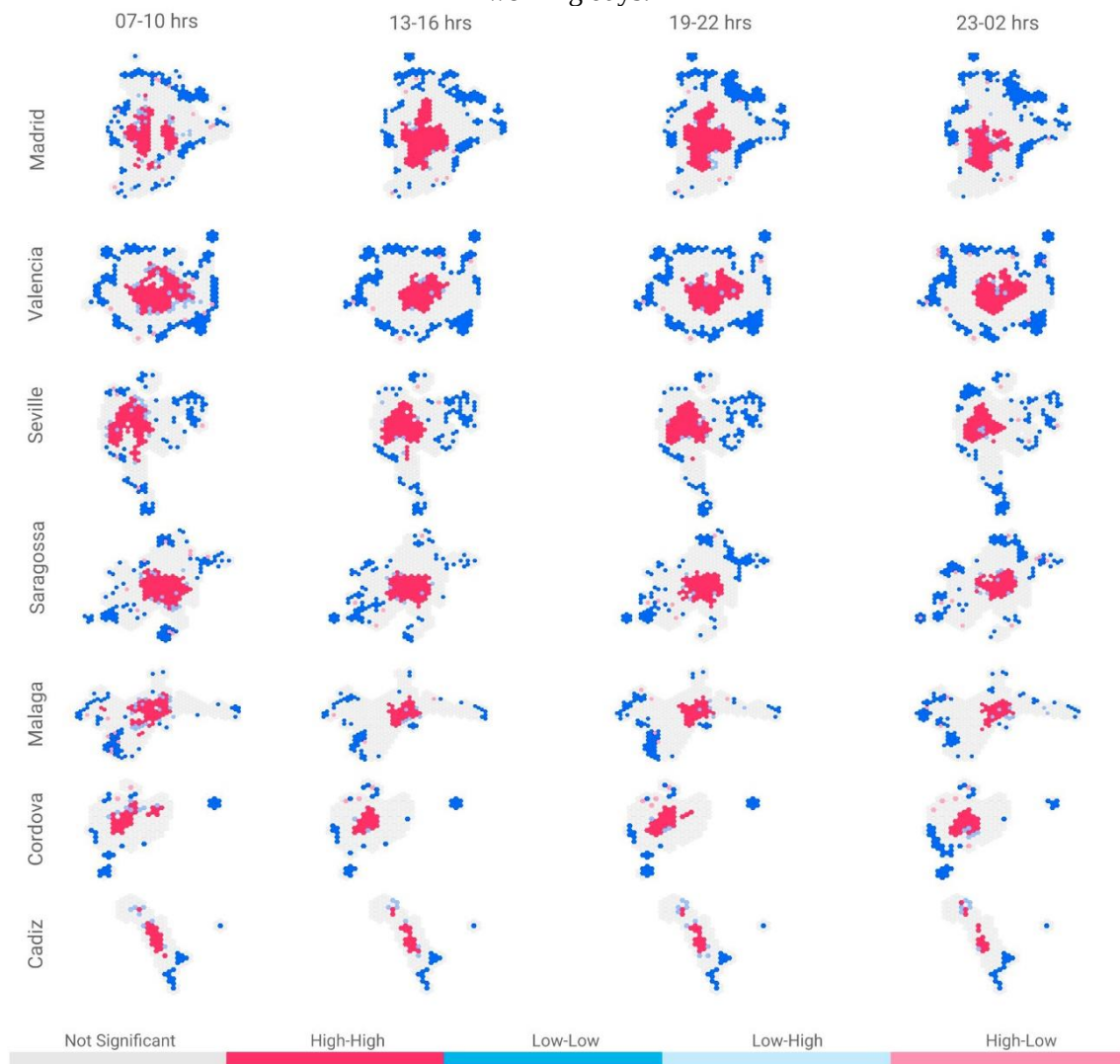
Figure 6.8 Visualisation of Madrid's spatial clusters on band 1 during working days.



Source: own elaboration.

Moreover, Bivariate Anselin Local Moran's I statistics for destinations around origins were calculated for every city and time band on working days. The results illustrated in Figure 6.9 show the same centre-periphery pattern for all case studies, with the exception of Cadiz, which seems to rather have a north-south pattern with HH clusters in the north area and LL clusters in the south. We observe that in time bands 2 and 3, HH clusters are more compacted around the city centres in comparison with bands 1 and 4.

Figure 6.9 Bivariate LISA cluster maps for origins around destinations by time bands for working days.

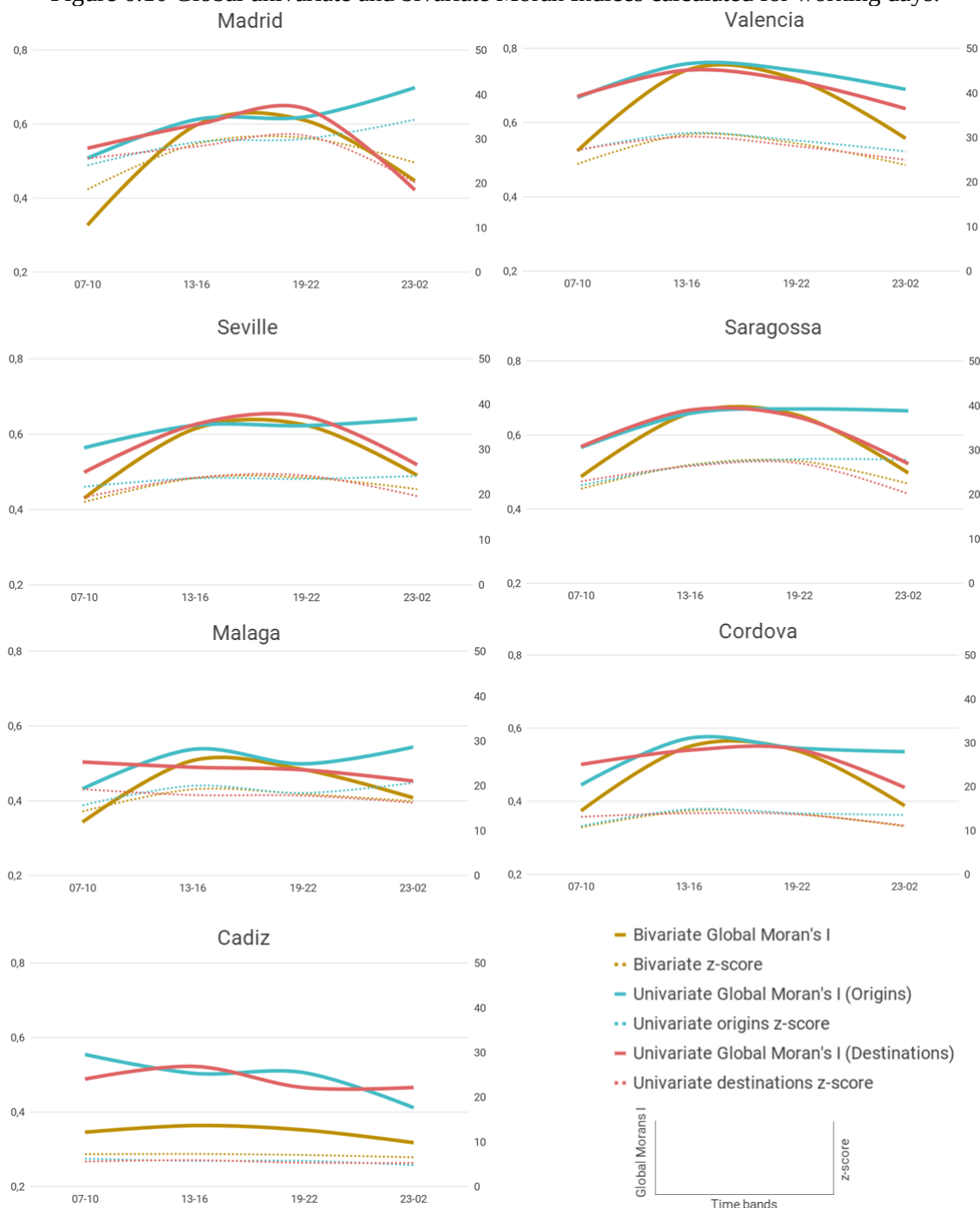


Source: own elaboration.

6.4.5. Spatial autocorrelation analysis: global trends

In order to better understand the system's spatiotemporal trends and assess its potential to be self-balanced, we graphed the calculated Global univariate and bivariate Moran's indices for each time band as seen in Figure 6.10. Most of the cities fall under the expected conceptual framework and their clustering degree is very similar in the central time bands (2 and 3), whereas origins are more clustered than destinations in late hours (band 4), and the opposite tends to occur in early hours (band 1). More interestingly, when observing the result from bivariate Global Moran's I statistics, the seven cities display the same dynamic: low values in early and late hours (07-10 and 23-02), since people are arriving at places where no trips are starting, and high values in midday and afternoon hours (13-16 and 19-22), since they are arriving at the same places where others are starting their trips. This dynamic makes the system less self-balanced during the first and last time bands, requiring moped redistribution, while band 2 and 3 are the hours when the system balances itself because mopeds are arriving where other users are starting their trips. An exception, as we mentioned before, is Cadiz, which in general behaves as an outlier, most likely influenced by its particular urban structure, since its urban centre is located on a narrow peninsula, detached from peripheral residential areas.

Figure 6.10 Global univariate and bivariate Moran Indices calculated for working days.



Source: own elaboration.

The bivariate LISA results for working days also show how destinations in one time band are similar to origins in the following time band. When considering the results from the bivariate local Moran's I statistic between destinations and origins in all time bands, the highest numbers are found in the relationships of destinations with origins in the next time band (see Table 6-5).

Table 6-5 Bivariate Moran's I (z-score) between destinations and origins for all time bands on working days.

Madrid				
	Origin (07-10 h)	Origin (13-16 h)	Origin (19-22 h)	Origin (23-02 h)
Destination (07-10 h)	0.327 (18.6)	0.529 (26.9)	0.486 (26.3)	0.393 (23.7)
Destination (13-16 h)	0.480 (24.5)	0.598 (28.9)	0.605 (29.6)	0.560 (30.1)
Destination (19-22 h)	0.516 (26.3)	0.574 (29.4)	0.610 (30.2)	0.626 (31.7)
Destination (23-02 h)	0.416 (21.4)	0.395 (21.8)	0.444 (23.6)	0.447 (24.7)
Valencia				
Destination (07-10 h)	0.524 (24.1)	0.705 (29.6)	0.655 (28.6)	0.584 (27.3)
Destination (13-16 h)	0.642 (28.0)	0.742 (30.7)	0.735 (30.0)	0.667 (28.4)
Destination (19-22 h)	0.652 (27.8)	0.681 (29.2)	0.717 (28.7)	0.680 (27.4)
Destination (23-02 h)	0.623 (26.3)	0.494 (23.6)	0.574 (25.2)	0.558 (23.9)
Seville				
Destination (07-10 h)	0.430 (18.3)	0.542 (21.5)	0.509 (21.0)	0.466 (20.5)
Destination (13-16 h)	0.561 (22.3)	0.615 (23.6)	0.620 (23.7)	0.589 (23.7)
Destination (19-22 h)	0.557 (22.8)	0.608 (23.9)	0.624 (23.7)	0.623 (24.0)
Destination (23-02 h)	0.524 (21.2)	0.504 (21.3)	0.525 (21.8)	0.491 (21.2)
Saragossa				
Destination (07-10 h)	0.488 (21.3)	0.595 (25.1)	0.593 (26.3)	0.571 (25.9)
Destination (13-16 h)	0.587 (24.2)	0.660 (26.7)	0.661 (27.5)	0.628 (27.1)
Destination (19-22 h)	0.562 (24.6)	0.639 (27.1)	0.653 (27.5)	0.641 (27.4)
Destination (23-02 h)	0.537 (22.3)	0.534 (23.2)	0.532 (23.5)	0.498 (22.4)
Malaga				
Destination (07-10 h)	0.343 (14.3)	0.505 (19.8)	0.465 (18.7)	0.445 (18.9)
Destination (13-16 h)	0.414 (16.2)	0.508 (19.2)	0.495 (18.6)	0.484 (19.1)
Destination (19-22 h)	0.412 (16.2)	0.486 (18.8)	0.484 (18.2)	0.494 (19.1)
Destination (23-02 h)	0.424 (16.7)	0.394 (16.3)	0.413 (16.7)	0.408 (16.6)
Cordova				
Destination (07-10 h)	0.374 (10.7)	0.526 (14.1)	0.493 (13.5)	0.471 (13.4)
Destination (13-16 h)	0.446 (11.9)	0.550 (14.5)	0.544 (14.2)	0.512 (13.8)
Destination (19-22 h)	0.432 (11.6)	0.546 (14.4)	0.539 (13.8)	0.520 (13.6)
Destination (23-02 h)	0.428 (11.3)	0.442 (12.4)	0.460 (12.4)	0.388 (11.0)
Cadiz				
Destination (07-10 h)	0.346 (7.2)	0.330 (6.8)	0.324 (6.8)	0.289 (6.3)
Destination (13-16 h)	0.398 (8.0)	0.364 (7.3)	0.363 (7.3)	0.318 (6.7)
Destination (19-22 h)	0.377 (7.7)	0.352 (7.1)	0.352 (7.1)	0.318 (6.5)
Destination (23-02 h)	0.401 (8.1)	0.365 (7.4)	0.366 (7.4)	0.318 (6.6)

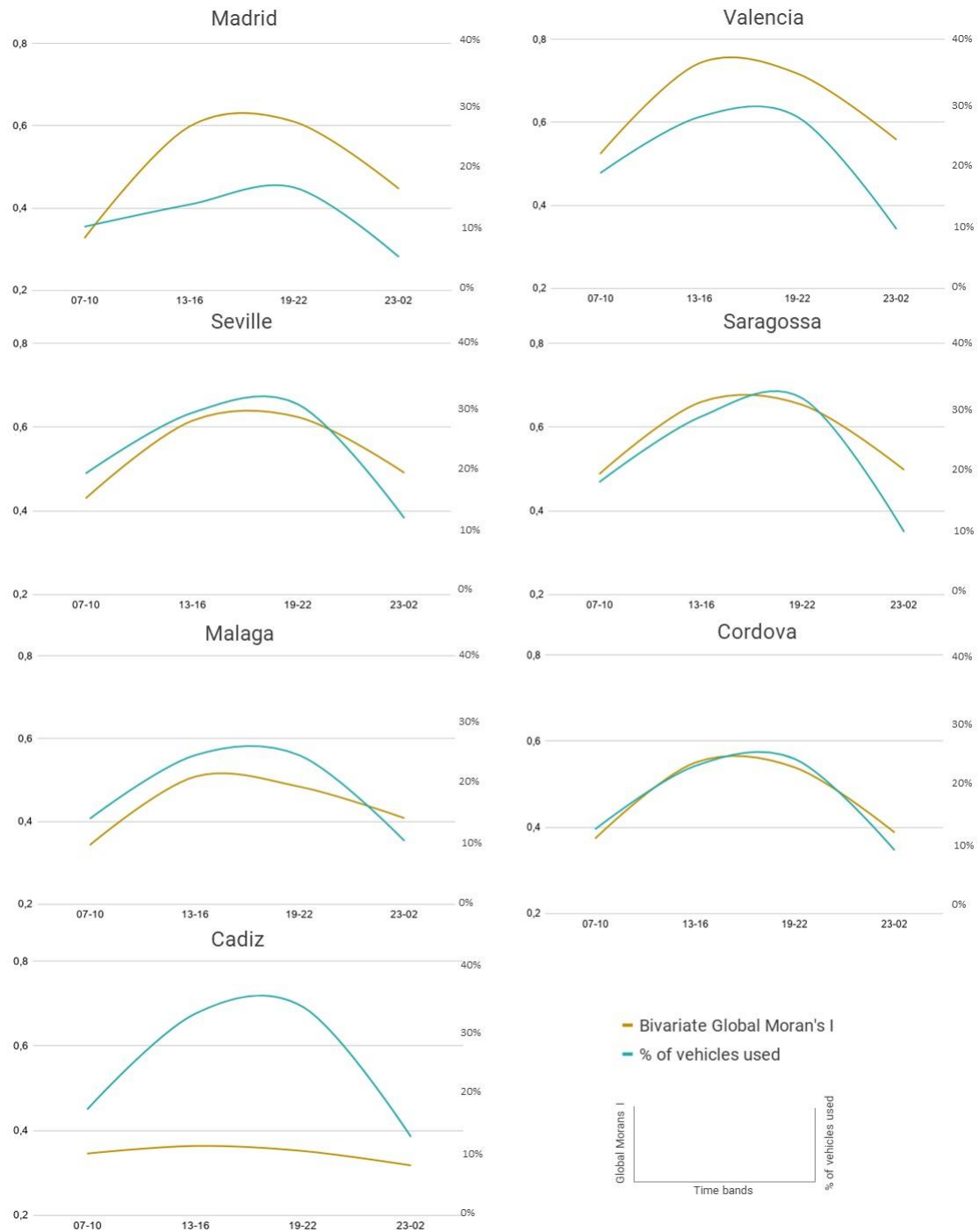
Source: own elaboration.

6.4.6. Relationship between spatial patterns and number of vehicles used

To explore the possible relationship between potential vehicle rotation and the number of vehicles used, we graphed the bivariate Global Moran's I results with the percentage of vehicles used by time band on working days (see Figure 6.11). A clear relationship was revealed, as the resulting curves tend to follow a similar pattern throughout the day for all the cities. Nevertheless, all the cities show a peak in the percentage of vehicles used around band 3 (19-22 hrs), while the peak for the bivariate results is in band 2 (13-16 hrs). Consequently, potential vehicle rotation could support and stimulate a higher number of trips, but not determine it. The number of trips would be the result of a high demand and high moped availability and proximity, increased when origins and destinations are closed to each other. Therefore, operators should foster this dynamic, especially in band 2 and 3. These differences between time bands are important when operators

need to know how many vehicles to deploy according to the day of the week. Hence, operators could adjust their logistics to respond to the different dynamics, which could reduce and optimise their distribution tasks.

Figure 6.11 Bivariate Moran vs. percentage of vehicles used (working days).



Source: own elaboration.

6.5. Conclusions

Based on GPS data collected, this study explored the different dynamics of a moped-style scooter sharing service in seven urban areas over the course of a day. The research provides valuable information regarding the temporal and spatial patterns of this scarcely studied micromobility service. More importantly, it proposes a useful methodology based on the use of ESDA tools to understand travel patterns, increasing our knowledge of where demand comes from, when the service's peaks and valleys take place, popular destinations, the extent to which the system is potentially self-balanced, and how this is related to the percentage of vehicles being used. Considering mopeds as subject of study, findings could be scalable to other micromobility services. All these are insights that contribute to making better decisions in the shared mobility sector.

A considerable number of users have subscribed to moped services and use this shared mode even across different cities, which is an interesting fact related to the introduction of new concepts like mobility as a service beyond the city scale. They ride mopeds mostly during warmer months in spring (May-June) and October when daily routines start. The dynamics revealed respond to certain patterns and variations that could be closely related to the existing land-use distribution in each city. In general, the spatiotemporal patterns identified correspond to what could be expected according to the conceptual framework initially outlined. We have learned that similarly to bicycles, mopeds are generally used for short urban trips (around 3,5 km). However, average speed is significantly higher for mopeds in comparison with cycling (14,3 kph in the case of bikeshare and 18,2 kph in the case of mopeds) (Romanillos & Gutiérrez, 2019). This fact makes this mode an attractive alternative, especially for cities like Madrid, which are not completely flat.

We have also demonstrated that time band 2 and 3 (13-16 and 19-22) are the most profitable hours for shared mopeds, as vehicle rotation (trip start and end locations are nearer) and the number of vehicles used are higher. Our methodology also allowed us to identify when demand is more clustered (HH clusters in the univariate analysis) and more self-balanced (HH clusters in the bivariate analysis), pointing to the most profitable areas within the cities, and other areas where demand is particularly low (LL clusters) or not self-balanced (HL outliers). The assessment of both, the location of demand hubs, and the extent to which the system can balance itself, are important aspects to consider when planning and managing these micromobility services. Some of the results of the study, are probably harder to observe or anticipate by shared mopeds operators just from operational experience. For example, being able to analyse all the cities' dynamics simultaneously and identify their similarities/differences could help operators arrange homogenous strategies for similar dynamics, saving time and effort. The different travel patterns along the day also showed to be related with land use activities, which helps operators predict or anticipate demand hubs in new cities where they plan to operate. And last but not least, one of the most useful insights of the study regards the fact that band 2 and 3 are the most profitable hours of the service, as vehicle rotation is higher and vehicle distribution is less required, reducing operative costs. Additionally, we have found that for some cities (e.g. Valencia and Malaga), the highest vehicle supply is used at a time band when vehicle rotation is not necessarily in its highest peak. This knowledge could help operators increase their vehicle supply at the exact time band when vehicle rotation is in its highest peak, which consequently could lead to increased profits.

Our exploration results are useful for operators and authorities to make better decisions related to shared mobility services, especially in the post-pandemic era, when most of them are experiencing a worldwide boom (Ardila-Gomez, 2020; Harrabin, 2020). As a clean alternative to cars, knowing where moped trips mostly start and end could have an impact on the infrastructure offered to improve the service and promote intermodality with mass transit. Our study also demonstrated the importance of analysing and representing the dynamics of mopeds over time and illustrating

activity during working days and weekends, which provides relevant knowledge when promoting policies or measures for specific periods of time. Policy recommendations include the allocation of parking infrastructure as mentioned by (Pérez-Fernández & García-Palomares, 2021) or the establishment of partnerships between the City and micromobility operators to promote and include shared mobility in regional/local plans as mentioned by (Shaheen et al., 2016, 2020). As recommendations for operators, we could point briefly at two: 1) collecting track-related data which will make possible to obtain insightful knowledge about mopeds' routes, and 2) tagging redistribution trips (made by operators for vehicle redistribution) as the approach used in this work was overly conservative likely erroneously removing actual trips from analysis in order to not include redistribution trips. This was an unfortunate necessity which could be rectified by the data providers tagging trips as either user trips, or administrative trips.

The fact that our methodology was tried in different cities allowed for comparisons and demonstrated that our methods are replicable. As main limitation of the study, we can point out to the fact that the dataset used was provided by one of the many moped-style scooter-sharing operators. Hence, it is important to consider that, while the sample is absolutely representative in small- and medium-sized cities where no other companies besides Muving operate (we have all records), this is not the case for Madrid, Valencia, Seville, and Saragossa, which have more than one moped operator. In these cities, results must be carefully interpreted, as we are not covering the entire available moped fleet. For example, when considering Madrid, Muving represented 14% of the available moped fleet during 2019, thus the presence of other companies would vary the vehicle density in some areas, which could have an impact that we are not yet able to identify. Nevertheless, the dataset allowed us to glean more meaningful insights into a sharing sector that has not been exhaustively studied. Future studies could complement our study by applying the same methodology to analyse all moped-sharing services in cities with more than one operator, and even by considering other shared services (like bike-sharing and scooter-sharing), in order to holistically comprehend what basically conforms the interconnected Mobility as a Service network. Future research lines could also focus on monitoring travel behaviour in the coming months and even years, monitoring and visualising the impact of the COVID-19 pandemic on the use of this and other shared modes.

7. Identifying spatiotemporal clusters of micromobility

7.1. Introduction

The introduction of the sharing economy has impacted many economic sectors, including transportation. New services, like micromobility, are offered each day and users have access to multiple transport options, radically changing their travel behaviour (Jiao & Bai, 2020). Micromobility has been defined as the short-term access to low-speed shared vehicles, according to the user's needs and convenience, instead of requiring vehicle ownership (Lazarus et al., 2020; Shaheen & Cohen, 2019). In the past decade, micromobility services have gained attention as they are changing urban mobility dynamics by offering a flexible transport option capable of avoiding road congestion, reducing the required parking space, and lowering noise/air pollution, since all vehicles are hybrid electric/electric, and finally, encouraging intermodality with mass transit (Aguilera-García et al., 2020; Arias-Molinares, Romanillos, et al., 2021).

The growth of micromobility services is being enabled by the rapid development of information and communication technologies (ICTs), along with the improved Geographical Information Systems (GIS), the emergence of new data sources and the advanced processing capabilities using programming. Individuals now move using the latest location-aware technology, which requires data that fits personal needs and thus, the elementary questions related to geospatial data such as “what?”, “where?” and “when?” are becoming incredibly relevant (Kraak, 2003). This technology generates a huge amount of data, with high spatio-temporal detail, all of which explains the revival and growing interest in Hägerstrand's Time Geography (Miller, 2005; Shen, Kwan, and Chai 2013).

The time-geographic framework proposed by (Hagerstrand, 1970) at the end of the sixties provided a useful means for exploring the spatio-temporal component of the human activity. However, when this model was introduced, the available data and the tools for its visualization and analysis were scarce. Therefore, despite the usefulness of Time Geography, only a few studies implemented its visualizations up to the mid-1990s (Kwan, 2004). Today's software's advanced capabilities and the increasing availability of geo-referenced data collected by global positioning systems (GPS) offer high spatio-temporal granularity which enables, more than ever before, the operationalization and implementation of time-geographic constructs in multiple research areas like crime, public health and traffic safety (M. R. Desjardins et al., 2020; Jing et al., 2020; Nakaya, 2010; L. Yang et al., 2017).

Transport planning is also one of the potential application fields for Time Geography (Miller, 2007). Studies related to the use of st-paths include (Frihida & Marceau, 2004; Shaw & Wang, 2000), that delved into the spatio-temporal characteristics of travel patterns or (Kapler & Wright, 2005; Kraak & He, 2009) that included novelties in annotations and the incorporation of icons/images to describe the activities related to the movements. To explore and process large datasets, (Shaw et al. 2008) proposed a generalized method for st-paths to explore temporal changes among individuals. Other studies used prisms to understand space-time accessibilities and analyse complex activities (Huisman and Forer 1999 or 1998; Miller 1999; Dijst and Vidakovic 2000; O'sullivan et al. 2000; Hornsby and Egenhofer 2002; Timmermans, Arentze, and Joh 2002; Jacquez et al. 2005; Miller 2005; Ratcliffe 2006; Kuijpers and Othman 2009; Neutens 2010; Kuijpers et al. 2011).

All these previously mentioned studies applied Hagerstrand's concepts to their topics of interest, as they analysed *people's movements*. In this paper, we do not intend to strictly apply Time Geography, but rather depart from its tools and concepts, and use them to try to innovate and accomplish the task of visualizing massive micromobility data. Therefore, we continue the line of research set, for example, in (L. Yang et al., 2020) that proposed a space-time demand cube

framework to represent and capture the fine-grained spatio-temporal variations in bike demand using GPS records from a dockless bike-sharing operator in China. They used space-time cubes to aggregate trip origins which helped them to visualize and understand historical and dynamic bike demands. Another example is found in (Pereira et al., 2022), that took the space-time path idea and created a package called “{gtfs2gps}” which helps to easily process static GTFS and visualize trajectories of public transport vehicles at fine spatial and temporal resolutions. Instead of working with an individual’s path, they graphed bus routes. They understood the boarding/alighting of passengers as ‘fixed activities’ that occur at public transport stations. As a result, they obtained a graphic visualization of each route’s trip frequency in a 3D space-time aquarium with a sequence of space-time paths, one for each trip, stacked over time. On both studies, Time Geography represents the base from which they take off and delve into new ways of visualizing mobility data, which is the aim of this paper.

Using this approach, we try to address the need to understand the logic of space-time organizations and how it impacts micromobility’s operational tasks, as well as the opportunity to analyse demand patterns with more spatiotemporal detail. We can use space-time cubes (STC) to visualize and analyse the spatio-temporal distribution of micromobility supply and, consequently, its impact on the urban landscape and the new challenges it generates (parking space needed and conflicts with pedestrians, competition with other modes, etc.). Additionally, we can investigate the spatio-temporal capability constraints between supply (distribution of vehicles) and demand (through land uses).

Hence, our study aims at contributing to the literature that explores micromobility spatio-temporal travel patterns using GPS records and space-time cubes. More specifically, using GPS origin point records from three different shared modes (bikes, mopeds and scooters), we intend to identify the most important hot spot areas, analyse trip generations according to the time of the day and finally, be able to identify different types of areas (location clusters) that share a similar behaviour in space and time in terms of micromobility departures. We believe that these types of studies are necessary and more feasible nowadays with the new available sources of massive data, that are allowing researchers to go beyond what has been done traditionally, and rather innovating in new approaches to address mobility issues. Transport authorities and micromobility operators could feed their decision-making processes with insights obtained from understanding spatio-temporal patterns from a space-time perspective. The rest of the article is structured in four sections. Section 2 summarizes related literature, while Section 3 introduces the study case, data and methods used, following Section 4 with results and lastly Section 5 offers discussion and conclusions.

7.2. Background

7.2.1. Research on micromobility’s spatio-temporal patterns

In the last decade, there has been a growing body of literature related to studying spatio-temporal travel patterns for shared mobility and micromobility services, especially bike-sharing programs as they were the first schemes deployed. For example, (Corcoran et al., 2014) used GPS data and explored the effects of weather and calendar events on spatio-temporal patterns of bike-sharing using multivariate regression models. Another similar study conducted by (Purnama, 2018) also analysed GPS records from the public bike-sharing system in London and New York and use the Pearson’s correlation coefficient to observe the correlation of external factors with the daily usage. Similarly, (Nickkar et al., 2019) used GPS records to study the influence of socio-demographic factors on travel patterns in Baltimore and evaluated the relationship between gender and land use in terms of the trip’s origin and destination locations by using statistical analysis.

More recently, with the introduction of new micromobility modes like mopeds and scooters, more studies have become available regarding comparative analyses between existing bike-sharing schemes and moped-style or scooter-sharing ones. One of these studies, conducted by (Zhu et al.,

2020) compared dockless bike-sharing and station-based scooter-sharing services using GPS records (for bikes) and a scraping tool (for scooters) to estimate redistribution trips and fleet sizes as well as other descriptive characteristics that help understand the heterogeneity of the two services. Moreover, (Younes et al., 2020) used open-access Application Programming Interfaces (APIs) for six dockless scooter-sharing services and historical trip data for the city's public bike-sharing service (Capital Bikeshare, Washington DC) to estimate two variables: hourly number of trips and hourly median duration of trips. This estimation was based on a negative-binomial regression model including environmental and economic variables such as weather-related data, gasoline prices, local events or disturbances, day of the week, and time of day. Regarding moped-style scooter-sharing services (also known as moto-sharing), four recent studies are found. One of them by (Pérez-Fernández & García-Palomares, 2021) that used GPS datasets and proposed a methodology to locate parking places based on the varying distribution of demand over the day. (Jiao & Bai, 2020) applied univariate LISA to identify areas of high demand (hot spots) in the use of shared e-scooters, as a preliminary step before applying regression models. Moreover, (Arias-Molinares, Romanillos, et al., 2021) also used mopeds' trip data to analyse locational patterns over time and assess how the different factors influenced its usage level and self-balance potential using Exploratory Spatial Data Analysis (ESDA) tools. And lastly, (Bach et al., 2023) examined the determinants of the spatial coverage of four moped-style scooter sharing services in Barcelona. Their results suggest that territorial coverage is defined by centrality, household disposable income, and topography, with low-accessibility areas consistently omitted from services. Based on previous literature, our main contribution is the comparison of spatio-temporal patterns of three different micromobility modes simultaneously (docked bikes and dockless scooters and mopeds). These analyses offer useful insights into similarities and differences in the usage patterns of these systems across different parts of Madrid, over different hours of the day, according to weekdays and weekends, and how they relate to land use.

7.2.2. Building upon the ideas of Time Geography to create new ways of visualizing micromobility data

We link Time Geography and micromobility data with the offer of a potential tool for processing and visualizing massive amounts of data, especially GPS records. As stated by (Pereira et al., 2022), space-time cubes make it possible to visualize and explore mobility data in ways that they were not easily done before. We depart from the fact that micromobility services are filling the gap or being breach modes between walking and motorized transport alternatives. With shared services, users have now the alternative to not walk and neither use a motorized transport, but rather use an eco-friendly option like a bike, moped or scooter that has no CO2 emissions and allows faster speeds (with respect to walking). But for a micromobility trip to even occur, an individual has to both, be located inside a service area and also find an available shared vehicle. Therefore, we focus on the *access to these shared services* which are represented by the occurrence of a *trip departure*, which are the places where these two conditions were fulfilled. By aggregating trip origins into space-time cubes, we visualize the access locations to shared services and its spatio-temporal patterns over time. Based on the notion of stationary activities, trip departures constitute the locations where an individual spent some time in order to locate, reserve and initiate a shared mobility trip. These departures are also sparsely distributed in space and time, where the fleet is available, being also related to the service's constraints. Thus, micromobility could be perceived as a subject to authority restrictions as each service have specific areas of coverage (service geo-fence). Its capacity as a mobility service is limited by the number of vehicles (fleet size), the distance that can be travelled (mostly short trips), and its geographical distribution throughout the day. Finally, the system's success depends on the coupling of the vehicles' location and its demand, and thus, the redistribution of vehicles becomes one of the most fundamental elements to consider.

Continuing with this line of research, we intend to explore how spatio-temporal dynamics change over a day (hourly), according to different types of days (weekdays and weekends), and how these

dynamics are linked to land uses. Additionally, we will conduct these analyses not only regarding bikes but also other micromobility services like shared mopeds and scooters so that comparisons are allowed. We believe space-time cubes are a useful tool to study aggregated micromobility patterns because it offers a better overall understanding of the spatio-temporal patterns in large datasets, enabling researchers to quickly identify the most relevant changes in dynamics along space and time, which becomes a harder task to do by only using traditional 2D maps.

7.3. Data and methods

As was mentioned previously, collaboration agreements were established with the companies named “Movo” (mopeds + scooters) and “Muving” (mopeds). In the case of “BiciMAD” (bikes), this was not necessary because they publicly share their data on their website. We obtained datasets for Movo and Muving covering the months from the last semester of 2019 (from June to December), thus the same period was downloaded for BiciMAD to cover the same timeframe for all the services evaluated.

- BiciMAD: data was extracted from the website: [https://opendata.emtmadrid.es/Datos-estaticos/Datos-generales-\(1\)](https://opendata.emtmadrid.es/Datos-estaticos/Datos-generales-(1)). They monthly upload datasets (in JSON format). BiciMAD datasets offer the origin location (point with XY coordinates) of each trip and the exact time when it started (timestamp). It also offers information on trip time (seconds). Only BiciMAD separates those origins of administrative trips (redistribution of vehicles) which is highly useful to filter data.
- Movo: the company provided us with a dataset (in JSON format). Movo datasets offer information of the original location (point with XY coordinates) of each trip, the time when it started (timestamp), and the vehicle type (moped/scooter). It also offers information on trip time (seconds).
- Muving: the company provided us with a dataset (in CSV format). Muving datasets offer information of the original location (point with XY coordinates) of each trip and the time when it started (timestamp). It also has information on the trip time (minutes) and distance (km).
- Land use data and transport zone data: to perform certain spatial analyses, we use land use data provided by the Directorate-General for Cadastre in Spain (Cadastre), by a built entity of the study area. The databases define the surface area [m²] of each type of land use. These data are updated every 6 months and the data set used corresponds to the update of January 24, 2020.

The data processing workflow covered entering, cleaning, transforming, and outputting the final valid datasets (using Python vs. 3.8). For all the datasets, the initial cleaning process involved eliminating those observations (origin points) with trip distance or time equal to zero (erratic data). A second cleaning stage consisted of filtering datasets by making certain assumptions, such as not considering the origins of trips that lasted over a certain time or cover large distances (as seen in the filtering criterion in Table 7-1Table 7-1). This was necessary to eliminate unrealistically long-distance trips (probably GPS errors) and redistribution trips (as only BiciMAD tagged them). Thus, we cleaned BiciMAD and Movo datasets by trip time and in the case of Muving, we cleaned the dataset by both trip time and distance.

Table 7-1 Filtering criterion for the second stage of dataset cleaning.

Variable	Min value	Max value	Filtering criterion
Time	60 seconds	2 hours	- Min value: trip duration longer than one minute was kept in our study dataset (McKenzie, 2019b). Trips with a duration less than 60 seconds are probably cases of users that had problems with the vehicle/app. - Max value: two hours is the maximum battery life of an electric vehicle given continuous movement. Any trip lasting longer than two hours implies that the vehicle was offline for some period (i.e, recharging or in a truck for relocation).
Distance	100 meters	70 km	- Min value: only those trips with a road network distance greater than 100 meters were kept (McKenzie, 2019b). - Max value: mostly, micromobility vehicles' autonomy is 70km.

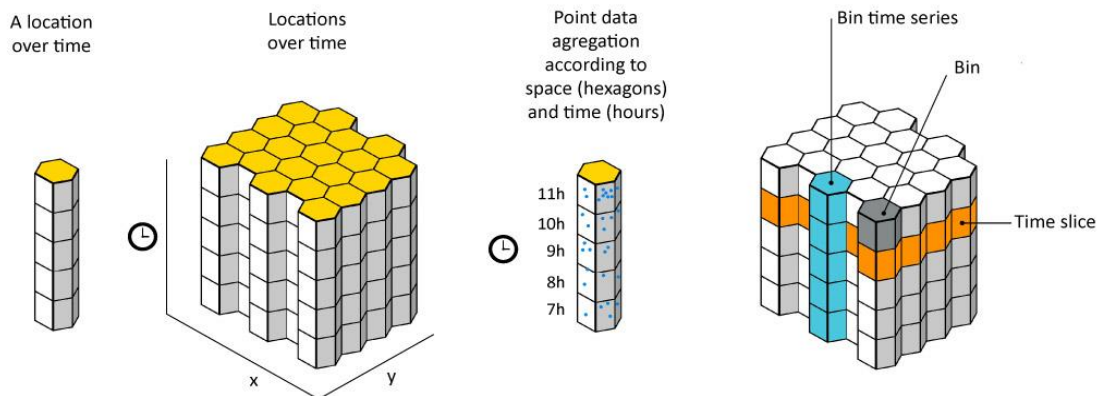
Source: own elaboration.

After obtaining the cleaned datasets for all services (bikes, mopeds and scooters), we decided to separate the databases according to different scenarios based on the day of the week: weekdays (from Mondays to Fridays) and weekends (Saturdays and Sundays). We also determined to work with the count of origin points for an average day. Therefore, we divided the weekdays databases by 120 (5 days * 4 weeks * 6 months = 120 weekdays in six months) and the weekends databases by 48 (2 days * 4 weeks * 6 months = 48 weekends in the same period).

7.3.1. Understanding spatiotemporal travel patterns

Once our cleaned and averaged datasets were obtained, we visualise and analyse origins (departures) using STC. Geography was represented according to a hexagonal grid (with a centroid-to-centroid distance equal to 250m that covers the study area, while the height was representing each hour of the day. A 250m-sided hexagonal grid was determined based on similar research as this size ensures that each cell contains several city blocks (Degele et al., 2018; García-Palomares et al., 2015; McKenzie, 2019b; Mckenzie, 2019; Megler et al., 2014). Following this scheme (see Figure 7.1), when creating the STCs, we aggregate each origin (departure point) to the correspondent bin (hexagons and hour) when the trip was initiated. STCs were then created for weekdays and weekends. This step results in the creation of six cubes: bikes-weekdays, bikes-weekends, mopeds-weekdays, mopeds-weekends, scooters-weekdays and scooters-weekends, which are the input layers for the rest of the analyses, performed with ArcGIS Pro vs. 2.8.3.

Figure 7.1 Space-time cube models' scheme



Source: own elaboration.

With the STCs created, the first analysis intends to capture micromobility's different dynamics with two complemental visualisations: daily (2D maps) and hourly (3d maps) behaviour. For 2D visualisations, we make a map representing the total amount of departures (origin points) by hexagon according to the day of the week and mode. In the case of 3D visualisations, two STCs are created. The first one, shows hourly departures (origin points) hourly, while the other represents the hot and cold spot analyses hourly, using Getis-Ord's index (Gi). This statistic

measures the degree of clustering for either high or low values. The resultant z-scores and p-values report where features (in this case hexagons) with either high or low values are clustering spatially. This method analyses each feature within the context of neighbouring features, for which we determined a 500m distance band, as it will include all the neighbours surrounding each hexagonal cell and based on similar previous research (García-Palomares et al., 2015). For both 3D visualisations, and due to space reasons, we determined to show results at certain relevant hours (instead of all hours), which helped to understand and highlight important dynamics throughout the day: 00 hrs (majority of people at home or nightlife activities), 08 hrs (rush peak AM hour), 14 hrs (lunch and midday activities) and 19 hrs (rush peak PM hour and nightlife activities). Finally, the results of Hot Spot Analysis by each hour are summarised in a 2D map that represents the percentage of times that each hexagon was a hot spot throughout the day.

7.3.2. Identifying locations that share similar travel behaviour

The second analysis intends to identify and group locations that shared similar space-time behaviour in terms of micromobility's departures. This helps to categorise types of spaces obtaining what we called "location profile-time clusters". To this end, we used Time Series Clustering, which is the process of partitioning a time-series dataset into a certain number of clusters, according to a certain similarity criterion (X. Huang et al., 2020; Zhang et al., 2020). Clustering is a data mining technique in which similar data is placed into related/homogeneous groups without knowing the group's definition. More specifically, clusters are formed by grouping objects that have maximum similarity with other objects within the group and minimum similarity with objects outside the group (Aghabozorgi et al., 2015). A special type of clustering is time-series clustering. A sequence composed of a series of nominal symbols from a particular alphabet is usually called a temporal sequence, while a sequence of continuous, real-valued elements is known as a time series. A time series is dynamic because its feature values change as a function of time, which means that the value(s) of each point of a time series is/are one or more observations that are made chronologically. Hence, time series are a type of temporal data which is high dimensional and large in data size (Aghabozorgi et al., 2015; Keogh & Shrutli, 2003; Rani & Sikka, 2012; Warren-Liao, 2005). The Time Series Clustering method identifies the locations in a space-time cube that are most similar and partitions them into distinct clusters in which members of each cluster have similar time series characteristics. These techniques have been applied in several research (Y. Li & Xu, 2021; Mattera, 2022; J. Wang et al., 2021; K. Wang et al., 2021). Time series can be clustered, so they have similar values across time, stay in proportion across time, or display similar smooth periodic patterns across time. This latter one is the Profile (Fourier) type, and it is used to cluster time series that have similar smooth, periodic patterns in their values across time. These periods are sometimes called cycles or seasons, and they represent the durations of a single pattern that then repeats in a new period. As micromobility services follow repetitive seasonal trends, we determined to use this approach.

7.3.3. Analysis of coupling constraints between profile-time clusters and land use

The cluster results finally help us to explore the relationship between the types of locations (profile-time clusters) and land use. To that end, we first identify the predominant land use in each hexagon in Madrid. The predominant land use was then grouped into three generic land uses, according to cadastral data: residential (when more than 66.6% of built-up area in the zone is residential), activity (when more than the 66.6 % is non-residential, i.e., offices, industry, retail or education) and mixed residential (all other cases). Finally, the spatial intersection of the resulted types of locations with this generic land use information enabled us to obtain the number

of hexagons that represent a certain type of profile-time cluster and that are located at certain land use. This analysis resulted in a summary table indicating the percentage of hexagons for each type of land use according to clusters.

7.4. Results

7.4.1. General patterns

Table 7-2 summarises the main characteristics of the datasets analysed. As it can be seen, bikes are the most important shared mode with the highest departures (origin points). To grasp bikes' importance, we can state that for every person that took a moped or scooter to travel during weekdays in 2019, there were approximately 4 and 24 people respectively, taking a bike. For weekends, however, the difference is slightly reduced as for every person taking a moped or scooter, approximately 3 and 18 people were taking a bike respectively. When identifying the days of the week with the highest departure counts, bikes are mostly used on Tuesdays while the dockless modes are mostly used towards the weekends on Thursdays (in the case of scooters) and Fridays (for mopeds). Preferred hours are also different for station-based and dockless services as BiciMAD's peak hour is at 17hrs while in the case of both dockless services, peaks are shown at 19hrs. These preferred days and hours for the different services could suggest that station-based bikes are mostly being used for commuting or conducting routinary activities as their *prime time* is when the week starts and especially in the PM rush hour when people usually are returning home, while the dockless services could be more related to other leisure/recreational activities, which supports what has been found in similar research (Ji et al., 2020; McKenzie, 2019; McKenzie, 2019b).

When analysing the weekend behaviour, we observe that for all the three modes, the highest departure counts are found on Saturdays and bikes and mopeds are preferred for an hour later (18 and 20 hrs respectively) while scooters' preference is maintained at 19hrs. Hence, we can infer that scooters' behaviour is very similar disregarding the day of the week, while bikes and mopeds vary from weekdays to weekends. This is also noticeable when analysing the coefficients of variation which describe how the services behave during the day, showing a more stable pattern for BiciMAD against a more unstable pattern shown for mopeds and scooters. Interestingly, the coefficient of variation in the three modes is lower for weekends, meaning that they behave with fewer variations along these days.

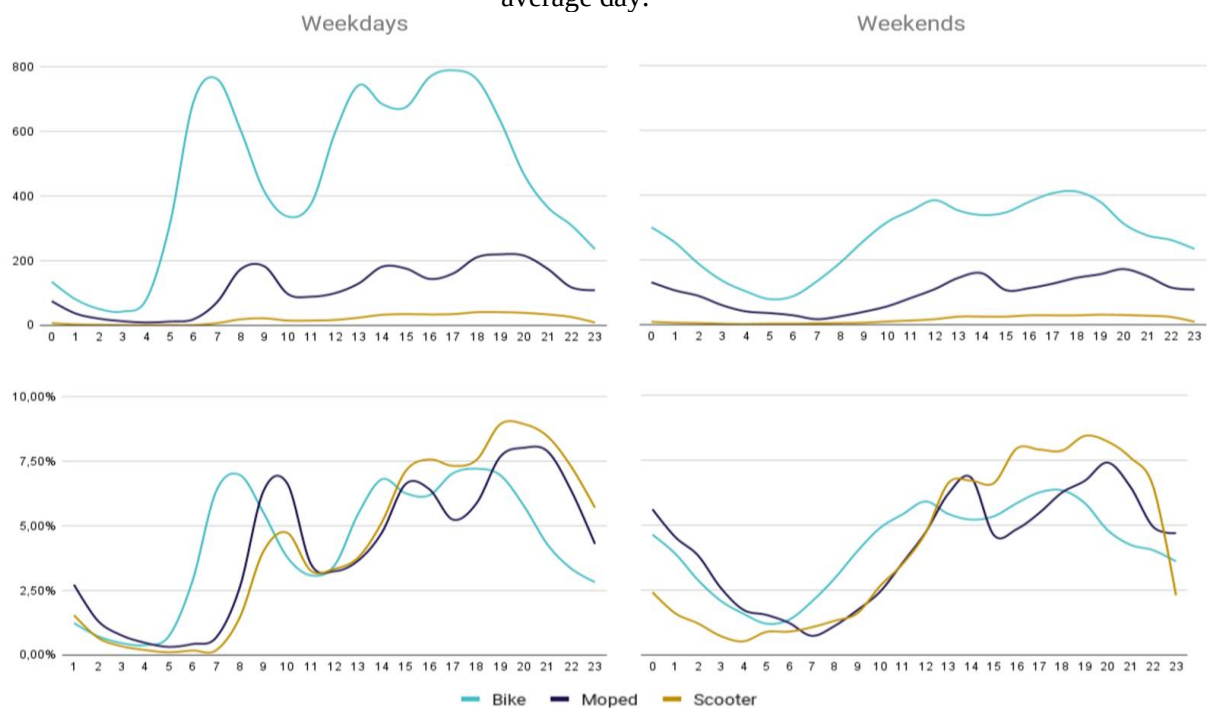
Table 7-2 Descriptive characteristics of the datasets analysed for micromobility services

	Characteristic	Bikes	Mopeds	Scooters
Weekdays	Total departures	1.311.372	329.094	55.242
	Departures on an average day	10.928	2.742	460
	Departures in peak day of week	274.499 (Tuesday)	71.729 (Friday)	11.733 (Thursday)
	Departures in peak hour	94.740 (17 hrs)	26.410 (19 hrs)	4.944 (19 hrs)
	Average departures by hour	455	114	19
	Standard Deviation	260	71	15
	Coefficient of variation	57	62	79
	Max	790	220	41
	Min	43	9	1
Weekends	Total departures	311.589	111.427	17.746
	Departures on an average day	6.491	2.321	370
	Departures in peak day of week	167.337 (Saturday)	60.899 (Saturday)	9.356 (Saturday)
	Departures in peak hour	19.784 (18 hrs)	8.270 (20 hrs)	1.500 (19 hrs)
	Average departures by hour	271	97	15
	Standard Deviation	105	48	11
	Coefficient of variation	39	49	73
	Max	412	172	31
	Min	79	17	2

Source: own elaboration.

Figure 7.2 represents the absolute and percentual distribution of departures along the course of an average day. During weekdays, the three modes show three peaks associated with AM and PM rush hours and lunch or midday activities. However, some differences are noticed. The first one is that bikes are seen to be used in earlier hours (at 07, 13 and 17 hrs) compared to dockless services (at 09, 14-15 and 18-19 hrs). Secondly, bikes are used in the morning almost in the same way as they are used in the afternoon, which supports that the service has a more homogenous trip distribution about dockless services. Dockless services' departures increase towards the afternoon (especially scooters) showing a more unbalanced usage throughout the day. In the case of weekends, the AM rush hour peak disappears, and origins trips increase towards the afternoon in all modes, especially scooters and mopeds from 19 to 20 hrs. A new peak is seen though for all three modes in the early morning hours from 00 to 01 hrs, which is closely related to nightlife activities during weekends.

Figure 7.2 Absolute (top) and percentual (bottom) distribution of departures by mode over an average day.



Source: own elaboration.

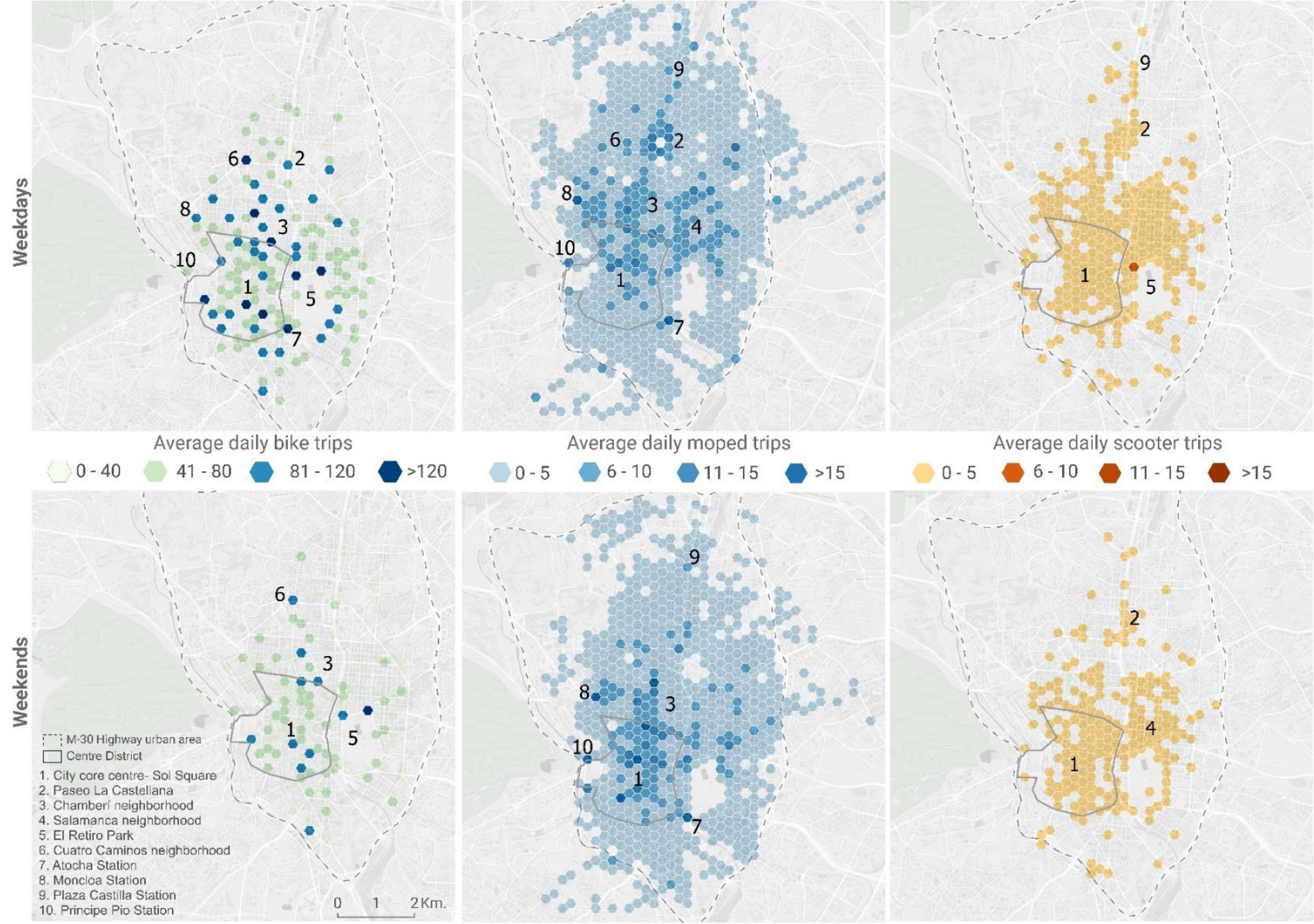
Figure 7.3 shows the daily behaviour for departures (total count of origin points) by mode and according to the day of the week. The first noticeable difference is how each service's departures behave spatially. With bikes being a station-based model, they show a higher scale (ranging from cells that have from 8 to 215 departures on an average day) which means a more intense usage of space as all origin points are aggregated only in those hexagons where bike stations fall at. On the contrary, dockless services allow users to start their trip at any location within the service's geo-fence, which causes a more dispersed usage of space as origin points are aggregated in more cells (ranging from 1 to 22 departures on an average day).

Moreover, the map yields the important differences between weekdays and weekends. During weekdays, trip departures cover a more extensive area, although none of them, except mopeds, extends beyond the M-30 highway urban area (central area of the city). When comparing both scenarios (weekdays and weekends), we see more trips starting from high employment areas of the city during weekdays (i.e., the north-south axe of Paseo la Castellana), as was also found in (Forest, 2019; Lazarus et al., 2020). During weekends, however, these work-related activity areas are mostly turned off in terms of micromobility trip departures and they rather tend to be more

concentrated around the city core centre, especially, in the case of bikes. With most users not having to work or conduct routinary activities, weekends' behaviour is more active at the city core centre where most of the recreational/leisure/commercial areas are located as well as the most touristic and visited areas, also similar to findings in (McKenzie, 2019b; L. Yang et al., 2020).

In general, departures for the three modes seem to be quite related to transport infrastructure and this relationship is maintained on both, weekdays, and weekends. Transport intermodal stations are very attractive and could be considered relevant infrastructures in terms of micromobility services, supporting findings from (Duran-Rodas et al., 2019a; Romanillos, 2018; Teixeira & Lopes, 2020). Central districts show to be important no matter the day of the week for both dockless services. These areas of the city concentrate on mixed-residential land use that hold a varied offer of activities throughout the day and throughout the whole week. While, in the case of bikes, a close relationship between the spatial distribution of departures with the location of cycling infrastructure (i.e., segregated cycling lanes) can be observed, supporting what was also found by (Romanillos et al., 2018; Talavera-García & Pérez-Campaña, 2021).

Figure 7.3 Daily departures by mode and according to the day of the week



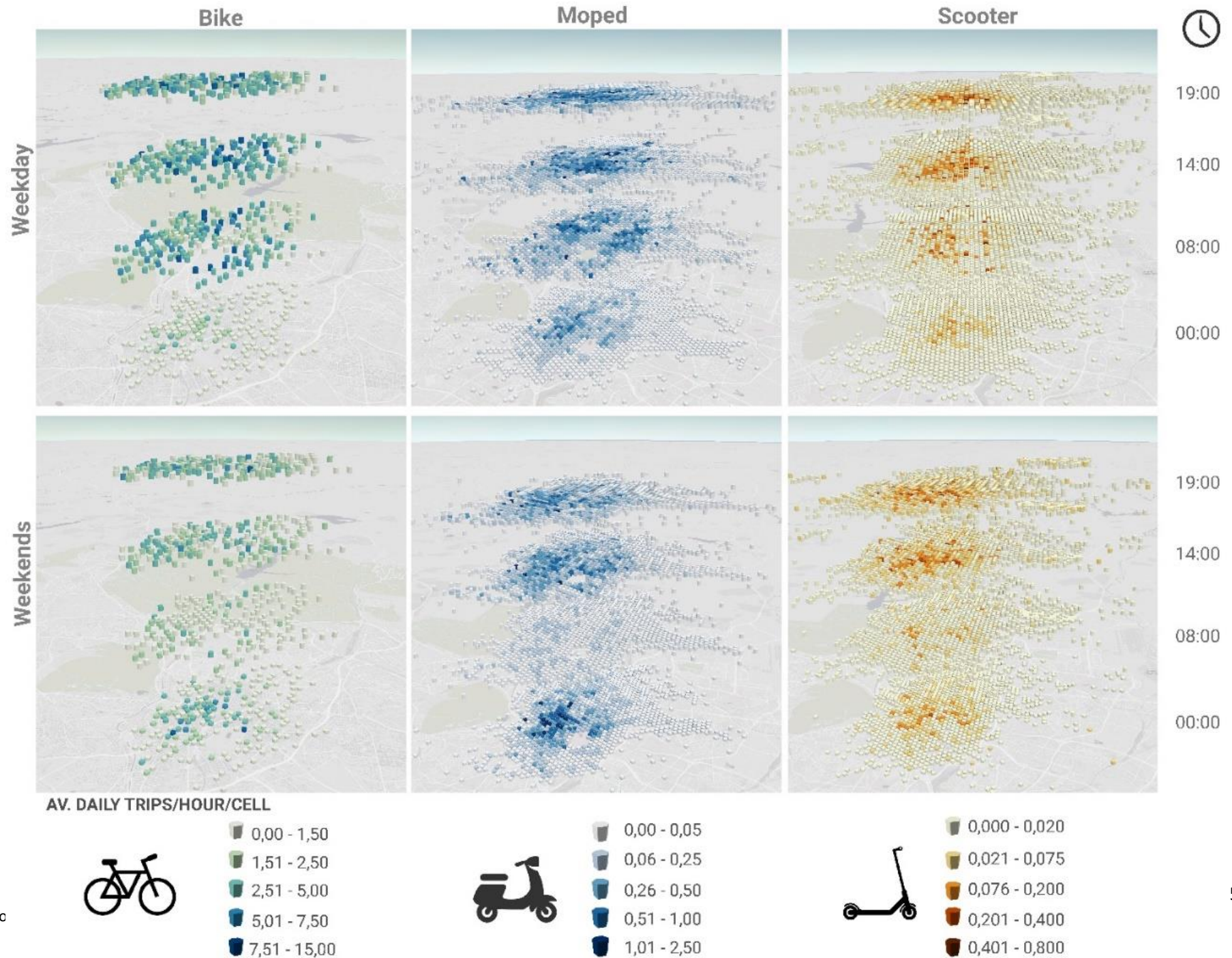
Source: own elaboration.

7.4.2. Understanding spatiotemporal patterns

We take the advantage of STC constructs and visualise how departures distribute across space and along different hours of the day, which enables a better understanding of urban dynamics in a more granular manner (see Figure 7.4). Results clearly illustrate some important differences between weekdays and weekends dynamics. For all three modes, there are two main differences. The first one related to routinary activities (work/education or other) that take place during the morning rush hours, as at 08:00 hrs on weekends, trips drastically decrease (most people are free from routinary activities), while at this same time on weekdays, many trips are starting, and especially coming from residential zones. The second difference is related to nightlife activities that take place mostly during late night and early hours, as we can see the trips at 00:00 hrs considerable higher in weekends and mostly starting from locations at the city core centre where most entertainment places are concentrated.

From space-time cubes, we can also infer that afternoon hour (from lunch on) are the most profitable ones for micromobility operators, as departures are maintained in high counts no matter the scenario (weekday or weekend) and they seem to be better distributed around the city urban area (greater coverage). In the case of weekdays, we can see the relevance that holds some of the most important office/workplace areas of Madrid where a high number of departures are observed around 14:00 hrs (lunch) and 19:00 hrs (return to home).

Figure 7.4 Spatiotemporal distribution of micromobility departures on an average day.

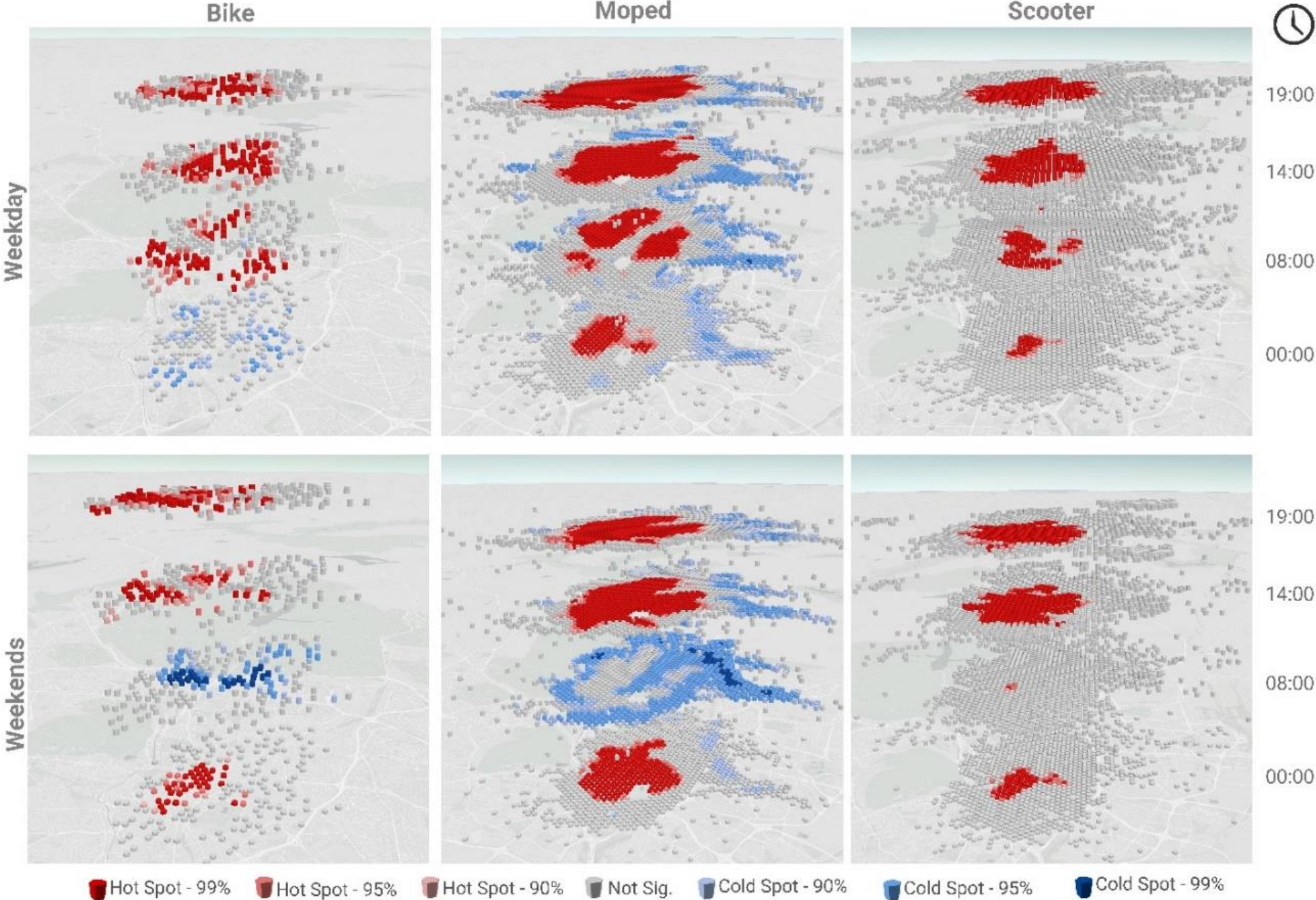


Source: own elaboration.

Hot and cold spot results support and emphasise the previous findings (see Figure 7.5). There are few hot spots at 08:00 hrs on weekends and few hot spots at 00:00 hrs on weekdays. Additionally, from the hot spots results, we infer that afternoon hours are the most profitable time of the day, as they cover a greater surface in the city, disregarding the day of the week, even though they still tend to concentrate more on the city core centre on weekends. These findings support what was also found in (Arias-Molinares, Julio, et al., 2021). Therefore, hot spot areas represent the places of the city that have greater vitality and attractiveness in terms of micromobility departures, maintaining high counts throughout the day and not just specific hours which benefits operators as they do not need to redistribute as many vehicles. As we have seen, using STC visualisation methods brings a new perspective to GPS data, as they complement what 2D maps are not able to capture, which is a more granular (hourly) analysis of differences/similarities.

Figure 7.6 shows the percentage of times that each location (hexagon) is a hot spot (with a p-value 0,05) which enables us to quickly identify the most important areas of the city regarding micromobility departures (origin points). The general pattern shows that trips start from a more extensive area during weekdays, covering those areas with a high concentration of workplaces/office sites. On the contrary, departures on weekends tend to be concentrated mainly around the city core centre for all three modes. Mopeds represent the mode with the highest hot-spot coverage area during weekdays and especially during weekends, which means its users are departing from many different locations of the city, while in the case of the other two modes (bikes and scooters), they tend to start their trips in more particular areas. Both maps allow the identification of the city core centre and its surroundings as areas with more vitality in terms of micromobility departures during weekdays and weekends. This is related to the fact that these areas hold great employment and residential zones, a consolidated public transport and cycling infrastructure as well as a varied offer of commercial and recreational activities supporting findings (Yan et al., 2021; H. Yang et al., 2021).

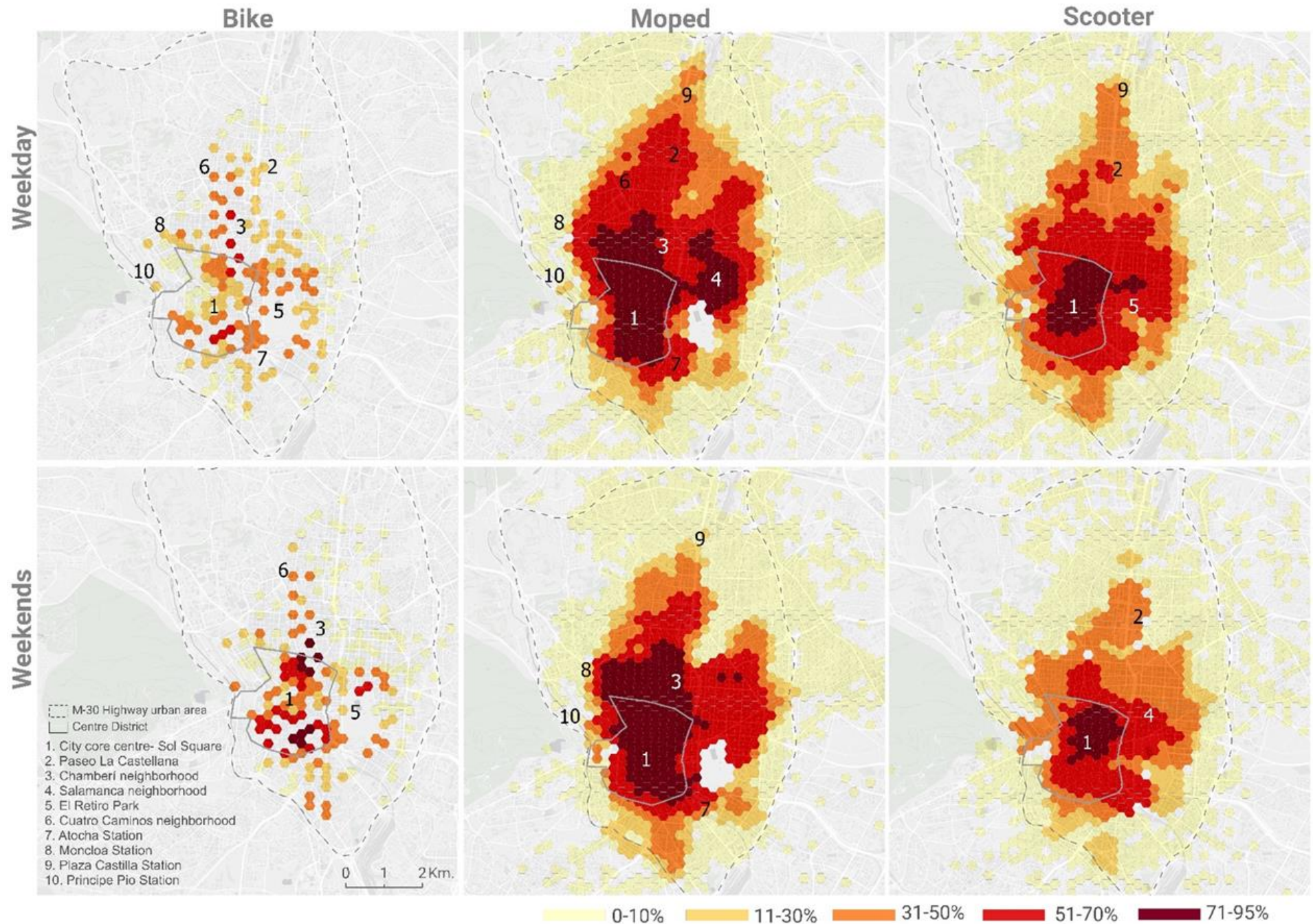
Figure 7.5 Hot and cold spots results across time



spatiotemporal analysis of micromobility services, placing bikesharing in context

Source: own elaboration.

Figure 7.6 Locations with the highest/lowest percentage of times being Hot Spots (p-value 0,05)



Source: own elaboration.

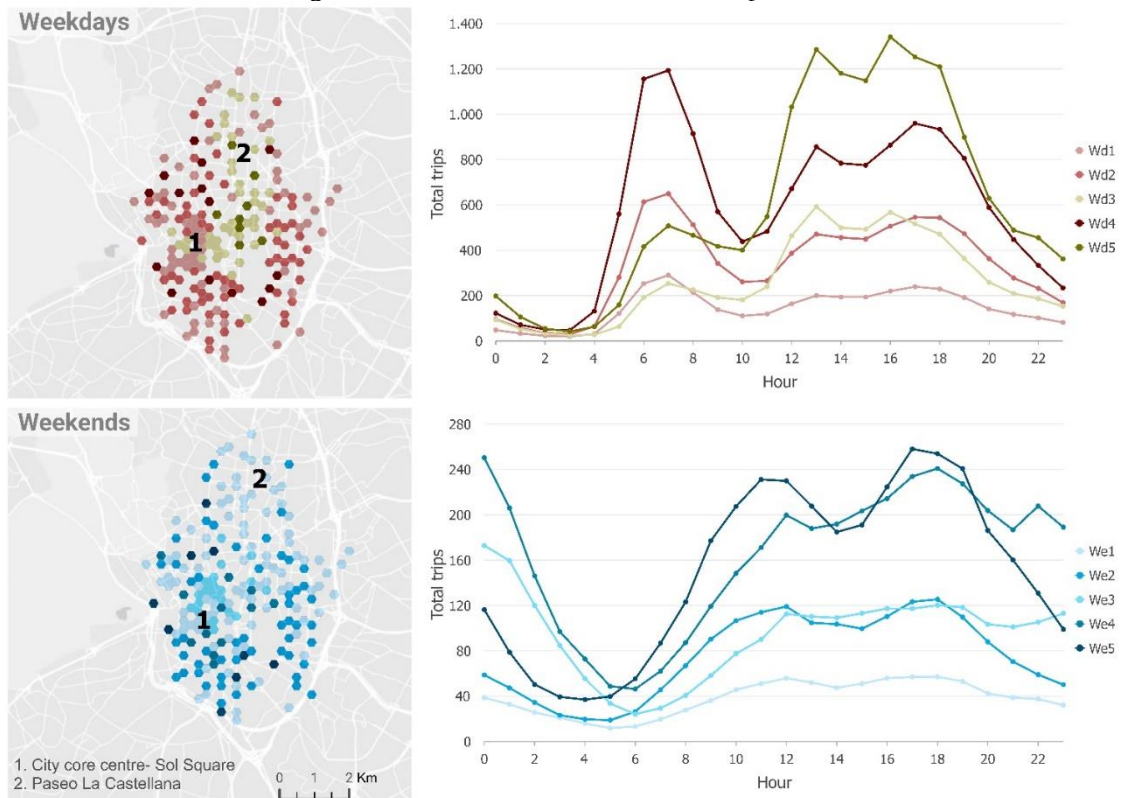
7.4.3. Identifying locations with similar profile time

Once we understand the different daily/hourly dynamics, we can furtherly identify and group types of locations that share a similar space-time behaviour regarding micromobility departures. The results of the Time Series Clustering analysis enable the identification of different clusters. Based on this method, and after different tests, our results show that the maximum dissimilarity between groups and maximin similarity within each group was obtained at five (5) clusters for each mode during weekdays and weekends (see Figure 7.7, Figure 7.8 and Figure 7.9).

The results obtained for the different clusters can be analysed in terms of intensity (departure counts) and temporal variations. On one hand, regarding intensity, we observe differences for both, weekday and weekend scenarios, as the types Wd4/Wd5 and We4/We5 show a more intense usage (“intensity types” with higher departure counts) than the rest of the clusters. On the other hand, in terms of temporal variations, differences are more noticeable in the weekday scenario, as some types show high departure counts in both morning and afternoon hours (i.e., Wd4, Wd2 and Wd1), while others increase only towards the afternoon (i.e., Wd3 and Wd5). In the case of weekends, all the clusters increase in departures in the afternoon hours, being more similar in terms of temporal patterns and only differentiating themselves by usage intensity.

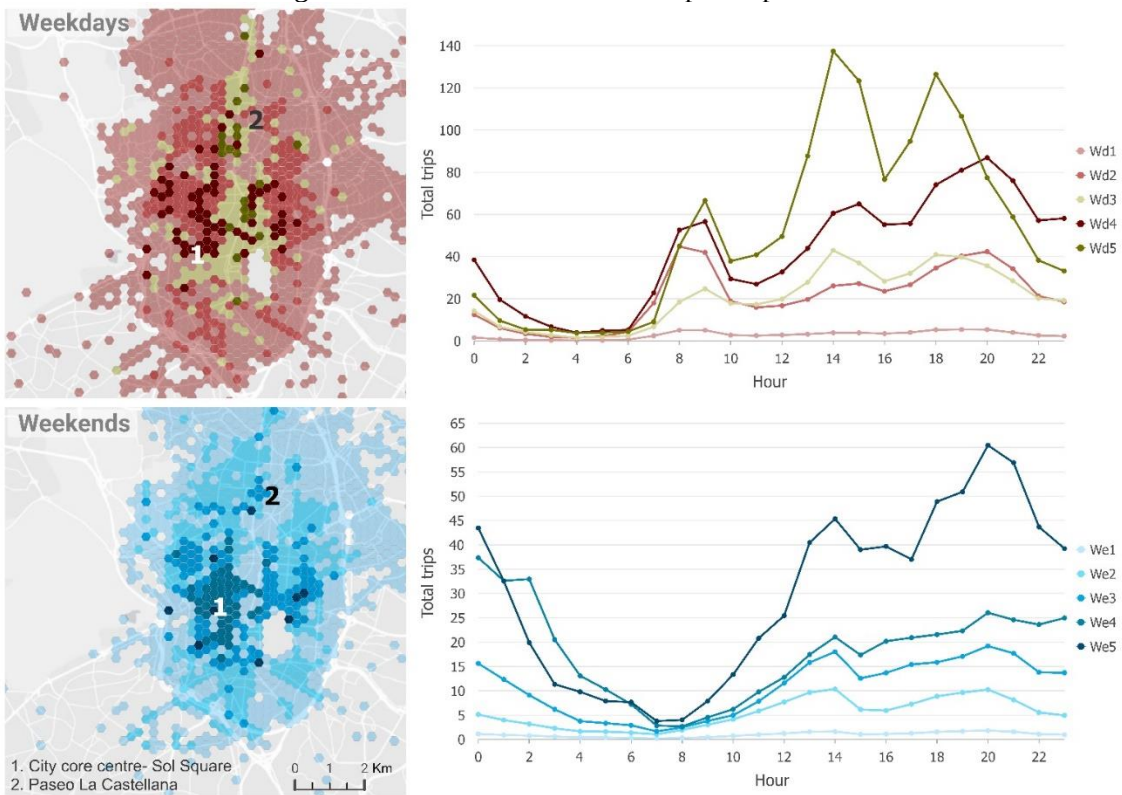
Moreover, the clusters’ spatial distribution shows some important findings. One of them regards the different dynamics of weekdays and weekends and the other highlights the different land uses that are more active at certain hours. Regarding the first difference, during weekends, most high-intensity clusters are mainly concentrated around the city core centre, except BiciMAD which seems to have a more homogeneously distributed pattern (in some cases related to transport intermodal stations). Regarding the second difference, results show for all three modes, a consistent tendency for weekdays. During morning hours, areas with high usage (departures) intensity are mostly residential zones (types Wd1 and Wd2), while during the afternoon hours, the most active areas are workplace/office sites (Wd3 and Wd5). Those areas that have intense activity from both, morning and afternoon hours (Wd4), are the most profitable for micromobility operators. In these hours, the system is balancing itself with high vehicle rotation, while other areas, that have activity only during certain periods, require more vehicle redistribution.

Figure 7.7 Location clusters for bike departures.



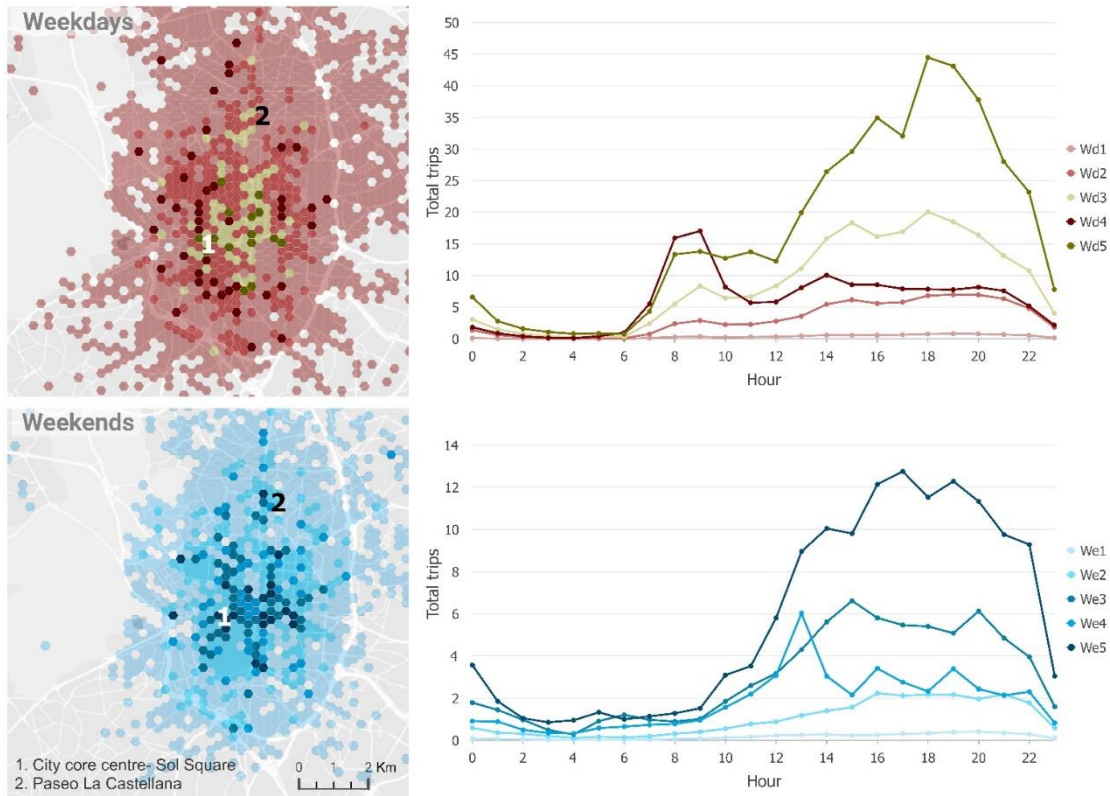
Source: own elaboration.

Figure 7.8 Location clusters for moped departures.



Source: own elaboration.

Figure 7.9 Location clusters for scooter departures.



Source: own elaboration.

7.4.4. Coupling between time profiles and land use

As we have seen in previous figures, the different types of locations seem to be related to the dynamics associated with land use activity. Therefore, we try to explore this relationship in more detail by overlaying land use with the resulted clusters for the weekday scenario (Table 7-3). In general, for all three modes, we can observe that residential and mixed-residential land use concentrate the highest percentages of clustered hexagons. Clusters Wd1 and Wd2 (low intensity and morning-afternoon peak) are mostly associated with departures from residential areas, with moderate usage intensity in departures for both, morning, and afternoon hours. Similarly, Wd3 (medium intensity), Wd4, and Wd5 (high intensity) are mainly located near mixed-residential land uses but show high usage intensity in departures for both morning and afternoon hours. Hence, we could infer that mixed-residential land use represents the most attractive areas for starting micromobility trips during the entire day.

On the other hand, some differences are noticed when considering other land uses. The highest percentage of hexagons associated with work activities are clustered Wd3 and Wd5 in the case of bikes, Wd5 for mopeds, and Wd1 and Wd3 for scooters, which are all clusters that share the characteristics of increased departures counts towards the afternoon. Consequently, bikes, mopeds, and scooters have a close relationship with departures in the afternoon from work-related areas (commute to return home). Moreover, educational land use is related mostly to clusters Wd1 for all modes, which is characterised by a low usage intensity but a clear morning peak period (probably related to the entrance to schools). Finally, parks are mostly associated with cluster Wd5 for bikes and scooters, and Wd1 and Wd3 for mopeds. Therefore, bikes and scooters show

to be closely related to intense use of this mode for recreational purposes (especially in the afternoon hours), while mopeds are shown to have a more moderate usage related to this land use.

Table 7-3 Distribution of location clusters (percent of hexagons) over land uses during weekdays.

Mode	Land use	Wd1	Wd2	Wd3	Wd4	Wd5
Bike	Residential	36%	36%	12%	28%	23%
	Mixed-residential	46%	52%	71%	54%	59%
	Commercial	4%	2%	2%	0%	0%
	Workplaces (office)	3%	2%	9%	0%	9%
	Education	1%	1%	0%	0%	0%
	Parks	3%	2%	2%	8%	9%
	Other	7%	7%	4%	10%	0%
	Total	100%	100%	100%	100%	100%
Moped	Residential	55%	46%	21%	24%	14%
	Mixed-residential	28%	47%	63%	66%	61%
	Commercial	2%	1%	1%	3%	0%
	Workplaces (office)	7%	1%	7%	1%	22%
	Education	4%	1%	3%	1%	0%
	Parks	4%	2%	4%	2%	2%
	Other	1%	2%	1%	2%	0%
	Total	100%	100%	100%	100%	100%
Scooter	Residential	57%	29%	15%	31%	27%
	Mixed-residential	25%	57%	67%	57%	59%
	Commercial	2%	2%	4%	2%	5%
	Workplaces (office)	8%	3%	7%	2%	2%
	Education	4%	1%	0%	2%	0%
	Parks	4%	2%	5%	2%	7%
	Other	0%	5%	2%	3%	0%
	Total	100%	100%	100%	100%	100%

Source: own elaboration.

7.5. Conclusions

This study has shown that the exploration of spatio-temporal micromobility travel patterns can be better understood within the Time Geography framework, using space-time cubes. Micromobility systems generate huge amounts of data, in the form of trip GPS records, with high spatio-temporal resolution. This data facilitates the representation of spatio-temporal patterns in Space-Time Cubes (STC). One of the main findings is that bikes are the most important shared mode analysed in the city as it shows high departure counts throughout the day while mopeds, and especially scooters gain importance towards the afternoon. In the case of Madrid, we have found that central (midday) and late afternoon hours (from 18 to 20 hrs) are the most profitable time for micromobility operators, as hot spots are more homogeneously distributed.

In addition, the analyses performed allowed us to identify the areas of the city with the highest vitality and attractiveness in terms of micromobility departures. These areas concentrate residential, mixed-residential, commercial, and work-related land uses that are closely linked to an intense usage during the entire day (morning and afternoon). Therefore, clusters Wd4/We4 and Wd5/We5 are the types of locations that represent the better scenario for micromobility operators, as redistribution trips could be reduced due to users starting their trips in the most attractive areas where others previously have left a vehicle as was also found in (Arias-Molinares et al., 2021). This study identified five types of places according to each scenario (weekdays and weekends) and each mode, which offers valuable insights for micromobility operators to distribute their vehicles in the areas and at the specific times that increase profitability. During weekdays, the results show that there are some locations associated with high departure counts coming from residential (clusters Wd1 and Wd2) and commercial areas (Wd1), as well as the importance of

certain modes to conduct certain activities (for example, mopeds in the afternoon and departing from work-related areas, as well as bike and scooter in the afternoon departing from parks). Nevertheless, micromobility seems to have a good capacity to serve trips associated with activities that Hagerstrand called flexible activities, such as leisure. Thus, the peaks are usually shown in the afternoon and evening hours, especially during the weekend. On these trips, micromobility is a good complement to public transport.

The proposed methodology could be implemented in any city and could offer operators and authorities useful insights regarding the hourly-changing dynamics of shared services. Our aggregation approach was to add each origin point to the hexagonal grid (XY-axis) and bin (z-axis) that contained it, according to the specific location and time of the starting point, and then totalize (adding) all the origin points (departures) by hexagon over the day (daily) or hourly. This helped us to understand the spatial and temporal distribution of the origins of micromobility trips, identifying the most important areas and times of the day and their relationship with land uses. For policy-oriented decision processes, authorities should try to understand the different dynamics according to the day of the week and hourly patterns. Promoting dense, mixed-residential land use, and offering micromobility infrastructures such as segregated cycle lanes and parking places in hot spot areas could increase the importance and usage levels of these shared mobility modes.

As limitations of the study, we could highlight one related to the moped and scooter datasets used, which were provided by two and one respectively, of the many operators in Madrid. Hence, it is important to consider that, while in the case of bikes with BiciMAD, we almost cover all records as there are few shared bike operators in Madrid, this is not the case for the other two modes. For dockless services, results must be carefully interpreted, as we are not covering the entire available moped (27%) and scooter (15%) fleet, thus the presence of other companies would vary the vehicle density in some areas, which could have an impact that we are not yet able to identify. Future research could try to include more operators to analyse a better sample and conduct regression models to better explain the relationship between the types of locations (clusters) and the different land uses.

8. Assessing the impact of the global COVID-19 pandemic on BiciMAD and other dockless micromobility services

8.1. Introduction and background⁵

On March 2020, the World Health Organization (WHO) declared the novel Coronavirus Disease caused by the SARS-CoV-2 virus (hereafter, COVID-19), as a global pandemic. As an effort to mitigate its rapid spread, lockdowns were imposed causing many changes in travel behaviour, not yet exactly quantified, or understood, offering numerous possibilities for exploration: one of them being the impacts of this pandemic on BiciMAD and other dockless micromobility services. Before the pandemic outbreak, micromobility experienced a burst worldwide, with operative services in over two hundred cities and many investors valuing these companies in the billions of dollars (Wiggers, 2019). Due to its already mentioned benefits, micromobility's scientific literature is and will continue to grow. The available studies can be divided in two groups. The first one includes all the studies that used GPS trip data to approach different analyses of single shared modes. For example, (Degele et al., 2018) clustered shared moped's users according to their different characteristics, while (Xu et al., 2019) explored the variations of temporal signatures during weekdays and weekends for dockless bikes, and (Caspi et al., 2020) found scooters' usage was concentrated mainly in the city centre and closely related to high employment zones and areas with cycling infrastructure. The second group of studies are focused on the comparison of more than one type of shared mode. For example, (Zhang et al., 2020) compared dockless bike and scooter-sharing services and their findings showed that scooters had a more compact spatial distribution than bikes and that their high demand was associated with points of interests, metros, and residential zones. Similarly, (Lazarus et al., 2020; McKenzie, 2019b) compared docked and dockless bikes; the results from the first study revealed that dockless bikes travelled for longer distances, while in the second study the author compared docked and dockless bikes with scooter services concluding that the docked systems were predominantly used for commuting while dockless scooters suggested a more recreational use.

All the above-mentioned studies were published before the pandemic. The scientific literature that addresses micromobility services after the pandemic is just beginning to be published and available, especially now, as these services are demonstrating to be crucial for improving the cities' resilience (European Commission, 2020). After lockdowns were relaxed, grey literature suggested that micromobility services grew in popularity and that they help increase cities' resilience to pandemics (Ardila-Gomez, 2020; Asenjo, 2021; Blanchar, 2020; Harrabin, 2020; Lomas & Dillet, 2020; Oltermann, 2020; Porcel, 2021). However, scientific research supporting/contrasting these statements continue to be scarce and the few studies found are mostly based on online surveys (Awad Núñez et al., 2020; Beck & Hensher, 2020; Bergantino et al., 2021; Campisi et al., 2020; Christoforou et al., 2021; Meena, 2020; Nikiforiadis et al., 2020; Pawar et al., 2020). The study done by (Dias et al., 2021) conducted a systematic literature review on the spread of shared scooters and analysed the case of Braga in Portugal where the city relied on scooters to maintain social distance. Other studies like (D. Wang et al., 2021) estimate the effects that public transport restrictions may have in increasing private car usage and traffic congestion. The authors recommended that these restrictions should be accompanied with a support for micromobility services and congestion alleviation strategies. Survey-based studies include, for example, the survey conducted by (Awad Núñez et al., 2020) which found that even though the demand for micromobility services was marginal before the outbreak, the willingness to use bike-sharing or scooter-sharing services was relatively high during the first months of the pandemic (67,7%). Another survey conducted in Greece showed that bike-sharing was not

⁵ The content of this chapter has been published in (Arias-Molinares et al., 2022b)

perceived as safe as walking or using a private car, but it was seen safer than using a taxi or public transit (Nikiforiadis et al., 2020). Both studies pointed to the fear of contagion as the main reason behind micromobility's increased popularity after COVID-19, stating that more sustainable modal choices could be a temporal behaviour and not necessarily a permanent one. This latter issue was the focus of the research by (Monterde-I-bort et al., 2022) that distributed a survey around 10 countries to evaluate the extent to which pandemic travel behaviour will be retained. They applied the survey in two phases: phase 1- spring 2020 and phase 2-fall 2020 obtaining 636 cases. During lockdowns, the majority of respondents reported a reduced car usage, but also public transport and walking. In phase 2, when the lockdowns were relaxed, they reported going back to using the car and walking as normal but in the case of public transport, pre-pandemic levels were not achieved yet. The least affected mode reported was bike as respondents declared that its usage hardly changed at all. This was also the case in (Štefancová et al., 2022) which conducted a survey to 1.048 people in Slovakia and evaluated the impact of COVID-19 in travel behaviour. Their results showed that many of the respondents reduced the use of public transport but as an alternative, they started using more bikes and scooters. Similarly, (Fistola et al., 2022) obtained almost 200 responses from an online survey distributed around university students in Italy and found that 81,6% of the students were willing to change their travel behaviour towards more sustainable modes after the pandemic. The study demonstrated that micromobility services are highly appreciated by university students in study campuses. Their results also suggested that reducing the service's price (especially those that demand a payment for unlocking the vehicle), offering bonuses to buy electric bikes or scooters and increasing segregated cycling infrastructure were demanded strategic measures to promote micromobility. The study conducted by (Nguyen & Pojani, 2022) examined recreational cycling in Hanoi, Vietnam after the pandemic. Their results from a sample of 356 face-to-face surveys collected in April 2021 showed that a quarter of them started cycling recreationally since the first lockdown and nearly half of them cycled regularly (more than four times per week).

Although all these surveys offer useful insights, we aim to explore studies that used another type of data source (GPS records) and analysed COVID-19 impacts as done in (A. Li et al., 2020; Liu et al., 2021; Molloy et al., 2021; Teixeira & Lopes, 2020). The study by (Teixeira & Lopes, 2020) addressed how New York's subway and bike-sharing systems were affected by COVID-19 outbreak. Their findings revealed that bikes were more resilient with a less significant ridership drop (71% vs 90% ridership drop), an increased average trip duration (from 13 min to 19 min) and an observed modal transfer from some subway users to the bike sharing system. Their study provided evidence on the role of the bike-sharing system and cycling in general, to ameliorate the effects of the pandemic, as it quickly provided an alternative transport option reinforcing the transport offer in areas with higher demand at a fraction of the cost of new roads or public transport infrastructure. (A. Li et al., 2020) evaluated the changes of micromobility services' behaviour before and during COVID-19 pandemic period in Zurich, Switzerland. They considered four types of shared services: 1) docked bike, 2) docked e-bike, 3) dockless e-bike and 4) dockless e-scooter. Their results showed that micromobility trips were longer in distance and duration after the pandemic and that activities related to home, park and groceries were more relevant, while leisure and shopping decreased in importance. (Song et al., 2022) used trip data to apply graph-based techniques and spatial correlation models to analyse the changes of the bike-sharing behaviour after the pandemic in Singapore. They estimated that bike ridership climbed by 150% after lockdowns were relaxed and they found a positive spatial autocorrelation between bike ridership with centrality measures, high residential densities and mixed land use. These studies published after the pandemic, tried to address impacts, the changes in modal choices, spatiotemporal distribution of people or shared mobility trips, the effects of lockdowns/telework and online studies and the extent to which these changes could be temporal or become permanent in a post-COVID transition.

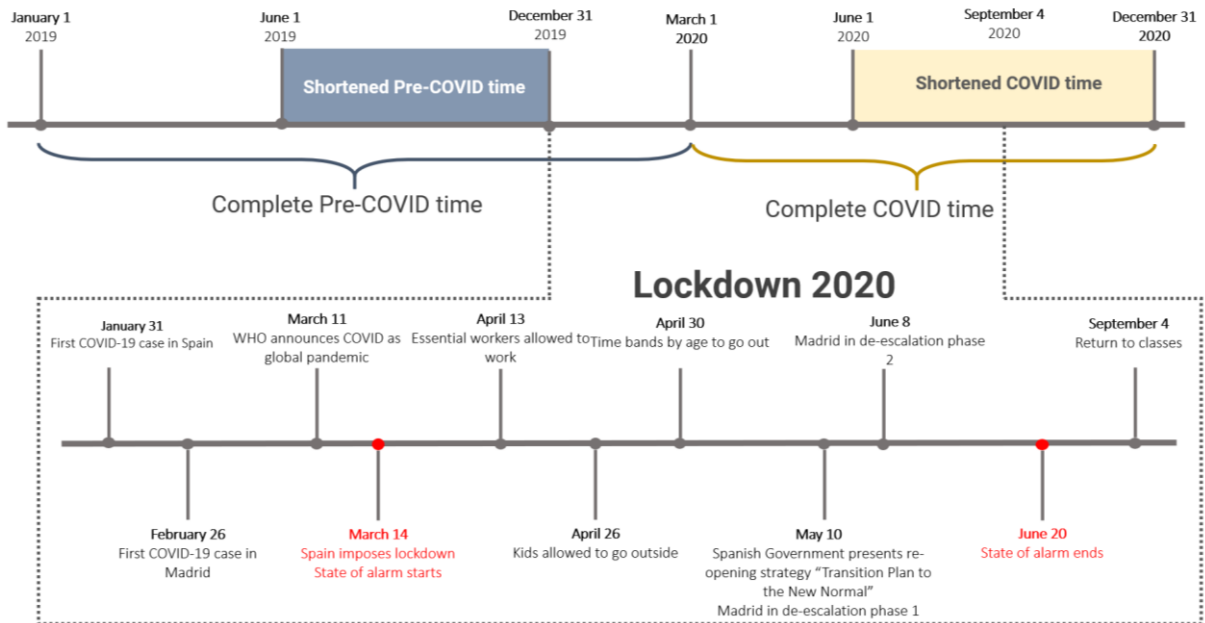
Following on this line of research, the objective of this paper is to answer the following question: how were BiciMAD and other dockless micromobility services affected by the pandemic? We aim to measure the extent to which the services' usage levels dropped, how did they recover and the key aspects to understand their recovery in relation to urban activities and land uses. To that end, taking the city of Madrid as case study, we evaluate the changes in travel behaviour comparing two scenarios: pre-COVID time for 2019 and the first two months of 2020 and COVID time for the rest of 2020. We analyse generated and attracted micromobility trips throughout the day and during morning and afternoon peak hours (capturing commuting behaviour to/from home) and explore its relationship with different land uses to assess which activities gained/lost importance.

Our study contributes to the literature in several ways. Firstly, to our knowledge, this is one of the few studies that analyses and compares three different micromobility services' usage patterns before and after the pandemic using trip data (GPS records). Unlike many of the recent publications, our study will focus not on users' responses, but rather on their trips by analysing GPS records collected by different micromobility services. Secondly, with most studies considering daily behaviour, our study's temporal resolution offers larger granularity as it evaluates how the travel patterns change throughout the day, considering the morning and afternoon peak hours. Thirdly, we relate micromobility trips with the distribution of land uses, using spatial regression models. This makes it possible to know if the pandemic has altered the spatial patterns of the use of micromobility systems. The selection of Madrid as a case study is also of special interest, as it is known as one of Europe's most important living labs for shared mobility and one of the metropolitan areas that was most affected by COVID-19 pandemic. Therefore, this is an effort-worthy topic of interest, as before COVID-19 city planners and transport authorities were already struggling to assess micromobility impacts on travel behaviour and existing infrastructure. Nowadays, it is more necessary to explore how the pandemic has changed travel patterns and urban dynamics, as it will be essential for decision-making processes and formulating future regulations (Romanillos et al., 2021).

8.2. Case of study: Madrid during the COVID-19 pandemic

As previously mentioned in Chapter 3-Study Case, our thesis is mainly focused on Madrid as it has a multiple and varied shared mobility supply, great diversity of land use and high densities of population and employment with more than 6 million people in the Metropolitan Region, and half located in the Municipality of Madrid (Instituto Nacional de Estadística, 2018). As many cities worldwide, Madrid imposed a lockdown from March to June 2020 in order to reduce social interaction (Ministerio de la Presidencia, 2020) (see Figure 8.1). In general, (Romanillos et al., 2021) identified five phases with different lockdown rules in Madrid (see Table 8-1). This measure resulted in approximately an 80% public transport ridership drop during the pandemic-peak months (March, April and May). From June on, lockdowns were relaxed, and services began to slowly recover with the re-opening strategy launched in May (called "Transition Plan to the New Normal") (Glodeanu et al., 2021). Most micromobility operators in Madrid started to conduct hygiene/disinfection duties to their fleet of vehicles and inform customers about it (as so did the public transport systems), as well as offering free face masks and hand sanitizer, in order to increase safety.

Figure 8.1 Timeframes for the research databases and Madrid's timeline related to COVID-19 mobility restrictions.



Source: own elaboration.

Table 8-1 Lockdown rules for Madrid.

Phase	Dates (2020)	Summary of lockdown rules
1	Declaration of a State of Alarm 14–28 March	- Suspension of face-to-face classes in all learning centres. - Prohibition to circulate in the streets, except for: Buying food or medicine, going to health centres, going to or coming from the workplace, going to banks or insurance companies, taking care of the elderly or children. - Recommendation of teleworking (most companies where it was possible adopted this recommendation) - Closure of most premises, shops and businesses. Exceptions: Food stores, pharmacies, medical centres, gas stations, and others. - Closure of museums, libraries and leisure or sports centres. - The public transport service is maintained, with exceptional measures depending on the specific service This is the phase with the greatest restriction of activities. The measures adopted during the State of Alarm also include:
2	Extension of State of Alarm 1 29 March - 12 April	Suspension of non-essential face-to-face work activity. Fundamentally, the following are considered essential activities: health, food and fuel distribution, public maintenance services, cleaning and waste collection, state security, postal services, funeral services and the media. Measures relating to those defined in the previous phase:
3	Extension of State of Alarm 2 13–26 April	- People are allowed to return to their workplaces for non-essential activities where teleworking measures cannot be implemented. - Circulation of private vehicles is allowed to carry out the permitted activities. Measures relating to those defined in the previous phase:
4	Extension of State of Alarm 3 27 April - 10 May	- Children under 14 years of age may go out with someone 1 h a day but must not go further than 1 km from home. - From 2 May: Those defined by the Transition Plan to the New Normal. On April 28, a 4-phase Transition Plan to the New Normal was established. On May 2, Madrid enters Phase 0 of the plan, allowing:
5	Transition Plan to the New Normality: De-escalation - Phase 0 2–10 May	- Departure for minors, individual non-contact sports activities and walks, once a day and at regulated hours. - Opening of establishments by appointment for individual customer service.

Source: own elaboration.

In this study, we used the trip data for BiciMAD, Movo and Muving (see Figure 8.2 and Table 8-2). Station-based services like BiciMAD, have designated locations where users pick and leave the vehicles at, while dockless services, like Movo and Muving, offer more flexibility as the

vehicles can be picked/returned at any location within a geographic area (also known as geofence).

Figure 8.2 Micromobility services analysed. From left to right: 1) Station-based bike-sharing (BiciMAD bikes), 2 and 3) dockless moped-style scooter-sharing (Movo and Muving mopeds) and 4) dockless scooter-sharing (Movo scooters).



Source: own elaboration.

Table 8-2 Main characteristics of the three micromobility operators analysed.

Micromobility service	Operator	Modes included	Model	Operating since	Subscribers	Vehicles
BiciMAD	Public EMT Bus Company	• Bike-sharing	Station-based	2014-today	75.000	2900 bikes 264 stations
MOVO	Private Cabify	• Moped-style scooter-sharing • Scooter-sharing	Dockless	2018-today	No info	500 mopeds 1.400 scooters
MUING	Private Sharing Muving	• Moped-style scooter-sharing	Dockless	2018-2020	31.934	755 mopeds

Source: own elaboration.

One of the aspects that most differentiates these services is their area of coverage (geofence), which is closely related to their different models. In the case of BiciMAD, being a station-based model, it covers essentially the city's core centre area. In the case of dockless services, the geofence is much larger reaching other peripheral areas and being more homogeneously distributed in the city which creates a relatively less intense usage in each location. This study performs the spatiotemporal analyses of each service considering these different geofences, which are all inside Madrid's Municipality.

8.3. Data and methods

The data used for this study was:

- BiciMAD: data was extracted from the website: [https://opendata.emtmadrid.es/Datos-estaticos/Datos-generales-\(1\)](https://opendata.emtmadrid.es/Datos-estaticos/Datos-generales-(1)). Only BiciMAD separates users' trips from administrative trips (redistribution of vehicles) allowing us to discard redistribution trips. BiciMAD datasets offer the location (xy coordinates) of the trip origin and destination as well as the exact time when the trip started (timestamp).
- Movo: information of trip origin and destination coordinates, trip origin and destination timestamp and the vehicle type (if it is a moped or scooter).
- Muving: information of trip origin and destination coordinates, trip origin and destination timestamp, trip time (minutes) and trip distance (km). The operator informed us that they ceased operations in Madrid from September on, so the dataset for the COVID time scenario only includes trips made between March 2020 and August 2020.

- Territorial boundaries, land use and income data: in order to perform the spatial analyses, we used as territorial boundary the 605 transport zones inside the Municipality of Madrid which were obtained from the Open Data Portal of the Consorcio de Transportes de la Comunidad de Madrid (<https://data-crtm.opendata.arcgis.com> accessed 05.06.20). Land use data was provided by the Directorate General for Cadastre in Spain (Cadastre), and the databases define the surface area [km²] of each type of land use by each transport zone. Finally, income data is provided by the City of Madrid in its open data website and the shapefile contains the 2017 average annual home income by census section of Madrid which was crossed with the transport zones layer.

Methodologically, the data processing workflow covered entering, cleaning, transforming, and outputting the final valid datasets (using Python vs. 3.8). With the same cleaning criterion used in Chapter 6, we obtained the valid datasets. Next, we decided to create two databases, in order to serve different purposes in the analysis. One of them, called “complete database” which included all the data and a second one, called “shortened database” which included only the data for the last semesters (from June to December of 2019 and 2020) (see Figure 8.1).

Complete database timeframe:

- Pre-COVID time: from 01-01-2019 at 00:00:00 to 29-02-2020 at 23:59:59.
- COVID time: from 01-03-2020 at 00:00:00 to 31-12-2020 at 23:59:59.

Shortened database timeframe:

- Shortened pre-COVID time: from 01-06-2019 00:00:00 to 31-12-2019 at 23:59:59.
- Shortened COVID time: from 01-06-2020 00:00:00 to 31-12-2020 at 23:59:59.

The creation of these two databases was necessary, as we used the complete one for the initial description of the trip datasets and to visualise temporal patterns in monthly behaviour. While further on, we determined to work with the shortened one (second semester), in order to make the services’ usage temporal and spatial patterns more comparable. Due to micromobility services being closed during the pandemic-peak months (March, April and May), better comparison analysis could result from considering the data from June on, when the lockdown measures were relaxed, and urban mobility began to slowly recover. Therefore, the shortened database was used to also describe the trip datasets, to continue assessing temporal patterns but now across weekdays and hourly behaviour and finally to conduct spatial patterns analyses.

For the spatial analysis, we segregated each trip by its origin and destination and analysed daily behaviour (total daily trips) and the behaviour according to different time bands. Two bands were defined: AM peak hours for 06 to 10 hr and PM peak hours for 16 to 20 hours in order to explore commuting patterns. The process included the aggregation of micromobility trips to Madrid Municipality’s transport zones (605 transport zones), as well as the average income data (euros/year) and information related to land uses. Land use data consist of residential, workplaces (offices + industrial areas), commercial, educational, cultural + entertainment, transport, parks, and other uses. Finally, a variable named “distance to the city centre” was also calculated in order to get the distance [km] from each transport zone to the one that included the “Sol Square” which is usually considered Madrid’s city centre area.

With all the variables calculated, we conducted Ordinary Least Squares (OLS) and Spatial Lag regression models. The models explain the relationship between micromobility trips (starting/ending) and the characteristics of each transport zone. Regressions were conducted for each scenario (pre and COVID time), for each mode (bikes, mopeds, and scooters), and for daily behaviour (only considering origins) and by time band (considering both, origins and destinations). The following equation was used in the OLS models:

$$y = x\beta + \varepsilon$$

Where the dependent variable y is the number of departures or arrivals by the particular mode and by time band analysed (numeric discrete variable) and the explanatory variables x are the average income and the amount of build-up [Km2] of each type of land use (all of which are numeric continuous variable). Distance to the city centre was included in the models as a control variable measuring centrality. β are the coefficients of the explanatory variables and ε is a vector of error terms.

All the regressions had significant F-statistic values at the 0.000 level. The equations have the expected signs in the coefficients of the explanatory variables: positive for the land uses variables and negative for distance to the city centre and average income. No collinearity problems have appeared in OLS models between the explanatory variables (VIF values less than 1.5). Some models have shown lack of stationarity or heteroskedasticity (Koenker statistic), but in these cases the Wald Statistic has validated the general relevance of the models and the robust probabilities (Robust_Pr) have shown the relevance of the coefficients of the independent variables.

Nevertheless, OLS models presented spatial dependence. This was found after running the initial OLS regression, in which the Robust LM-Lag indicators were significant ($p < 0.01$), showing that the distributions of the residuals were spatially autocorrelated. Hence, to mitigate spatial dependency, we decided to conduct different models with spatial error, and we finally kept the Spatial Lag models using GeoDa software (vs 1.16.0.16) (Anselin et al., 2010) for all the scenarios, as we obtained a better fit. Spatial Lag models incorporate spatial effects considering a spatially lagged dependent variable as an additional independent variable (Anselin, 1988, 2009; Srinivasan, 2015):

$$y = \rho Wy + x\beta + \varepsilon$$

Where y is the dependent variable, x is the set of explanatory variables, Wy is the spatial lagged dependent variable and ρ is the spatial autoregressive coefficient (Lag Coefficient Rho). The underlying idea for using Spatial Lag Models is that there is a spatial “contagion” effect (substantive spatial autocorrelation) in the sense that the use of micromobility services on a given zone is influenced by the use of micromobility on neighbouring zones.

The Spatial Lag models were calculated using a contiguity weight matrix of 1st order (queen contiguity). We use the spatial relationship of queen contiguity because both the distribution of the number of starting and ending trips in the different services presented the highest values of spatial autocorrelation (measured with Moran's I) using this degree of neighbourhood, and they decreased with greater distances. Also, the models offered a better fit with the queen contiguity relationship instead of longer distances. We show the results of the Spatial Lag models and the standardised coefficients of the independent variables. The changes in the coefficients throughout the two scenarios (pre-COVID and COVID times) show the type of land uses that were most active before and after the pandemic.

8.4. Results and discussions

In Table 8-3 and Table 8-4, we have summarised the main descriptive characteristics for the complete and shortened datasets analysed. As it can be seen, considering the entire dataset, there was a general micromobility ridership drop of around 10% due to the pandemic outbreak, which is quite low considering the downfall of trips in Madrid's public transport system (estimated in 80% during peak months). This result suggests that, as was found in other studies (Teixeira & Lopes, 2020), micromobility is more pandemic-resilient. Some services as the case of BiciMAD and Muving show an even better performance when considering only the last semesters of the 2019 and 2020, as the shortened datasets eliminate the weight of service closures during the peak months of the pandemic. Findings also show that BiciMAD is the most important micromobility

service as it accounts for 78,1% of the total micromobility trips, followed by mopeds (Movo and Muving) with 19,6%.

When considering only the last semesters (Table 8-4), we observe that the downfall in ridership is even lower (around 3% lower than considering the entire dataset). Interestingly, when comparing BiciMAD's performance in 2019 and 2020, it is the only service with no drops, but rather a 5,8% rise in ridership. In other words, our results are yelling that BiciMAD was the only micromobility service that show higher usage after COVID-19, being the most resilient one to the pandemic. This result is consistent with findings from (Song et al., 2022) that also demonstrated that bikes' usage climbed 150% in relation to pre pandemic levels. We speculate that the sustained usage of the bike-sharing system after the pandemic, may be related to the fact that it is one of the cheapest shared mobility services in the city of Madrid, which allowed many residents to move in a safer (by allowing social distance in comparison with crowded public transport systems) and flexible way after COVID-19. Additionally, based on the last BiciMAD's survey conducted in 2019, most of its subscribers were males, with 35 to 49 years old, employees with high education level that earn low-medium monthly income, yet 26,5% of them earn less than 1.300 €/month (relatively low income) (Arias-Molinares, Julio, et al., 2021). On this survey, results also showed that the main trip purpose when using BiciMAD was commuting, with 46% of cyclists using it for work/study motives at least once a week or more (of which 22% use it on a daily basis) (Arias-Molinares, Julio, et al., 2021). All these facts may indicate that the bike-sharing system could have been an attractive alternative transport option for those essential workers with no cars and low income that were avoiding crowded public transport systems (fear of contagion). On the other hand, scooters seem to be the most affected service with a downfall of 84%. Moreover, in general, average trip times, distances and speeds had minimal variations in 2020 with respect to 2019 (10 seconds, 100 meters and 0,2 points less respectively).

More specifically for the case of BiciMAD and supporting the findings from (A. Li et al., 2020; McKenzie & Adams, 2020; Molloy et al., 2021), average trip time rose 1,2 minutes, average trip distance rose 200 meters while the speed was maintained at 11,3 km/hr from 2019 to 2020. As was mentioned earlier, with the fear of contagion, and with bikes allowing social distancing, BiciMAD users could possibly be travelling for longer distances replacing public transport options (more crowded metros or buses). In the case of scooter-sharing on the other hand, trip time decreased one minute from pre-COVID to COVID times, average trip distance decreased 200m and average speed rose 20 seconds. Scooter users travelled less distance but at a faster pace which could be related to a "traffic-calming effect" after the outbreak, as automobile traffic flows were reduced with the introduction of telework and mobility restrictions. And finally in the case of mopeds, all the indicators dropped in the case of Movo (70 seconds, 300 meters and 0,9 points less respectively) and were maintained in the case of Muving (with the exception of speed that lowered 0,3 points). Overall, results show that trip times distances and speeds are very similar for all modes and are maintained similar after the outbreak. Muving mopeds are the ones that travel longer distances and at a faster pace, followed by Movo's mopeds, BiciMAD's bikes and lastly Movo's scooters.

Table 8-3 Descriptive characteristics of the complete dataset.

Micromobility service	Total trips		Months operative		Monthly trips				Change (Trips)		Average trip time (min)		Average trip distance (km)		Average speed (km/hr)	
	Pre	COVID	Pre (14)	COVID (10)	Pre	%	COVID	%	Total	%	Pre	COVID	Pre	COVID	Pre	COVID
Bikes (BiciMAD)	3.191.488	1.965.997	14	8,7	227.963	78,13%	225.976	85,72%	-1.987	-0,87%	12,59	13,8	2,3	2,5	11,3	11,3
Scooters (Movo)	85.825	11.632	13	7	6.601	2,26%	1.661	0,63%	-4.940	-74,84%	12,3	11,3	2,0	1,8	10,1	10,3
Mopeds (Movo)	469.575	230.658	13	7	36.121	12,38%	32.951	12,50%	-3.170	-8,78%	12,55	11,8	2,7	2,4	13,2	12,6
Mopeds (Muving)	295.038	15.154	14	5	21.074	7,23%	3.030	1,15%	-18.044	-85,62%	11,78	11,8	3,5	3,5	17,9	17,6
Total	4.041.926	2.223.441			291.759	100%	263.618	100%	-28.141	-9,65%	12,31	12,19	2,623	2,57	13,108	12,94

Source: own elaboration. *BiciMAD was closed from March 13 to April 22 (41 days = 1,3 months).

Table 8-4 Descriptive characteristics of the shortened dataset.

Micromobility service	Total trips		Months operative		Monthly trips				Change (Trips)	
	Pre	COVID	Pre (7)	COVID (7)	Pre	%	COVID	%	Total	%
Bikes (BiciMAD)	1.622.961	1.717.334	7	7	231.851	75,97%	245.333	86,52%	13.482	5,81%
Scooters (Movo)	72.988	11.632	7	7	10.426	3,42%	1.661	0,59%	-8.765	-84,07%
Mopeds (Movo)	296.001	230.639	7	7	42.285	13,85%	32.948	11,62%	-9.337	-22,08%
Mopeds (Muving)	144.520	10.826	7	3	20.645	6,76%	3.608	1,27%	-17.037	-82,52%
Total	2.136.470	1.970.431			305.207	100%	283.550	100%	-21.657	-7,10%

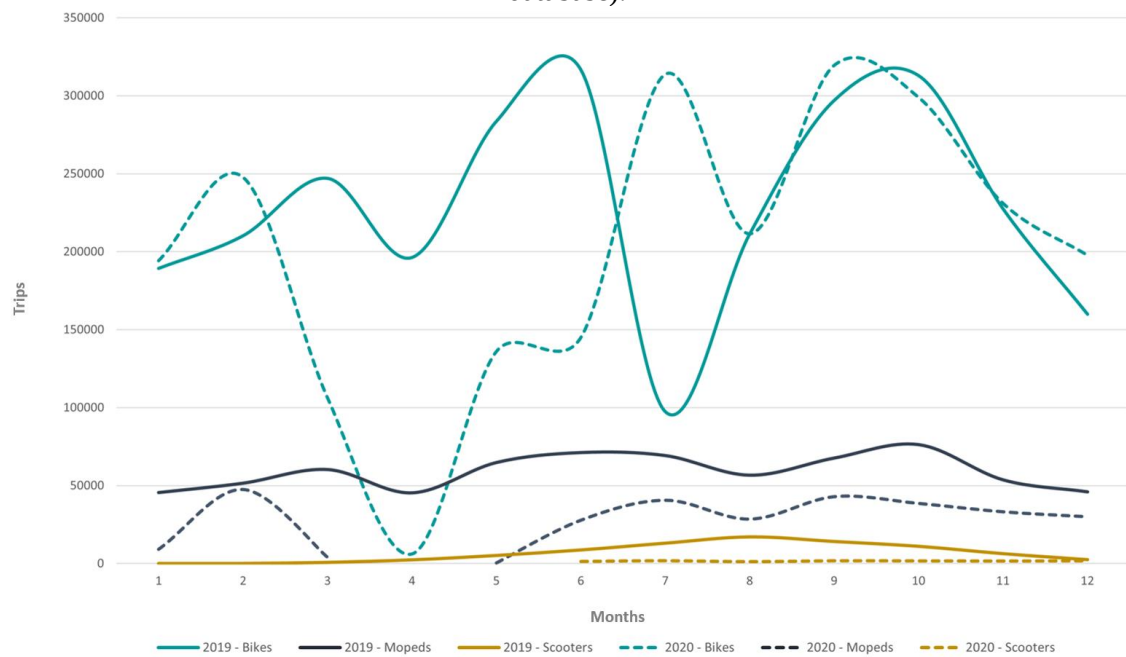
Source: own elaboration. Average trip time, average trip distance and average speed for the shortened dataset had minimal variations with respect to Table 8-3.

8.4.1. Temporal patterns

Figure 8.3 shows pre and COVID time temporal behaviour for micromobility trips aggregated by month of the year. In the normal situation prior to the COVID-19 outbreak, BiciMAD had high trip counts on the months when most residents are in town with daily routines (not vacations) and temperatures are warmer (spring and fall). These peaks are shown in the months of March and June (spring season) and then again in September and October (fall season). On the contrary, low trip counts are observed on those months towards the summer season, when usually Madrilenians travel out of town for the Holy Week holidays (spring), summer or Christmas vacations, and especially in summer or winter when the temperatures are extreme. In the case of mopeds, there is a slight difference with respect to BiciMAD's pattern around the months of summer season (July and August), as Muving and Movo seem to better retain their trip counts during vacations. Moreover, with regards to scooters, the pattern is completely different from the other two modes, as trip counts are mostly low and tend to increase, mostly towards the summer season (July, August and September). These temporal patterns may be suggesting an interesting finding: that BiciMAD's users are mostly residents of Madrid, that moped's users seem to be a mix of residents and tourists while scooter's users could mostly be visitors, supporting findings from (Hosseinzadeh et al., 2021; McKenzie, 2019; McKenzie, 2019b, 2019a).

Regarding the second scenario (COVID-19 time), the yearly pattern drastically changed due to all the services being closed for mobility restrictions during the pandemic peak period (March and April). However, once the services re-opened in May, the monthly patterns seem to recover and showed a "back-to-normal" tendency, which in the case of BiciMAD was better than the normal scenario surpassing its trip record in July, after the lockdown measures were relaxed. The month of July 2020 shows an essential change produced by the COVID outbreak: in July 2019 trip counts were low reflecting the usual patterns of Madrilenians that go on summer vacations, while in 2020, with the tourism decay and most people spending their vacations at their place of residence, the service had almost the same number of trips (313.745 trips) that the month of June 2019 (316.769 trips) which was the best trip record of 2019. For BiciMAD service, July 2020 represented the "boom" of bikes with a rise in ridership of 220% with respect to July 2019. Not only that, but in September the service reached its best record with (319.497 monthly trips) which was 7% higher with respect to the same month in 2019.

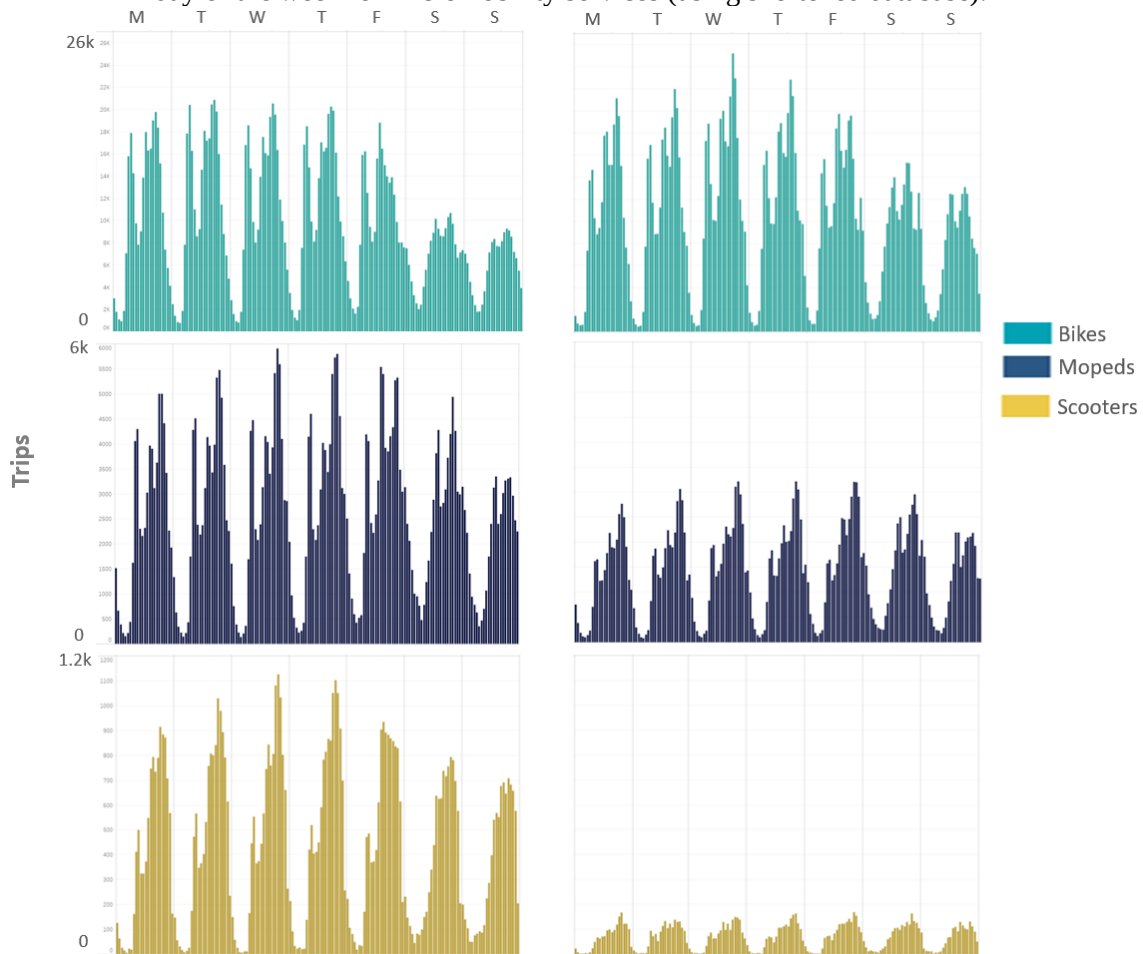
Figure 8.3 Pre and COVID time micromobility trip counts by month of the year (using complete database).



Source: own elaboration.

Exploring the weekly behaviour, Figure 8.4 shows the temporal signatures of each service across hours and days of the week. In general, the plots clearly show that the most pandemic-resilient service was BiciMAD, maintaining and even surpassing its previous trip counts after the pandemic. In the normal scenario the signatures show that the services were mostly used for commuting morning hours on Tuesdays (in the case of BiciMAD and scooters) and Thursdays (for mopeds). Preferred modes for the morning commuting hours seem to be bicycles and mopeds while scooters are preferred for the afternoon hours. In COVID times, the signatures show less trips at morning peak hours, as many people stayed at home with teleworking measures. On the pre-COVID scenario, we can observe that the most profitable days for micromobility services were Wednesdays (BiciMAD), while in the case of mopeds and scooters, the weekly pattern flattens and seems to have a similar preference from Wednesdays to Fridays (for mopeds and scooters). On weekends, Saturdays are more profitable for all modes and for all the scenarios, especially in the afternoon and night hours.

Figure 8.4 Temporal signatures for Pre (left) and COVID time(right) aggregated to hours and day of the week for micromobility services (using shortened database).



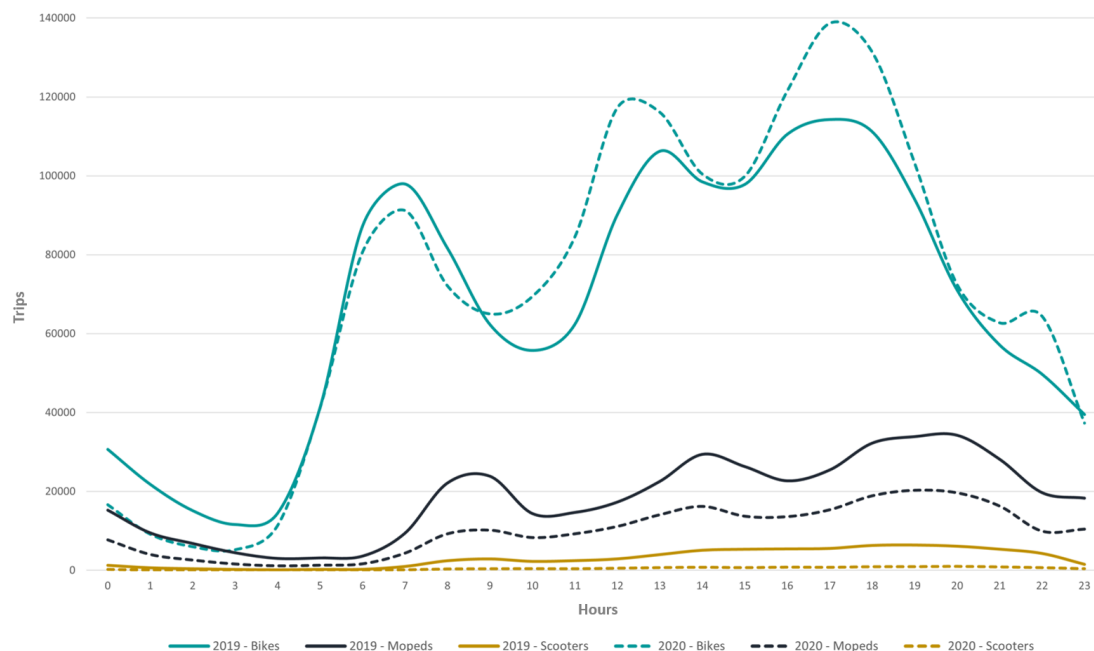
Source: own elaboration. Notably, each y-axis is different as the trip volume differs between services.

When considering the hourly behaviour, Figure 8.5 shows that in general, all three modes have three peaks: the smallest one in the morning commuting hours (from 06 to 10 hrs), a middle one for lunch hours (13 to 15 hrs) and the highest one for the afternoon (from 17 to 22 hrs). The only service that follows a slightly different pattern is scooter-sharing, as trip counts increase mostly from lunch on (14 to 21 hrs) with less trips on morning commuting hours and the highest counts on the afternoon (around 19 hrs), which supports the hypothesis of recreational use. Additionally, regarding the morning commute hours, BiciMAD is used mostly from 06 to 08 hours, while dockless services (mopeds and scooters) are preferred for later hours (from 08 to 10 hr). The same occurs in the afternoon, with BiciMAD showing higher trip counts from 16 to 18 hrs, while the dockless show their peaks later from 18 to 20 hrs.

Considering the hourly behaviour after COVID-19, we can observe that the curves follow the same temporal trend with three peaks, but these peaks seem to have been displaced into earlier hours, especially in the case of BiciMAD service (for lunch at 12 hrs and for afternoon commute at 17 hrs). With the consolidation of online studying and telework, the most noticeable difference is observed at morning peak hours, with trips at 07 hrs being considerably lower for bikes and at 8-9 hrs for mopeds and scooters. This supports findings from similar research by (A. Li et al., 2020) which found that the only peak that was maintained after COVID-19 was the afternoon commute as the number of commuting trips decreased due to telework measures. Mid-morning

trips (from 10 to 12 hrs) also rose, which could be related to people teleworking and having more flexibility to carry errands in this period, similar to findings in (Molloy et al., 2021) that noticed a higher number of trips occurring over midday, hinting that these trips were not conducted for commuting purpose.

Figure 8.5 Pre and COVID time micromobility trip counts aggregated by hours of the day (using shortened database).



Source: own elaboration.

8.4.2. Spatial patterns

8.4.2.1. Micromobility trips and land use

Regarding spatial patterns, we conducted different regression models in order to assess the relationship between Madrid's land use distribution and the generation/attraction of micromobility trips. To that end, we used OLS and Spatial Lag models. After conducting OLS models, our results showed spatial dependence with the distribution of the residuals being spatially autocorrelated. Therefore, Spatial Lag models perform better for all the scenarios studied. Our results for the Spatial Lag models are shown in Table 8-5 for the daily behaviour (considering trip origins) and in Table 8-6 and Table 8-7 for the analyses in the morning and afternoon peak hours (differentiating origins and destinations).

In general, both pre-COVID and COVID-time models show similar coefficients of determination, which ranged from 0,42 to 0,81 according to the scenario evaluated, supporting the close link between micromobility trips and the distribution of different land uses. Additionally, better results were found in those models that consider the trip counts on peak hours (AM and PM), especially for the models considering trip destinations (arrivals) as pointed in (Durán-Rodas, 2021). In order to be able to compare the results between the pre and post COVID scenarios, the models present the standardised coefficients (z-score). In all cases, residential and commercial areas gained importance after the pandemic, while workplace locations (office and industrial), educational and transport facilities lost relevance with teleworking and online studying, supporting findings in (A. Li et al., 2020). We can also highlight that the control variable (distance to the city centre) shows the expected result, by appearing with negative values for all models, meaning a greater intensity

of use in central spaces. These results are consistent with similar studies like (Song et al., 2022) which also found that centrality measures were positively influencing micromobility usage.

More specifically, in Table 8-5 we can appreciate the land uses that gained/lost importance after the pandemic in explaining micromobility trip generation. We can observe that residential, workplaces and commercial areas are significant for all three modes, while other land use result significant only for a certain mode, which is the case of educational areas for mopeds and transport-related areas for bikes. The models show that after the COVID-19 outbreak, more trips were generated from residential and commercial areas in bikes, while in the case of mopeds/scooters the contrary occurs. On the other hand, work-related activities lost importance in relation to trip generation for all three modes after the pandemic, especially for mopeds and scooters. Moreover, after the pandemic, mopeds were also less used to start trips from educational areas and bikes were less used to start trips from transport-related facilities. All these patterns are, as mentioned before, caused by the radical changes produced in travel behaviour due to imposed lockdowns and most of the people teleworking from their homes even after confinement was relaxed. Very interestingly, we can observe that average income behaves differently according to the studied mode; in the case of bikes and mopeds, as the income increases in a certain area, the probability to start a trip decreases, but in the case of scooters, starting trips are being generated where high income zones are located (usually the most important touristic areas), which supports that this mode is mostly used for recreational purposes and to visit important points of interest in the city.

Table 8-5 Spatial Lag Model results for departures (starting) micromobility trips by scenario (pre and COVID time) throughout the day (daily trips).

Spatial Lag Model	Starting daily trips					
	Station-based bike-sharing		Dockless moped-style scooter-sharing		Dockless scooter-sharing	
	Pre-COVID	COVID	Pre-COVID	COVID	Pre-COVID	COVID
	Standardized coefficients (z-score)		Standardized coefficients (z-score)		Standardized coefficients (z-score)	
(Constant)	2.00086**	2.26149**	-1.90426*	-2.48882**	0.067112	0.912296
Residential [Km2]	4.37805***	5.25785***	11.7005***	11.4014***	4.81427***	1.50856
Workplaces (Office + Industrial) [Km2]	2.56227**	2.42129**	6.37765***	5.57063***	4.00733***	2.15515**
Commercial [km2]	3.294***	3.88051***	5.43366***	4.57269***	4.4929***	3.38802***
Educational [km2]	0.772802	0.974268	3.04985***	2.33358**	1.58836	0.448024
Cultural+ Entertainment [km2]	1.13572	1.16185	1.88252*	2.02609**	1.91372*	1.70551*
Parks [Km2]	0.836737	0.784931	0.698776	0.830101	1.32786	1.42199
Transport [Km2]	3.06613***	2.43228**	2.15758**	1.39818	1.0196	0.480445
Other [Km2]	1.68713*	1.78321*	4.26145***	3.43407***	1.83576*	1.25939
Distance [km]	-5.18099***	-5.36846***	-3.776***	-2.8951***	-3.94837***	-3.47266***
Av. Income [€/year]	-0.596996	-1.13035	-1.63452	-1.72362*	0.0175316	0.0730372
Lag coeff. (Rho)	8.1689***	7.91815***	20.371***	21.1718***	15.7084***	10.4621***
No. Observations	605	605	605	605	605	605
R ²	0,48	0,50	0,81	0,80	0,69	0,46
AIC	12179.6	12139.8	9569.68	8451.46	7870.19	6539.54

Source: own elaboration.

8.4.2.2. Micromobility behaviour at morning peak hours (06-10 hrs)

With findings of how micromobility generations behave throughout the day, we continue by delving further into models that offer more granularity analysing the commuting patterns in morning peak hours (06-10 hrs) (Table 8-6). In general, the morning patterns are very similar from the daily behaviour as the land uses that result significant are the same: residential, workplaces and commercial for all modes, while educational and transport-related areas result significant only for mopeds and bikes respectively. However, we can now observe some important differences with respect to the daily models, in relation to the type of trip (generated or attracted) by segregating by origins and destinations.

In the case of starting trips from residential areas, we see the same pattern as the daily models, with bikes increasing their importance after the pandemic and mopeds and scooters losing it. However, this is not the case of ending trips, as we now can appreciate that residential areas also attracted more mopeds trips after the pandemic. Similarly, starting trips in mopeds from commercial areas during morning hours decreased, but the contrary occurs with destinations, as commercial areas attracted more moped trips after the pandemic. Hence, the main difference noticed is that when considering morning peak hours and segregating by origins and destinations, residential areas gained importance for generating bike trips, but residential and commercial areas also gained importance for attracting moped trips. The fact that commercial areas gained importance after COVID-19 for BiciMAD users, may be related with the avoidance of public transport for fear of contagion when traveling to food shops, restaurants, retail stores and other commercial establishments. In the particular case of supermarkets, they revealed increased sales after COVID-19 as many people bought groceries to stay at home and be able to reduce eating out (Balsero et al., 2021; Glodeanu et al., 2021). Our results are similar to (Song et al., 2022) that found residential and mixed land uses to be more relevant after the pandemic, as well as (A. Li et al., 2020) that showed that groceries became highly demanded after the pandemic. We can also highlight average income results, as it behaves differently by the type of trip. For morning peak hours, all the models considering starting trips have a negative coefficient, which means that as income increases, the probability to use the services lowers. In contrast, morning ending trips for all the models show positive coefficients, meaning that micromobility trips end mostly at high income areas (touristic areas and places of interest).

Table 8-6 Spatial Lag Model results for departure(starting) and arrival(ending) micromobility trips by scenario (pre and COVID time) during morning peak hours (06-10 hrs).

Spatial Lag Model	Starting trips during AM peak hours (06-10 hrs)						Ending trips during AM peak hours (06-10 hrs)					
	Station-based bike-sharing		Dockless moped-style scooter-sharing		Dockless scooter-sharing		Station-based bike-sharing		Dockless moped-style scooter-sharing		Dockless scooter-sharing	
	Pre-COVID	COVID	Pre-COVID	COVID	Pre-COVID	COVID	Pre-COVID	COVID	Pre-COVID	COVID	Pre-COVID	COVID
	Stand. coeff. (z-score)		Stand. coeff. (z-score)		Stand. coeff. (z-score)		Stand. coeff. (z-score)		Stand. coeff. (z-score)		Stand. coeff. (z-score)	
(Constant)	2.85968***	2.7306***	-1.94443*	-1.98632**	2.01501**	1.18713	0.485967	0.668267	-2.58094***	-3.12986***	-1.49892	-0.888981
Residential [Km2]	4.69324***	5.56329***	12.6026***	11.1196***	4.26385***	2.00482**	3.30951***	4.41446***	5.13905***	6.7445***	3.45303***	2.59153***
Workplaces (Office + Industrial) [Km2]	1.82995*	1.85571*	4.09992***	3.50782***	2.57582*	0.980659	3.25625***	3.2268***	6.53726***	6.12833***	6.40636***	2.72013***
Commercial [km2]	2.24458**	3.11094***	3.08102***	2.74141***	3.44774***	2.11852**	2.79858***	3.5705***	2.65248***	3.20502***	3.0556***	3.26792***
Educational [km2]	0.725555	1.00753	2.32901**	2.13262**	1.42064	0.464121	0.548284	0.809377	1.32016	1.5814	2.34445**	0.538187
Cultural+ Entertainment [km2]	0.300689	0.676184	1.32815	2.1311**	2.03681**	2.04547**	1.39134	1.69082*	1.18194	1.49774	1.2093	1.9855**
Parks [Km2]	0.870349	0.800217	0.69211	0.808235	0.554433	1.17172	0.769545	0.747893	-0.0829867	0.174391	0.293192	0.567735
Transport [Km2]	3.44161***	2.4042 **	2.28582**	1.51637	0.558423	0.174512	2.91055***	2.38453**	1.34787	1.41079	0.681708	0.897788
Other [Km2]	1.52974	1.68787*	3.69724***	2.84997***	1.12484	1.0647	1.54175	1.80179*	2.32122**	2.3129**	1.70636*	1.39676
Distance [km]	-5.46468***	-5.18149***	-2.40945**	-1.73999*	-4.41006***	-2.74763***	-4.3395***	-4.70973***	-3.64003***	-3.35723***	-	-2.91183***
Av. Income [€/year]	-1.17064	-1.97134**	-	-3.08515***	-1.32035	-1.07899	0.928113	0.524161	3.24411***	2.56069**	1.8876*	1.39651
Lag coeff. (Rho)	6.89492***	8.33322***	21.6743***	23.3689***	13.0097***	14.0185***	9.94371***	9.20871***	11.4974***	13.9022***	17.0489***	13.2692***
No. Observations	605	605	605	605	605	605	605	605	605	605	605	605
R ²	0.42	0.49	0.79	0.77	0.59	0.49	0.50	0.52	0.57	0.65	0.64	0.53
AIC	10521.6	10323.9	7060.77	6096.17	5515.51	4043.5	10519.1	10367.3	7705.93	6412.84	5467.62	3738.63

Source: own elaboration.

8.4.2.3. Micromobility behaviour at afternoon peak hours (16-20 hrs)

The results for afternoon peak hours (16-20) (see Table 8-7) show that residential areas gained importance for attracting and generating trips in bikes after the outbreak. In the case of mopeds, more trips were generated from residential areas after COVID-19, but few less were attracted. And in the case of scooters, the pandemic caused a lost in importance for both, starting and ending trips. In the case of commercial areas, results for afternoon hours show that these areas gained importance in the generation/attraction of trips only for bikes, while losing importance for attracting or generating trips in mopeds and scooters. The rest of the results are consistent with the daily behaviour: activity areas lost importance and residential and commercial places were generators or attractors for micromobility trips. These results are also consistent with what was found, also for the case of Madrid, by (Romanillos et al., 2021) using mobile phone data. With most of the population teleworking or studying online, micromobility trips for commuting reason were drastically reduced. Regarding average income variable in the afternoon peak models, they show that for starting and endings trips have negative coefficients, with the exception of scooters, meaning that only in the case of scooters, starting trips tend to departure from high income areas, supporting the theory of touristic use.

Table 8-7 Spatial Lag Model results for departure(starting) and arrival(ending) micromobility trips by scenario (pre and COVID time) during afternoon peak hours (16-20 hrs).

Spatial Lag Model	Starting trips during PM peak hours (16-20 hrs)						Ending trips during PM peak hours (16-20 hrs)					
	Station-based bike-sharing		Dockless moped-style scooter-sharing		Dockless scooter-sharing		Station-based bike-sharing		Dockless moped-style scooter-sharing		Dockless scooter-sharing	
	Pre-COVID	COVID	Pre-COVID	COVID	Pre-COVID	COVID	Pre-COVID	COVID	Pre-COVID	COVID	Pre-COVID	COVID
	Stand. coeff. (z-score)		Stand. coeff. (z-score)		Stand. coeff. (z-score)		Stand. coeff. (z-score)		Stand. coeff. (z-score)		Stand. coeff. (z-score)	
(Constant)	1.60662	2.20886**	-2.31598**	-2.6997***	-0.189644	0.793257	2.67755***	2.76434***	-1.81773*	-2.15227**	0.447729	0.975273
Residential [Km2]	4.41327***	5.03675***	10.7412***	10.8152***	4.03713***	1.21909	4.309***	5.0933***	11.7545***	11.0121***	7.8836***	4.7422***
Workplaces (Office + Industrial) [Km2]	2.84674***	2.5362**	6.23679***	5.78668***	3.82372***	2.22223**	1.84707*	1.89516*	4.67922***	4.79896***	3.9743***	2.97832***
Commercial [km2]	3.54359***	4.08096***	5.1678***	4.76592***	4.18485***	3.53267***	3.19803***	3.82228***	5.53157***	4.21891***	5.67326***	3.33522***
Educational [km2]	0.776865	0.937593	2.79137***	2.32248**	1.28736	0.416922	0.832051	1.00752	2.97229***	2.31447**	1.8373*	0.878672
Cultural+ Entertainment [km2]	1.42924	1.26218	1.89987*	1.63875	1.35233	1.4752	0.973696	1.07849	2.13779**	2.02407**	1.92853*	1.81462*
Parks [Km2]	0.778721	0.795213	0.621742	0.780047	1.40707	1.40763	0.786458	0.731408	0.935488	0.928319	1.61606	1.36543
Transport [Km2]	2.90108***	2.39437**	2.14372**	1.41021	1.2992	0.652213	2.75934***	1.99932**	2.33728**	1.13835	2.38285**	0.971706
Other [Km2]	1.50659	1.60474	3.64648***	2.99995***	1.59874	1.20876	1.36552	1.54665	3.76623***	3.40624***	2.36011**	1.23208
Distance [km]	-5.14382***	-5.49555***	-3.7685***	-2.96123***	-3.94324***	-	-5.0224***	-5.20789***	-	-2.75792***	-	-
Av. Income [€/year]	-0.137943	-0.776565	-0.393491	-0.932162	0.97861	0.616022	-1.68754*	-1.9854**	-2.55983**	-2.0627**	-1.13322	-0.903908
Lag coeff. (Rho)	8.03225***	7.27166***	18.5668***	19.5252***	13.9811***	9.06884***	8.172***	7.90297***	21.2751***	20.4741***	16.744***	12.2972***
No. Observations	605	605	605	605	605	605	605	605	605	605	605	605
R ²	0.48	0.48	0.78	0.78	0.64	0.42	0.46	0.48	0.81	0.78	0.76	0.58
AIC	10758.2	10831.9	7883.47	7182.94	6942.25	5469.03	10829	10858	7802.19	7163.31	6399	4889.55

Source: own elaboration.

8.5. Conclusions

Micromobility services have demonstrated to be a crucial part of the solution to achieve sustainability (European Commission, 2020; Fulton, 2018; Lazarus et al., 2020; Teixeira & Lopes, 2020). These recently introduced services are offered as an alternative to the private car, promising a shift to a more sustainable travel pattern by reducing car-dependency and thus, the environment pollution. With the COVID-19 pandemic, the need for this modal shift has grown and so does the need to understand the changed urban dynamics. We have processed and studied real data from three micromobility operators, which allowed us to compare the last semesters of 2019 and 2020. This exploration helped us to begin to measure and understand the impact of a global pandemic in one of the most affected regions of Europe (Madrid). Our descriptive analysis yields that after COVID-19, BiciMAD actually gained and surpassed its trip records (September 2020). We also found that, as in (A. Li et al., 2020; Molloy et al., 2021; Teixeira & Lopes, 2020), average trip time and distance for bike-sharing increased with COVID-19. Multiple regression results showed that residential and commercial areas became more relevant activities after the pandemic, while workplace locations (office and industrial) and education facilities had a downfall, especially in the early morning commutes. Our results are similar to previous studies (Song et al., 2022; Zhu et al., 2020) that have found a close link between micromobility usage and high residential densities. This is closely related to the fact that a great extent of micromobility users were confined at their homes and began to telework or to study online. This caused a ridership drop of 80% in public transport. However, our findings show that micromobility trips were down, in general, only by 10%, which is a relatively better performance.

Consequently, one conclusion for our study is that the pandemic has highlighted the importance of micromobility services as they seem to be more pandemic-resilient than mass transit as other studies have also found (Julio & Monzon, 2022). Interestingly, for the case of Madrid parks were not significant in the models, in contrast to other studies like (A. Li et al., 2020) in which they found park activity, mainly done in open areas, increased their attractiveness after COVID-19. Data also suggests that, as mentioned by previous studies, fear of contagion could have influenced customers to adopt alternative shared modes for their last mile trips (Arias-Molinares, Julio, et al., 2021; A. Li et al., 2020). In general, our results are consistent with the literature revised, as micromobility trips' time and distance increased after the pandemic and some uses associated with residential and commercial areas were more relevant than others related to activities like work, study, leisure or cultural points of interest.

These results could be of help to understand the impacts brought by the pandemic and which places became more attractive at a certain time of the day, to implement better-informed policies that could help improve urban mobility. Micromobility services had shown to be crucial for maintaining social distance while at the same time being a flexible transport option, thus the positive outcomes brought by the pandemic (increased bike trips) should be maintained or improved by designing and planning better cycling infrastructure and parking facilities for shared mobility. As some studies suggest, the lack of car traffic during the lockdown undoubtedly made cycling more attractive with higher number of trips and bicycle sales (Molloy et al., 2021). We have entered the era of pandemic-resilient cities as an indicator of sustainability (POLIS, 2021). Hence, cities should consider micromobility services as a crucial part in the mobility ecosystem and as a solution to limit future contagions. As circumstances become normal again, many residents will go back to their pre-pandemic mobility patterns. With the fear of contagion still influencing, some users may decide to start using their private automobiles. Some studies have

already shown that as lockdown measures were relaxed, a higher share of kilometres was performed using motorized transport but also active mobility (walking and cycling), with public transport recovering at a slower pace (more gradually) (Molloy et al., 2021). As (D. Wang et al., 2021) estimated, a 50% restriction of public transport capacity could derive in a 142% increase of car usage. Hence, these measures should always be accompanied with other complementary strategies that promote micromobility services, like adequate parking, attractive pricing schemes and traffic calming measures. Authorities and transport planners should avoid the unsustainable modal shift to private cars by promoting shared mobility and safety measures in public transport. Strategies to promote cycling include the addition of new cycling infrastructure (e.g., transitioning from pop-up cycling lanes to permanent ones), designing and implementing new mobility hubs and reallocating large swaths of street space from the car to active modes. Such policies oriented to connect and increase cycling paths and lanes, to make intersections and circulation for cyclists safe, to implement storage/parking infrastructure and to improve urban design for cycling are all elements to be considered and broadly adopted as they involve a relatively low-cost implementation with high flexibility. The increased preference for cycling as a result of the pandemic should make authorities and transport planners reflect on long-term policies to maintain this sustainable shift. Telework and online studies demonstrated to play an important role to stop the spread of COVID-19 in workplaces and public transport, hence an important issue will be to reflect on the extent to which these measures should be encouraged after the pandemic and its implications for transport policy as stated in (Molloy et al., 2021). On the other hand, micromobility operators could capitalise the opportunity that the pandemic has given them.

Recommendations for micromobility operators include maintaining hygiene/disinfection measures adopted during COVID-19, offering competitive prices and discounts to customers (including gamification strategies) and increasing the vehicle supply and coverage areas. Increasing coverage could be especially interesting for operators in those areas with high student densities as many studies have supported that young people tend to be more willing to use micromobility services (Degele et al., 2018; Fistola et al., 2022). Limitations in this study include the fact that cleaning the datasets required certain assumptions to be made of the underlying platforms, such as no trips over a certain speed, etc. The approach used in this work was overly conservative likely erroneously removing actual trips from analysis in order to not include redistribution trips. This was an unfortunate necessity which could be rectified by the data providers tagging trips as either user trips, or administrative trips. Additionally, a second limitation of the study regards that our datasets do not have any information about micromobility subscribers (e.g., unique id for exploring repeated customers and travel patterns or mode from which they are switching to/from) due to privacy issues. This is crucial to better understand the changes in modal choices and travel patterns after the pandemic. Future studies could analyse data for 2021 to see if the good resilient trends are maintained (the so called “bicycle boom” after COVID-19) and to evaluate in a better way the effect of the service recoveries as well as addressing the impacts of new BiciMAD expansions.

9. Integrating micromobility and public transport through mobility hubs

9.1. Introduction

New, shared mobility services have been introduced in many cities with the aim of tackling the current climate crisis. These new forms of mobility offer an alternative to the private automobile, covering the first/last mile connection of trips. Micromobility services are defined as the short-term access to low-speed shared mobility vehicles (Shaheen & Cohen, 2019). Investment and interest have sparked rapid expansion due to its benefits: low air/noise pollution, avoidance of congestion, reduction of parking space needed and intermodality potential with mass transit (Aguilera-García et al., 2020). Nevertheless, micromobility services still require some space to avoid conflicts with pedestrians, usually by occupying sidewalks while using urban planning to regulate them accordingly (Hendersen, 2019). In addition, by having more travel options available now, passengers may begin to increase their trip's transfers which is making the concept of intermodality and multimodal travel a key concern (Brand et al., 2017).

The concept of mobility hubs is presented in order to provide more attractive connections between various modes of micromobility alternatives and to organise them in a designated area (Aono, 2019; Aydin et al., 2022; Blad et al., 2022). Many definitions are offered for mobility hubs (Blad et al., 2022; Miramontes et al., 2017; Tran & Draeger, 2021), but the concept's central purpose is to create a space that integrates public and shared mobility modes to improve the public realm (comoUK, 2021). They are designed to be highly visible, safe and accessible to allocate public, shared and active travel modes while also offering relevant and enhanced community facilities (Bell, 2019).

To implement new mobility infrastructure, especially mobility hubs, decision-makers should solve multiple planning tasks simultaneously. One of the most important and strategic decisions is in regard to the location. In other words, an answer to the question: "where do we allocate a new mobility hub?". Proposing methodologies that assess how to prioritise and decide on where to install them are highly relevant for transport authorities. Previous studies have delved into this topic and proposed methodologies that consider three different approaches: 1) accessibility measurement oriented to maximise access to points of interest (POIs) and jobs (Ben-Elia & Benenson, 2019; Duran-Rodas et al., 2022; Guan et al., 2020; Hernandez, 2018), 2) mathematical optimization methods oriented to find the best locations based on the operators' perspectives (maximise profit or demand) (Nair & Miller-Hooks, 2016; Petrovic et al., 2019; Steiner & Irnich, 2020), or 3) a combination of both (Frank et al., 2021).

Few studies include micromobility use analysis in their modelling approaches, primarily because of its recent inception. We intend to contribute to this line of research by considering public transport usage for both intermodal stations and micromobility arrivals. If mobility hubs are the integration of both public transport and micromobility services, then we argue it's necessary to understand micromobility services in location-planning.

This study analyses micromobility data to understand the factors associated with the use of different shared services and to implement these findings in location planning of new mobility hubs. To that end, our research questions are: What are the common factors associated with the usage of different micromobility options? How can we take these factors in consideration when trying to allocate new mobility hubs? The aim is to first understand how micromobility functions and based on this finding, assess the best possible locations for micromobility hubs.

Our study uses GPS records of trip arrivals for three different micromobility services (shared bikes, mopeds, and scooters). We build regression models of each micromobility service to associate the trip arrivals with built environment factors. Additionally, we explore a second approach by merging the trip arrivals of different micromobility services as “one variable” using Principal Component Analysis (PCA) and then associating it with the built environment. These two approaches and resulting models are compared to identify the one that fits better the dataset (trip arrivals and built environment). Finally, the predicted usage will serve to build kernel density maps and thus, find the hot spot areas for potential locations for new mobility infrastructure.

9.2. Background

9.2.1. Current research on micromobility demand

The literature on micromobility services has increased in the last decade, particularly for bike-share programs as these were the first systems to be deployed. Quantitative studies done on micromobility service use and demand has only recently been taken up, leaving much to be explored. For example, (Corcoran et al., 2014) uses GPS data to explore the effects of weather and calendar events on spatio-temporal patterns of bike-sharing using multivariate regression models. Another similar study conducted by (Purnama, 2018) analyses GPS records from the public bike-sharing system in London and New York and uses Pearson’s correlation coefficient to observe the association of external factors with daily usage. Similarly, (Nickkar et al., 2019) uses GPS records to study the influence of socio-demographic factors on travel patterns in Baltimore and evaluates the relationship between gender and land use in terms of the trip’s origin and destination locations. While spatial factors are studied within a city, (Duran-Rodas et al., 2019b) identifies associated factors with bike-sharing usage in different cities. Moreover, on the study (Durán-Rodas, 2021) potential demand of bike sharing is estimated using structural equation models via the built and social environment. This latter study is similar to (E. Desjardins et al., 2022) that investigated how bike-sharing could increase accessibility to under-served neighbourhoods.

More recently, with the introduction of new shared micromobility modes like mopeds and scooters, studies have analysed factors associated with usage between existing bike-sharing, moped, and scooter systems. One of these studies, conducted by (Zhu et al., 2020) compares dockless bike-sharing and station-based scooter-sharing services using GPS records (of bikes) and a scraping tool (for scooters) to estimate redistribution trips. They also found that fleet sizes as well as other descriptive characteristics can help understand the differences of the two services. Moreover, (Younes et al., 2020) studies

six dockless scooter-sharing services and historical trip data for the city's public bike-sharing service (Capital Bikeshare in Washington DC) to estimate two variables: hourly number of trips and hourly median duration of trips. This estimation was based on a negative-binomial regression model including environmental and economic variables such as weather-related data, gasoline prices, local events or disturbances, day of the week, and time of day. Regarding moped-sharing services (also known as moto-sharing), two recent studies are found. (Pérez-Fernández & García-Palomares, 2021) uses GPS datasets and proposes a methodology to locate parking places based on the varying distribution of demand over the day. Additionally, (Jiao & Bai, 2020) applied univariate LISA to identify areas of high demand (hot spots) in the use of shared e-scooters, as a preliminary step before applying regression models. Similarly, our paper intends to analyse various modes of transport simultaneously (bikes, mopeds, and scooters) as a whole, i.e., which is one important step in the planning process for a mobility hub.

9.2.2. Current research on mobility hub allocation

The literature on mobility hubs is as recent as the nature of the concept itself (2000s) (comoUK, 2021). Moreover, the mobility hub allocation is a topic in need of new contributions. While some authors argue that the term “mobility hub” is relatively new, the ideas behind it are not (Rongen et al., 2022). Transit-Oriented Development (TOD) and Park and Ride (P+R) policies are two clear examples of urban planning strategies aimed at reducing resistance to transfers between public transport and micromobility services. It is argued that mobility hub allocation could also take into consideration the criterion that TODs and P+R's measures considered. For example, placing them where travellers find important destinations (POIs and jobs) or designing them differently according to their particular objective.

(Blad et al., 2022) developed and tested a methodology to determine suitable areas for mobility hubs in Rotterdam, incorporating government, end-user and operator perspectives. The authors focused on what they called the “regional” mobility hub located outside city centres to act as an intermodal point of transfer. Their methodology considered five criteria that measured location suitability: potential demand at a certain location, hub implementation costs, generalised travel costs to and from the hub, link to surrounding areas, and societal impact. Another study by (Aydin et al., 2022) applied a weighted multicriteria methodology considering a different criterion (public interest, structural suitability, demographic patterns, and accessibility) to select new mobility hub locations in Istanbul, Turkey. Their results supported a hub location within the city centre near transport facilities to increase intermodality.

Similarly, (Tran & Draeger, 2021) proposes a methodology that integrates network science and urban data analytics to spatially locate hubs and calculate performance metrics. These metrics include hub location, capacity, multimodal availability, travel times, and equity based on differential access to hubs by household income. The authors offer a tool for city planners to select urban hubs based on weights that reflect policy priorities and scenarios. The study by (Frank et al., 2021) develops a decision-support tool for rural decision-makers to locate mobility hubs, combining accessibility (access to important points of interest POIs and jobs) and optimisation-based modelling criteria. Their model

sought to improve accessibility planning to POIs by maximising the average share of POI categories that inhabitants may reach within a certain travel time threshold. Additionally, workplaces are considered by maximising the average ratio of travel time by car and the travel time of (intermodal) travel itineraries for rural commuters. (Nair & Miller-Hooks, 2016) present a bilevel network design model to minimise total travel time as well as costs for implementing mobility hubs. Their model includes decisions on shared mobility service locations and consider vehicle inventories and hub capacity.

(Petrovic et al., 2019) propose a methodology for allocating mobility hubs along a public rail transport route in a two-step methodology. First, they use a GIS-based approach to determine the best set of potential locations with consideration for population and catchment areas (population covered in a certain area). Second, they propose an optimisation algorithm to provide decisions on potential locations given a predefined number of final locations. All the mentioned studies considered only public transport system data, with the exception of (Tran & Draeger, 2021) which consider micromobility parking areas. Similarly, to the previous mentioned studies, we aim to include variables related to the built environment but differently from them, we also will include variables related to micromobility trip arrivals in the modelling process (see list of variables in Table 9-2).

9.3. Study case, data and methods

9.3.1. Study case

The study area takes place in Madrid, Spain, known as one of Europe's living labs for shared mobility, allowing its residents to be familiar with the emerging transport options, especially micromobility services (Aguilera-García et al., 2020). The multiple and varied shared mobility supply, along with a solid public transport system, a great land-use diversity and high population/employment densities has made Madrid an appropriate area for these new services to thrive (Arias-Molinares & García-Palomares, 2020a; Fluctuo, 2022; Granda & Sobrino, 2019). In 2019, the shared mobility fleet was estimated to be more than 20.000 vehicles (Arias-Molinares & García-Palomares, 2020a; Granda & Sobrino, 2019). These services are usually supported by mobile applications where their clients register and locate vehicles and in the case of Madrid, the whole micromobility fleet is electric.

For our study, we considered 3 micromobility operators: *BiciMAD*, *Movo*, and *Moving*. *BiciMAD* is Madrid's public bike-share system in operation since 2014, currently managed by the Municipal Transport Company (EMT) with around 75.000 subscribers (Ayuntamiento de Madrid, 2019a). Since its launch in 2014, four expansions have taken place with a total of 264 stations and 2.900 bikes. All vehicles in *BiciMAD*'s fleet are equipped with GPS trackers and pedal assistance up to 25 km/hr. *BiciMAD* is managed by a public transport authority and it is the first micromobility service deployed in the city. Another service option is *Movo*, a moped-style scooter-sharing (also known as moto-sharing) and scooter-sharing service launched in 2018, operating 500 mopeds and 1.400 scooters (Polo & González, 2019). Finally, *Moving* is a moped-style scooter-sharing operator that manages 755 mopeds. The company was operative in Madrid from 2018 to 2020 but is no longer in use (Arias-Molinares & García-Palomares, 2020a). *BiciMAD* has designated locations where users pick and leave the bicycles at, while dockless services,

like *Movo* and *Moving*, offer more flexibility as the vehicles can be picked/returned at any location within a geographic area (also known as geo-fence).

9.3.2. Data

This research used a dataset composed of information collected from six main different groups of variables (see Table 9-2):

- Micromobility trip arrivals: trip datasets were provided by micromobility operators through established collaboration agreements with *Movo* and *Moving* to access anonymised trip data. *BiciMAD*'s data is publicly shared through an open data portal ([https://opendata.emtmadrid.es/Datos-estaticos/Datos-generales-\(1\)](https://opendata.emtmadrid.es/Datos-estaticos/Datos-generales-(1))). For each service, we obtain information related to the trips' origin and destination. The datasets cover the timeframe from June to December 2019 (last semester of 2019). We decided to analyse based only on destinations only as previous similar studies as recommend in (Durán-Rodas, 2021). The reason behind this choice is that trip arrivals are more closely correlated with the trip purpose than departures.
- Cycling infrastructure and intermodal stations: Madrid's cycling infrastructure is collected from the City Hall's open data website: <https://datos.madrid.es/portal/site/egob/menuitem.c05c1f754a33a9fbe4b2e4b284f1a5a0/?vgnextoid=325e827b864f4410VgnVCM2000000c205a0aRCRD&vgnextchannel=374512b9ace9f310VgnVCM100000171f5a0aRCRD&vgnextfmt=default> which offers a layer of cycling infrastructure updated until 2014. They categorise cycling infrastructure into two categories according to the level of segregation with respect to traffic flow: 1) partly or fully segregated ("Vías de uso exclusivo o preferente"), and 2) non-segregated ("Vías de uso compartido"). Additionally, in order to consider the location of the main intermodal stations, we added information containing the average number of travellers entering these stations per day. This information was provided through a collaboration agreement with the transport authority of the city (Consortio Regional de Transportes de Madrid,) which manages intermodal stations. Intermodal stations in Madrid are pre-defined by the transport authorities as those transport infrastructures designated to facilitate intermodality (interchange connections) between different modes of public transport. Inside the city centre they defined the following 10 intermodal stations: Chamartín, Plaza Castilla, Moncloa, Atocha, Príncipe Pío, Avenida de América, Estación Sur, Nuevos Ministerios, Plaza Elíptica y Sol.
- Land use and employment: Land use data is provided by the Directorate General for Cadastre in Spain (Cadastre) with built entities of the study area (buildings). The databases define the surface area [m²] of each type of land use in the year 2020.
- Points of interest (POIS): A layer of more than 30.000 POIs is obtained from Google Places API (updated up until 2020). We grouped them according to two categories: 1) 18 specific categories, and 2) five general categories. The aggragation was done considering similar activities (see Table 9-2).
- Socio-demographic: Census data is obtained from the National Institute of Statistics (INE) which includes the population count for 2019. Additionally,

income data is provided by the City of Madrid's open data website, containing the average annual home income by census section of Madrid for 2018.

- Centrality measures: We calculate a network centrality measure called "closeness" in its normalised form. It indicates how close a node i is to all other nodes in the network. It is calculated using the following formulas:

Table 9-1 Network Centrality measure- closeness normalised

Measure	Definition	Normalization
Reach	$Reach[i]^r = \sum_{j \in G - \{i\}, d[i,j] \leq r} W[j]$	$Reach[i]^r_{norm} = \frac{Reach[i]^r}{\sum_{j \in G - \{i\}} W[j]}$
Closeness	$Closeness[i]^r = \frac{1}{\sum_{j \in G - \{i\}, d[i,j] \leq r} (d[i,j] \cdot W[j])}$	$Closeness[i]^r_{norm} = Closeness[i]^r \cdot Reach[i]^r$

Source: (Sevtsuk et al., 2016)

Table 9-2 Variables used for the study

Variable	Description	Group	Unit	Mean	Standard deviation	Min	Max
Trips_bike_arrivals	Average daily arrivals using BiciMAD bikes inside each 400m-catchment area	Mobility	arrivals	44	25	0	130
Trips_moped_arrivals	Average daily arrivals using mopeds inside each 400m-catchment area			10	6	1	33
Trips_scooter_arrivals	Average daily arrivals using scooters inside each 400m-catchment area			2	1	0	5
Intercity_train	Average daily number of travellers entering a intercity train station		travellers	847	5.606	0	52.950
Intercity_bus	Average daily number of travellers entering a intercity bus station			990	8.275	0	79.713
Closeness_norm	No distance defined = total network considered	Network centrality measures	degree	0,000336	0,000064	0,000191	0,000451
pop_20_49	Total residents between 20 and 49 years old covered inside each 400m-catchment area	Socio-demographics	inhabitants	1.999	1.565	0	8.825
income	2018 Average annual household income		Euros/year	54.388	17.162	26.743	91.933
cycling_infra	Proximity to cycling infrastructure	Proximity to cycling infrastructure	m	1.101,29	783,11	0,00	3.826,72
seg_cycling_infra	Proximity to segregated cycling infrastructure			150,03	326,50	0,00	2.345,22
nonseg_cycling_infra	Proximity to non-segregated cycling infrastructure			951,27	741,50	0,00	3.645,78
employment	Number of employees covered inside each 400m-catchment area	Employment	employees	3.588	2.668	276	16.559
Employ_edu	Number of employees in the educational sector covered inside each 400m-catchment area			193	194	0	1.060
Employ_health	Number of employees in the health sector covered inside each 400m-catchment area			180	182	0	992
Employ_hotel	Number of employees in the hospitality sector covered inside each 400m-catchment area			417	385	18	2.950
Employ_leisure_entertain	Number of employees in the leisure/entertainment sector covered inside each 400m-catchment area			94	118	0	663
Employ_office	Number of employees in offices covered inside each 400m-catchment area			1.232	1.361	48	9.264
Employ_retail	Number of employees in the retail sector covered inside each 400m-catchment area			422	403	0	2.526
LU_greenareas	Parks and green areas	Land use	m2	19.760,47	36.975,39	0,00	246.786,49
LU_industrial	Industrial			7.086,96	14.954,41	0,00	86.453,98
LU_entertain	Leisure and hotels			8.933,26	15.669,80	0,00	95.197,10
LU_office	Offices			44.659,56	48.507,00	1.293,43	290.493,99
LU_Residential	Residential			245.886,12	156.453,19	0,00	872.932,70
LU_Retail	Retail/commerce			33.596,89	23.046,01	224,99	128.040,71
LU_sport	Sport areas			2.462,85	7.985,61	0,00	68.743,69
cat_accomodation	Accommodation= lodgings	Points of interest (18 specific categories)	Number of POIS	0	0	0	1
cat_admin	Administration and public institutions = police, city hall, courthouse, embassy and local government office			1	1	0	9
cat_atm	ATM = ATM			1	2	0	10
cat_bar_rest	Bars and restaurants = bar, café, night club and restaurants			4	4	0	18
cat_cul_lei	Culture and leisure = amusement park, aquarium, art gallery, bowling alley, casino, library, movie theatre, museum and stadium			1	1	0	4
cat_education	Education = School, secondary school and university			0	0	0	2
cat_health_well_beu	Health, wellness and beauty = Beauty salon, dentist, doctor, drugstore, hair care, hospital, pharmacy, physiotherapist, veterinary care, gym and spa			8	7	0	40
cat_home_service	Home service= Electrician, locksmith, moving company, painter, plumber and roofing contractor			0	0	0	2
cat_home_food_deli	Home service- food delivery = meal delivery			1	1	0	8

Variable	Description	Group	Unit	Mean	Standard deviation	Min	Max
cat_open_air	Open air = Park and cemetery	Points of interest (5 general categories)	Number of POIS	0	1	0	4
cat_open_air_acco	Open air accommodation= campground			0	0	0	1
cat_religious	Religious = Church and mosque			0	1	0	3
cat_shop_basi	Shopping basic= Insurance agency, bakery, bank, clothing store, convenience store, furniture store, hardware store, home goods store, laundry, pet store, post office, real estate agency, shoe store, supermarket and lawyer			8	7	0	33
cat_shop_mall	Shopping department store mall= department store and shopping mall			0	0	0	3
cat_shop_optional	Shopping optional= accounting, travel agency, bicycle store, bookstore, car dealer, car rental, car repair, car wash, electronics store, florist, jewellery store, liquor store, meal takeaway, movie rental, storage and store			6	5	0	30
cat_tour_attrac	Touristic attractions= touristic attraction			0	1	0	3
cat_transp_private	Transport-private= parking and gas station			0	0	0	3
cat_transp_public	Transport-public= bus station, subway station, train station and transit station			0	1	0	10
cat_Dining	Dining = Bar, café, restaurant and meal delivery			5	4	0	22
cat_Entertainment	Entertainment= night club, amusement park, bowling alley, casino, movie theatre, stadium and spa			1	1	0	7
cat_Public_facilities	Public facilities= Police, city hall, courthouse, embassy, local government office, library, school, secondary school, university, hospital, cemetery, church, mosque, airport, bus station, subway station, train station, transit station			2	2	0	13
cat_Shopping	Shopping= beauty salon, drugstore, hair care, pharmacy, physiotherapist, electrician, locksmith, moving company, painter, plumber, roofing contractor, insurance agency, bakery, clothing store, convenience store, furniture store, hardware store, home goods store, laundry, pet store, post office, real estate agency, shoe store, supermarket, accounting, travel agency, bicycle store, book store, car dealer, car rental, car repair, car wash, department store, electronics store, florist, jewellery store, liquor store, meal takeaway, movie rental, storage, store, lawyer, shopping mall and gas station			19	14	0	77
cat_tour_attrac	Touristic attractions= aquarium, art gallery, museum, park, tourist attraction			1	1	0	6

Source: own elaboration.

9.3.3. Methods

The proposed method aims to estimate potential micromobility use in new areas of Madrid. To that end, we start with the data collection and cleaning and then follow a two-stage process: (1) stage- identification of common spatial factors associated with micromobility usage, and (2) stage- estimation of micromobility usage.

9.3.3.1. Data collection and cleaning

First, we processed, cleaned and prepared the datasets. For all services, the initial cleaning process involved keeping only trips with distances between 100m and 70 km and travelled time between 60 seconds and 2 hours as recommended in previous studies (Jaafar, 2022; McKenzie, 2019b). This was necessary in order to eliminate erratic data, unrealistically long-distance trips (probably GPS errors), and redistribution trips (as only BiciMAD tagged them). As we had the total arrivals of the last semester of 2019, we divided the total amount of arrivals in the six-month period by 180 days (30 days * 6 months= 180 days/semester) in order to obtain the average daily arrivals per mode. Once the data is cleaned, we created 400m-network-based catchment areas around each of the 205 BiciMAD stations that were operative until February 2020.

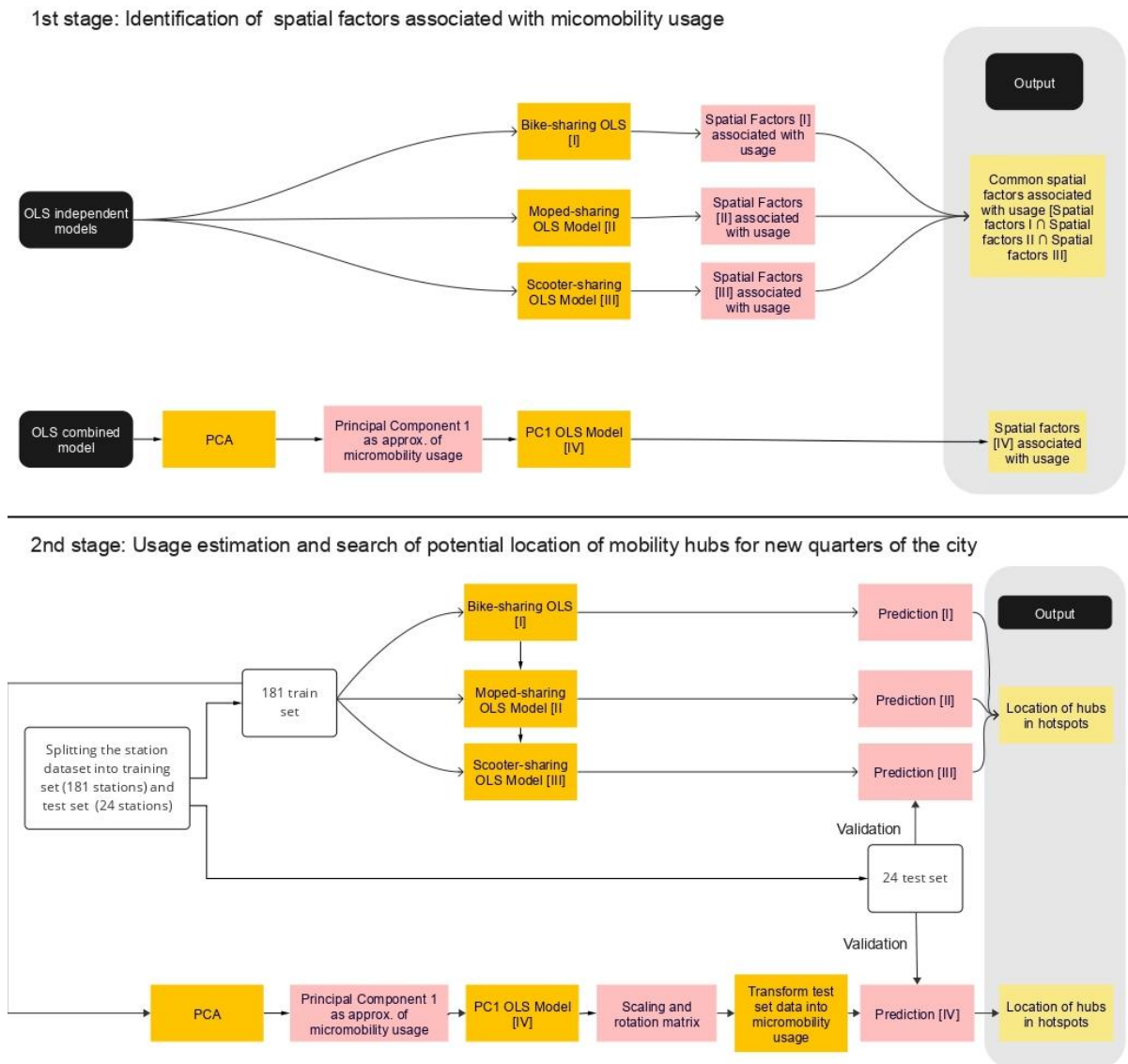
As a result, we obtained 205 catchment areas from the bike sharing stations (our spatial unit of analysis). These service areas are calculated around a 400m walking distance in the transport network and do not overlap each other. The choice of 400m was determined based on previous studies that stated that it is an acceptable walking distance (Aguilera-García et al., 2020; Tran & Draeger, 2021; D. Zhao et al., 2021). The 205 catchment areas are used to aggregate trip arrival information and the rest of the variables. Any shared bike, moped, or scooters' arrival point that falls within each of the 205 catchment areas is counted. As the catchment area sizes are smaller in the city centre where the density of BiciMAD stations is higher, the aggregation of the different variables is affected by the area of the catchment area. In order to make a comparable analysis between the different modes, we calculated each variable density per square metre (variable/m²). In other words, we divided all the variables that are area-related (with the exception of income and closeness), by the catchment area obtaining the unit of the variable per square metre (m²).

9.3.3.2. First stage: Identification of common spatial factors associated with micromobility usage

Following data preparation, we follow the methodology synthesised in Figure 9.1. In this stage, we follow two approaches. The first approach identifies the common spatial factors associated with micromobility usage by each micromobility mode individually, and in a second approach, we develop a combined variable that represents the three shared services together. Variables are preselected using Pearson's correlation coefficient threshold of 0.7 between all variables studied as done in (J. Zhao et al., 2014). In the first approach, variables with the highest correlation with trips arrivals were initial inputs for the stepwise OLS regression models for each shared service (bike, moped and scooter). The dependent variable was the count of trip arrivals per m2 (bike, moped and scooter

arrivals) and the independent variable considered were the built environment variables collected for each catchment area.

Figure 9.1 Methodology of the study



Source: own elaboration.

As a second approach, we used PCA to identify a component that represents the usage of the three modes together (combined model). Addressing micromobility services in general required the creation of a new latent variable called “micromobility usage” based on the first component of the PCA (PC1). The resulting PC1 intends to combine most of the variance (74,12 %) of trip arrivals of the three micromobility services. It is worth highlighting that the first component does not include the entire variance but the biggest proportion of it in a single variable. Furthermore, our main goal is not to capture the whole variance in the first principal component but to identify common factors with the majority of the variance and further estimate "hot or cold spots" (for decision making on potential location of mobility hubs) rather than the exact or precise estimation.

PCA aims to reduce dimensionality and weigh all observations based on a composite index variable (Bai et al., 2022; Patil & Sharma, 2022). In most scenarios, PCA is applied to

transform a high-dimensional dataset into a lower-dimensional dataset by using only the first few PCs, so that dimensionality is reduced with minimal loss of information. Its central idea is creating an index variable, in our case *micromobility usage*, from a set of correlated variables. It is commonly used to convert collinear variables into several, linearly uncorrelated variables named principal components (PCs). This is done by finding a new coordinate system, so that the information of the data is mainly concentrated on the new axes. In this conversion, each PC is a linear combination of the original variables, as shown in Eq. (1). After listing the eigenvalues of the correlation matrix of the original dataset in descending order, then the i th PC is associated with the i th eigenvalue, and the corresponding eigenvector $(\alpha_{i1}, \alpha_{i2}, \dots, \alpha_{ip})$ is used to summarise the original variables. The PC associated with the largest eigenvalue, that is, the first PC, captures the most information.

$$PC_i = \alpha_{i1}X_1 + \alpha_{i2}X_2 + \dots + \alpha_{ip}X_p \quad (1)$$

If n PCs are retained, they need to be weighted to obtain a total score, which, in our case, is going to be the approximation of *micromobility usage*. The weight of the k th PC is given by Eq. (2), and the final total score is given by Eq. (3):

$$W_k = \lambda_k / (\lambda_1 + \dots + \lambda_n) \quad (2)$$

$$Total\ score = \sum_{k=1}^n PC_k W_k \quad (3)$$

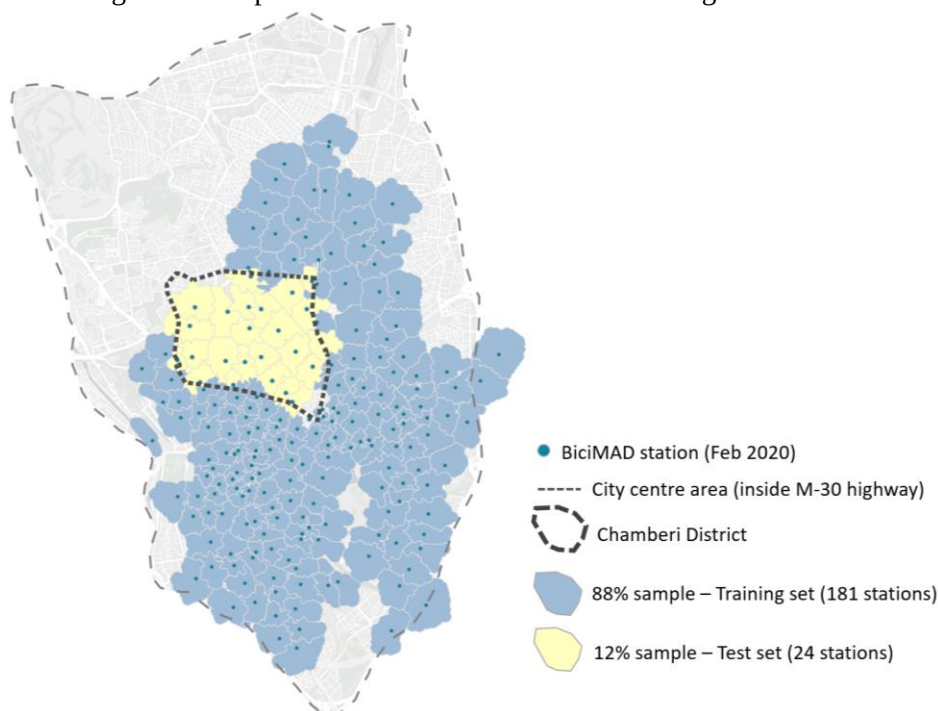
Where λ_k represents the associated eigenvalue of the k th PC.

Once we conducted the PCA and obtained the scores, we used these scores as the dependent variable for a new model as representative of micromobility usage. Consequently, this first part of the methodology results in three independent models (bike, moped and scooter model) and one combined model, allowing us to identify the common associated spatial factors in each particular mode and spatial factors associated with micromobility usage in general.

9.3.3.3. Second stage: Estimation of micromobility usage

The second stage involves testing the resulting models and comparing which one offered a better fit in comparison with historical data. We started by dividing the complete dataset (205 stations) into two separate ones: 1) train set: 88% of the stations and 2) test set: 12% of the stations corresponding to the Chamberi District (see Figure 9.2). We selected Chamberi district because it is a central residential area of Madrid characterised by mixed land use and most of the available cycling infrastructure. Choosing a complete district allowed us to test our model in a controlled area without doing the selection randomly. We applied the resulting equations from the previous stage to the training set and mapped results using kernel density to identify hot spot areas where the mobility hub could be located. We compared the five resulting maps: 1) estimated bike arrivals, 2) estimated moped arrivals, 3) estimated scooter arrivals, 4) sum of estimated arrivals (3 modes), and 5) estimated PCA micromobility usage scores. We contrasted these resulting maps with the historical data of arrivals to identify the best fitting model.

Figure 9.2 Map of the 205 stations divided in training and test sets



Source: own elaboration.

Finally, we applied all the models to the test set in Chamberi (24 stations) and contrasted the results with historical data. To compare the micromobility usage scores estimated by the combined model with those of the test set, the score for the arrival data of the test set is calculated by projecting them onto the same space as the training data. For this, we scaled the test set data using scaling information of the training set and then used the rotation matrix of the PCA from the training set. Once the validation of the model is observed, we could map hot spot areas for potential mobility hub locations.

9.4. Results

9.4.1. Identifying common influencing factors on micromobility usage

Our main results for the first stage of the study are described and summarised in Table 9-3. We have found that for all modes, the common associated factors are essentially three: 1) station's density (closeness), 2) the presence of cycling infrastructure, and 3) variables related to commercial land uses (employment in retail and points of interest of shopping). Hence, our results yield that people are attracted to travel to places where more BiciMAD stations are offered (near the city centre) and where there is abundant mixed land use and diverse activities available. We also highlight the importance of the presence of cycling infrastructure as, according to current legislation, this is the space where scooters can circulate while mopeds' flow is assigned to the road. Therefore, the presence of cycling infrastructure and the offer of commercial sites like restaurants, stores, etc., make an area highly attractive to arrive with micromobility services. All the models and their coefficients are shown in Table 9-3, and the combined model (PC1) offers the best fit ($R^2 = 0,66$).

In the case of bikes, the presence of a population between the ages of 20 and 49 years old is significant as well as culture, leisure, and entertainment points of interests. In the case

of mopeds, other variables that are associated with their usage are office land use and employees in the hospitality sector. In the case of scooters, we observe that variables associated with their usage are related to intermodal train stations and employees in the hospitality and entertainment sector. Last, in the combined model, we obtained significant variables from the presence of a population between the ages of 20-49 years old, the employment on hospitality and office sector and culture and leisure points of interest, especially in areas near the city centre.

After comparing common factors between the three separate models, we continue by comparing these common factors with the significant ones from the combined model. In Table 9-3, we have highlighted the common factors repeated in each of the four models and we have assigned similar colours to the variables that relate to the same land use or point of interest. From our results, we can infer commercial and office land use are highly relevant attractors of micromobility trips. Additionally, entertainment, cultural sites, and hotels are also important. Thus, we can state that bikes, mopeds and scooters are used for both, commuting and recreational activities. The higher the mix of land uses and the more central a point of interest is, the higher the probability that someone will arrive using a micromobility service.

Table 9-3 Common factors influencing micromobility services

Dependent variable		Independent variable	Coefficient	StdError	t-Statistic	Probability	Robust_SE	Robust_t	Robust_Pr	VIF
Bike arrivals per day		Intercept	-0,000383	0,000	-4,048	0,000*	0,000	-5,277	0,000*	-----
Akaike's Information Criterion (AICc)	-2838,538	Closeness	1,526718	0,280	5,449	0,000*	0,318	4,798	0,000*	1,236
Adjusted R-Squared	0,445	Population (20-49 years old)	0,008778	0,002	4,105	0,000*	0,002	4,308	0,000*	1,058
Joint F-Statistic	28,233	Segregated cycling infrastructure	0,023240	0,010	2,363	0,019*	0,009	2,669	0,008*	1,129
Joint Wald Statistic	194,078	Employment- retail	0,008595	0,003	2,811	0,005*	0,004	2,049	0,042*	1,403
Koenker (BP) Statistic	58,398	Culture & Leisure (cat19)	7,744891	1,847	4,194	0,000*	3,512	2,205	0,029*	1,294
Jarque-Bera Statistic	886,289	Entertainment (cat6)	5,262237	2,006	2,623	0,009*	4,647	1,132	0,259	1,246
Moped arrivals per day		Intercept	-0,000011	0,000	-0,703	0,483	0,000	-0,887	0,376	-----
Akaike's Information Criterion (AICc)	-3647,437	Closeness	0,203398	0,046	4,378	0,000*	0,041	4,967	0,000*	1,758
Adjusted R-Squared	0,499	Income	0	0,000	-2,356	0,019*	0,000	-2,341	0,020*	1,298
Joint F-Statistic	34,927	Land use- Office	0,000032	0,000	4,684	0,000*	0,000	3,144	0,002*	1,412
Joint Wald Statistic	168,793	Cycling infrastructure	0,001439	0,001	2,758	0,006*	0,001	2,628	0,009*	1,202
Koenker (BP) Statistic	47,097	Employment- hotels	0,001523	0,001	2,198	0,029*	0,001	1,800	0,073	1,949
Jarque-Bera Statistic	116,267	Shopping (cat6)	0,112776	0,027	4,185	0,000*	0,035	3,268	0,001*	1,195
Scooter arrivals per day		Intercept	-0,000011	0,000	-4,323	0,000*	0,000	-4,869	0,000*	-----
Akaike's Information Criterion (AICc)	-4346,117	Closeness	0,047324	0,008	5,796	0,000*	0,008	6,114	0,000*	1,640
Adjusted R-Squared	0,604	Train departures	0,000020	0,000	4,113	0,000*	0,000	9,222	0,000*	1,041
Joint F-Statistic	52,777	Cycling infrastructure	0,000212	0,000	2,264	0,024*	0,000	2,266	0,024*	1,168
Joint Wald Statistic	1229,486	Employment- hotels	0,000629	0,000	5,107	0,000*	0,000	3,789	0,000*	1,860
Koenker (BP) Statistic	32,982	Employment- entertainment	0,001074	0,000	2,737	0,006*	0,001	2,135	0,034*	1,342
Jarque-Bera Statistic	162,877	Shopping (cat6)	0,012895	0,005	2,646	0,008*	0,006	2,203	0,029*	1,181
PC1		Intercept	-3,825945	0,365	-10,484	0,000*	0,295	-12,991	0,000*	-----
Akaike's Information Criterion (AICc)	521,030	Closeness	6566,644912	1172,004	5,603	0,000*	1179,102	5,569	0,000*	1,660
Adjusted R-Squared	0,663	Population (20-49 years old)	41,689360	8,119	5,135	0,000*	8,767	4,755	0,000*	1,171
Joint F-Statistic	58,359	Cycling infrastructure	46,739071	13,689	3,414	0,001*	12,253	3,814	0,000*	1,228
Joint Wald Statistic	419,389	Employment- retail	41,762304	11,932	3,500	0,000*	14,567	2,867	0,005*	1,640
Koenker (BP) Statistic	30,375	Employment- hotels	90,067239	17,679	5,095	0,000*	23,514	3,830	0,000*	1,883
Jarque-Bera Statistic	116,861	Employment -Office	17,358206	6,447	2,693	0,008*	7,054	2,461	0,015*	1,500
		Culture & Leisure (cat19)	13970,452560	6477,110	2,157	0,032*	8655,715	1,614	0,108	1,222

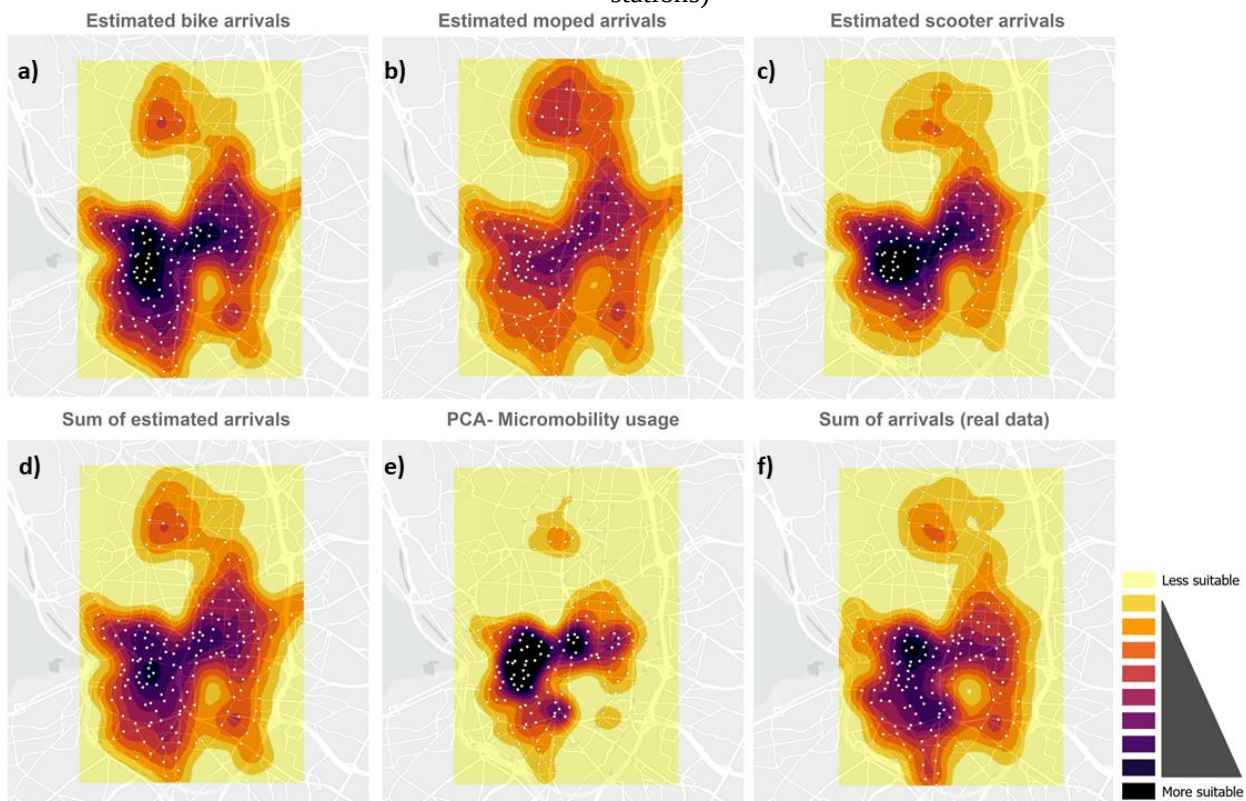
* statistically significant p-value ($p < 0,01$).

Source: own elaboration.

9.4.2. Identifying the best-fitting model to allocate new mobility hubs

Once we identified the associated factors of micromobility's usage, we now focus on finding the best location for mobility hubs. Figure 9.3 shows the resulting predictions when applying the different models to the 181 training stations. Based on these models, similarities arise between predictions. Bike and scooter predictions are similar by estimating the best locations in the city centre, while moped predictions highlight northern areas where many working sites are located. In the bottom maps (figure 4.d, 4.e and 4.f), we can see that estimated arrivals (figure 4.d) and the real arrivals (figure 4.f) give more priority to the city centre with the latter prioritising the locations more to the north of the centre district. Based on the associated factors, figure 4.e offers the best location according to the micromobility usage score which prioritises the city centre.

Figure 9.3 Results of usage estimations according to the different models (training set 181 stations)



Source: own elaboration.

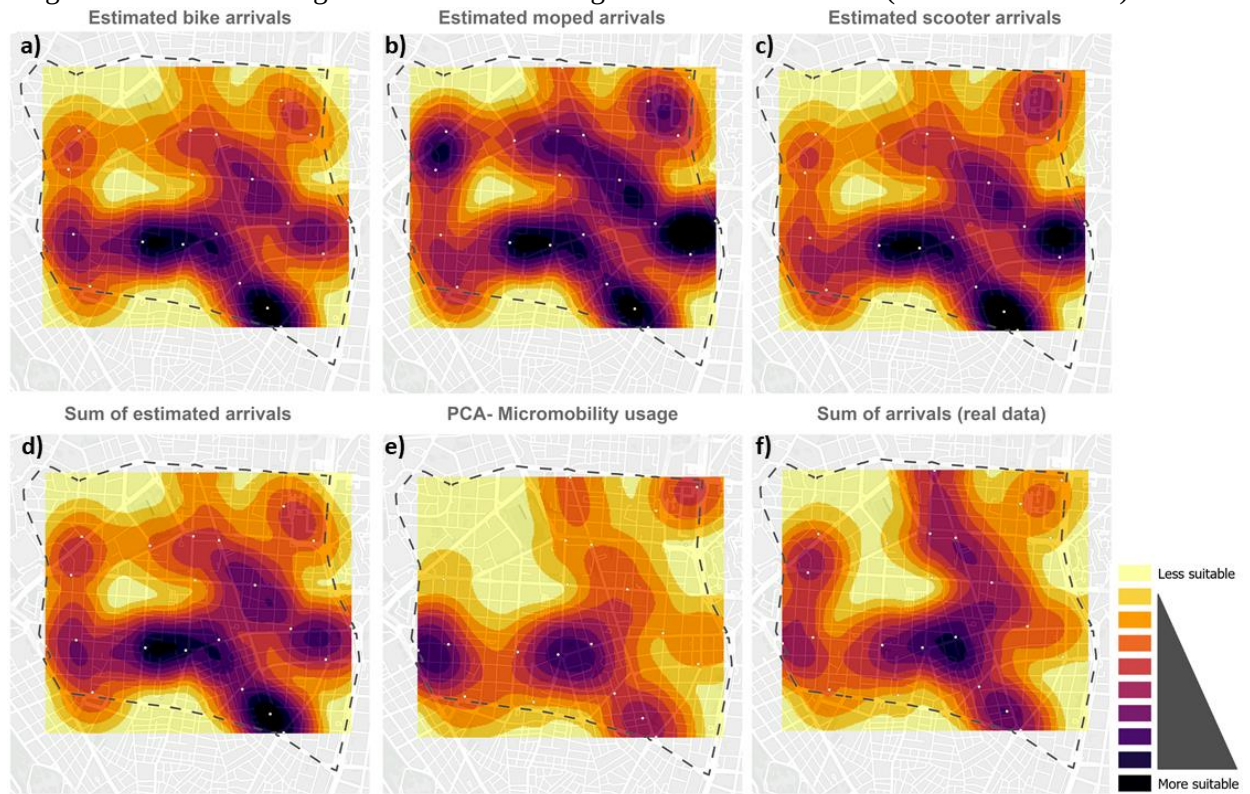
This kernel density maps were elaborated for the Chamberi district (test set) (see Figure 9.4). Results show that the most similar model with historical data is Figure 5.e (the micromobility usage score). Thus, the combined model can be seen as more robust (see Table 9-4).

Table 9-4 RMSE results

Model	Description	Normalised RMSE
1	Bike OLS model	0,283
2	Moped OLS model	0,256
3	Scooter OLS model	0,217
4	Sum of arrivals model	0,259
5	PC1 OLS model	0,231

Source: own elaboration.

Figure 9.4 Results of usage estimations according to the different models (Test set 24 stations)



Source: own elaboration.

9.5. Discussion

Based on this methodology, we can use micromobility usage scores to identify the best location for a possible mobility hub, using the areas with a highest score (yellow areas). Results are consistent with previous research that state the need to allocate this infrastructure in areas with mixed use and abundant points of interests (Aono, 2019; Aydin et al., 2022; comoUK, 2021; Tran & Draeger, 2021). In Madrid, we see that the most attractive areas are near the city centre as well as the Chamberi district. The analyses performed allowed us to identify the areas of the city with the highest vitality and attractiveness in terms of micromobility arrivals. These areas concentrate residential, mixed-residential, commercial, and work-related land uses that are closely linked to an intense usage.

This data-driven methodology could help planners in other cities to begin exploring areas for future mobility hub locations. The results could vary based on the data available and the local context of the city. Our main contribution relies on offering a data-driven methodology applied in Madrid and including different shared modes to address the location problem when implementing mobility hubs. Another contribution of this study is to have considered the PC1 as a proxy of the different micromobility modes usage altogether. This approach resulted in obtaining the most fitting-model in comparison with the single-mode models.

Further research could explore our data-driven methodology in different contexts to evaluate its suitability. The resulting maps offer a general area of where a potential mobility hub could be located based on the historical micromobility usage data, rather

than a specific location. This approach is based on historical usage which means that micromobility services are recommended to be placed where the current type of user groups perform different activities (e.g., living, working). Because of this, the possibility of offering them to other social groups, such as vulnerable population, could be hindered (Durán-Rodas, 2021).

9.6. Conclusions

In this study, we propose a methodology to include micromobility data into the planning process of mobility hubs. We have found that station's density, commercial, and cycling infrastructure are common associated factors with the use of micromobility, which we recommend as sites for potential mobility hubs. We have modelled each service and then proposed a combined model that helps us approach associated factors of all services, without differentiating by mode. Finally, we have applied our models to a test set of stations in Madrid to contrast resulting predictions with real data available. The micromobility usage score model is the one that showed a better fit with real data and considers these common associated factors.

This methodology could help policy planners and transport authorities in mobility hub location planning, making the investment of resources more efficient. In this case, we tested our models in the Chamberi District, a central area where we had arrival data and demonstrated that the micromobility usage score was a good fit for determining the hub location. In future studies in which no trip data is available, planners could use this micromobility usage score tool and the variables of built environment available to estimate potential usage of micromobility services. Although they may not operate in those areas yet, they can offer guidance in the start-up process. The methodology is applicable to similar cities as Madrid as it has not been tested in other kind of city and is therefore a limitation. For transferring the model into other areas, we recommend using our methodology, the city's trip data and its variables to estimate its own combined model. Another limitation of the study is that we consider the average daily arrivals of the aggregated data for the last semester of 2019. Future studies could differentiate between weekdays and weekends and between different time bands along the course of a day. Moreover, our initial OLS models were oriented to explore some of the influential factors on micromobility, and hence this part of the research constituted a start point to investigate the topic. But when tested for residual spatial autocorrelation, only the bike-sharing model resulted in residuals not being clustered, while dockless services did have residual spatial autocorrelation. Thus, further research could include other mathematical programming, multicriteria decision techniques or conduct a Geographically Weighted Regression (GWR) to overcome this issue. Future studies could also include other sources of data, such as phone data, in order to delve further into different dynamics that occur throughout the day.

10. Towards Mobility as a Service (MaaS)

10.1. Introduction and background ⁶

Once we have delved into the dynamics of BiciMAD and other dockless micromobility services, which we described in the introduction section as the web 2.0 of the new mobility paradigm, in this last chapter we furtherly explore the concept of Mobility as a Service (hereafter, MaaS), which constitutes the web 3.0 of the mobility paradigm. Promising to be future of the mobility paradigm and being our umbrella conceptual framework that shields shared mobility and micromobility concepts, we aim to analyse the MaaS topic in detail. Therefore, we describe the current definitions offered for MaaS, the obstacles/challenges in its implementation and the current ongoing pilots around the world, and in Madrid particularly. This bibliographic review and the findings from our previous studies could help us to lastly, outline the possible future role of BiciMAD and these emergent micromobility services in a MaaS offering for Madrid. Hence, this chapter is the result from the revision of a robust five-year old scientific literature base already available, summarising the key findings of the current research body related to the MaaS concept.

Previous systematic reviews of MaaS included conference papers and grey literature since scientific literature was scarce at the time due to the concept's recent nature. (Utriainen & Pöllänen, 2018), for example, selected 31 documents (20 journal articles and 11 conference papers), focusing on the roles of different transport modes in MaaS; (Durand et al., 2018) selected 14 documents (14 journal articles) and specifically analysed travel preferences and behaviour; whereas (Wittstock & Teuteberg, 2019) selected 95 documents (37 journal articles/conference papers and 58 grey literature) and attempted to identify MaaS' core elements. More recently (Cruz & Sarmento, 2020) delivered a literature review on the MaaS concept analysing 15 documents (including grey literature) and focusing on the existing business models and challenges for MaaS solutions. Our review adds value because it differs in methods and objective from previous ones. Regarding methods, it is the most extensive known and made exclusively of articles published in scientific journals. Additionally, our approach for this study is bottom-up: collecting peer-reviewed articles, abstracting them, and then conducting a frequency- analysis of terms. This approach differs from other reviews that usually define their own schemes and then fit the literature into it (top-down). Secondly, our aim is to extract from the review the key or common elements in MaaS definitions, analysing agreeing and disagreeing points from authors whereas other reviews focus on different topics.

10.2. Methods

This study involves a scoping literature review, made only with peer-reviewed journal articles (published or in press), for two main reasons. Firstly, because we now have more peer-reviewed journal articles related to MaaS. Secondly, we highly value the importance of journals' peer-review processes that best guarantee objectivity and limit our analysis solely to the most unbiased literature (we agree that grey literature is mostly biased in favour of MaaS as demonstrated by (Pangbourne et al., 2020)).

The search for the literature was carried out in September 2020 through Scopus and Web of Science. We searched for journal articles that had the exact words 'Mobility as a Service' or 'MaaS' in their title and that were written in English. Additional literature was obtained by applying backward snowballing, which consisted of searching for references: one paper led to another, and so on. After excluding duplicated records, we finally obtained 90 articles. After

⁶ The content of this chapter has been published in (Arias-Molinares et al., 2022a; Arias-Molinares & García-Palomares, 2020b)

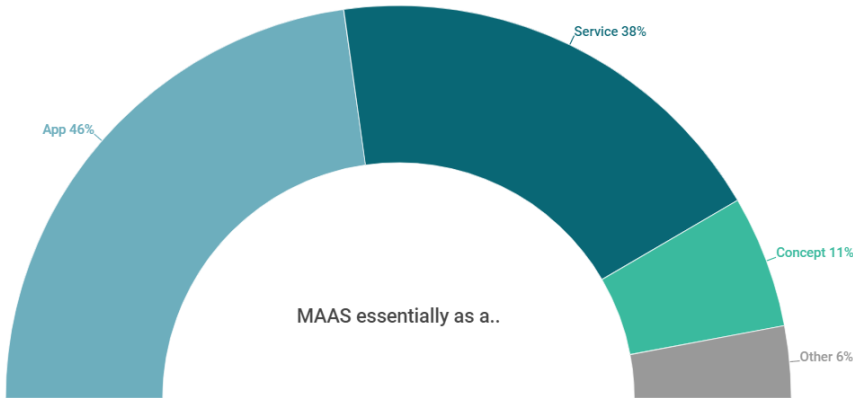
selecting the documents, we read and summarised the main findings in a summary file, which contained the MaaS definition proposed or reference in each article. It is important to highlight that some authors have presented a literature review and cited different authors' definitions of MaaS to introduce the concept; however, we considered the definition that the authors have given independently of the literature review, this meaning how they particularly understood the concept. With the definitions collected, we created different tables to synthesise information and be able to compare the different perspectives (agreeing and disagreeing points) of authors in relation to MaaS definition.

With the authors' definitions, a word frequency analysis followed. A script was made using Python to read and count all the term frequencies in order to identify the most mentioned words by authors when describing MaaS. The resulting list of words and frequencies has helped us to group terms with similar meaning, identifying key elements mentioned by the research community in MaaS definitions. With the common elements of MaaS identified (we call this the MaaS-checklist), we then proceed to analyse 21 MaaS-like schemes around the world. We focus only on operating and commercial schemes with available applications up to September 2020 (no longer operative MaaS pilots were discarded). We downloaded, analyse and review each application. Some of the MaaS-like schemes operate in more than one city around the world; therefore, we decided to choose the city where it first started operating as we believe this may be the place where the scheme is in a more advanced stage (e.g. Whim operates in more than three cities; hence, we chose the case of Helsinki, Finland). The results are graphed in a table and allow us to identify the most/least covered elements of the MaaS-checklist.

10.3. Exploring MaaS definitions

When revising authors' definitions of MaaS, we observe that they differ according to which element they put at the forefront of the MaaS definition, in other words, the key element that goes first when defining MaaS (See Figure 10.1 and Table 10-1). This is expected as it is a nascent concept and many authors are suggesting or proposing new definitions of MaaS, and this becomes the most noticeable difference or disagreeing point: the central element in MaaS definitions (app, service, concept and actors). Our results suggest that 46% of the articles define MaaS as a tech-based solution which emphasises the importance of technology, focusing on the model, app or system. On the other hand, 37% of the articles define it as a service, priorly highlighting the integration of different transport modes and focusing on the transport modes involved in MaaS. Lastly, 17% define MaaS as a new concept, an innovation or an ecosystem of actors organised to promote a new mobility product, focusing on the concept or actors that enable it.

Figure 10.1 Essential element in the forefront of scholars' MaaS definitions.



Source: own elaboration.

Table 10-1 Some of the definitions reviewed in MaaS literature based on the central element

MaaS defined essentially as a...	Definitions
App	A mobility distribution model in which a customer's major transportation needs are met over one interface and are offered by a service provider (Sochor et al., 2016)
	Via MaaS, system consumers can buy mobility services that are provided by the same or different operators by using just one platform and a single payment (Kamargianni et al., 2016)
	To use a single app to access and pay for various transport modes within a city or beyond (Y. Li & Voegel, 2017)
	Model that aims to provide seamless trips over one interface by combining different transport modes and services (Utriainen & Pöllänen, 2018)
	Offer a unique and seamless interface to users, aggregating heterogeneous transport options offered by different mobility providers handling the whole experience of traveling, from providing information, to travel planning, and payments (Melis et al., 2018)
	A system in which a comprehensive range of mobility services are provided to customers by mobility operators (Smith, Sochor, & Sarasini, 2018)
	Mobility system beyond the private car (Lyons et al., 2019)
Service	One single application including planning multimodal trips, paying tickets or fares, and even subscribing to a bundle to use unlimited transit, bike, taxi, and rental cars (Khaimook et al., 2019)
	A one-stop, travel management platform digitally unifying trip creation, purchase and delivery (Pagoni et al., 2020)
	Centralized platform for the planning, payment, and management of trips and combines multiple modes of transportation designed to increase the efficiency of the system (Tomaino et al., 2020)
	An innovative mobility service offering customized transport services to fit the individual traveller's needs and requirements (Sochor et al., 2015a)
	Mobility service that gives you access to all modes and real time information for each journey, as well as providing instant journey planning and booking (Ho et al., 2018)
	A single service available on demand and incorporating all transport services from cars to buses to rail and on-demand services (Mulley et al., 2018)
	To provide people with an easy-to-use service , bundling all imaginable forms of (shared and private) mobility into packages, that would be of a level of service that is competitive with private cars (Audouin & Finger, 2018)
Concept	The integration of various forms of transport services into a single mobility service accessible on demand (Liimatainen & Mladenovic, 2018)
	Where different shared modes of transportation are bundled into one easily accessible service (Hessलगren et al., 2020)
	A service that integrates different mobility services and provides one-stop access to these services through a common interface (Karlsson et al., 2020)
	Flexible, efficient, user-focused, and personalised service , uniting existing transport options, deploying the most appropriate mode for each journey, recognising customer preferences and real-time conditions of the transport network when the trip is requested (Ho et al., 2020)
	A variety of travel options tailored to their respective needs, either as a subscription package or in a pay-per-use approach, by an integrated mobility provider (Becker et al., 2020)
Other	Bundled public transport and shared mobility options that provide consumers with seamless mobility on par with and exceeding that of private vehicle ownership (Wong & Hensher, 2020)
	An emerging concept of new integrated transport services (Eckhardt et al., 2019)
	Is a novel concept that aims to create a shift in individuals' travel behaviour away from private car dependence maximizing the potential of more alternative modes (Alyavina et al., 2020)
	MaaS is not solely an app or the value concept of service packages, or even the revenue streams that define the business model, but it is a set of organizations, legislation, and other aspects , which collectively serve to lock a technology into society (Pangbourne et al., 2020)
	A new approach to achieving collaboration and integration between transport providers and where a user engages a single organisation to coordinate and facilitate their mobility needs (Mulley et al., 2020)

Source: own elaboration

The first common element in all definitions is that MaaS is offered through a single application. Having a unique channel makes it easier for users, avoiding the hassle of checking multiple mobility and travel applications, information sources, journey planners and ticketing platforms (König et al., 2016; Smith et al., 2017; Sochor et al., 2016). Besides having a single app, users can plan, pay and access their mobility services through this unique channel. The planning stage of the trip involves having real-time information on as many services as possible, offering an intermodal journey planner, as well as booking functions. Real-time information needs to be dynamic, meaning that it changes or adapts throughout the day according to incidences/anomalies, and for all mobility services included (Kamargianni et al., 2015). A recent study made by (Lopez-carreiro et al., 2020) also found that users are attracted to real-time information regarding passenger crowding, pollution levels, route facilities, vehicle conditions, and urban security. Moreover, the MaaS journey planner should be intermodal, because most of the existing journey planners do not offer information for intermodal trips, meaning that they do not combine more than one transport mode -with the exception of walking, which is usually the access and egress mode- and only include some of the transport modes available in an area (Matyas & Kamargianni, 2018a, 2018b). Another important aspect that should be considered in the MaaS app is payment integration, which basically means allowing consumers to pay through the app. The access stage of the trip has proven to be important, offering ticketing functions for users to validate and access mobility services (Y. Li & Voegelé, 2017; Sochor et al., 2016). Nowadays, the latter is generally done by carrying an intelligent transport card, which at most, integrates public transport, but not shared-mobility services. Being able to pay, access and travel through all modes available with nothing more than their smartphones is becoming highly appreciated.

The second agreed point in the revised literature involves offering multiple and diverse mobility services. Many apps only integrate the public transport systems, but no shared-mobility services. An ideal MaaS will try to include as many mobility services as possible, in order to cover most of the transport offer in the city. It is recommended to have as varied transport modes as possible: scooters, bicycles, mopeds, automobiles, buses, tram, subways, rail, etc. Many studies have found that the more mobility services included, the more attractive a MaaS service becomes (Matyas, 2018; Sochor et al., 2016). Nevertheless, studies have shown that the vital service to be included is the public transport offer, as it is the core service that users will look for when joining a MaaS platform (Ambrosino et al., 2016; Durand et al., 2018; Haahtela & Viitamo, 2017; Mulley et al., 2018; Rantasila, 2015; Strömberg et al., 2018).

Finally, the third core element in MaaS is mobility packages. Mobility packages are bundles of various transport modes that include a certain amount of km/minutes/points that can be utilised in exchange for a monthly payment (Hietanen, 2014; Jittrapirom et al., 2020). Some argue this is the real “new” aspect offered by MaaS, since information and payment integration already existed before MaaS became a topic (Aguilera-García et al., 2020; Lyons et al., 2020). With mobility packages, users join a monthly subscription (just like a phone plan) to cover all their travel needs and they receive a unique invoice at the end of the week/month/year with all the mobility expenses (Hietanen, 2014). Offering the ‘pay-as-you-go’ option is also recommended, as users do not know exactly how much they spend monthly on their transport expenses and they usually want to start on this basis and be able to thoroughly consider which mobility package best fits their needs (Matyas & Kamargianni, 2019). Mobility packages highlight the user-centric approach of the MaaS concept, as they can be tailored to satisfy particular travel needs (Ho et al., 2018; Nikitas et al., 2017). In the study conducted by (Kamargianni et al., 2015), the authors describe that as MaaS is not a physical product, but a digital system, the mobility packages’ customisation could be more viable, however (Pangbourne et al., 2020; Wong & Hensher, 2020) state that this could be difficult to do based only on user’s needs without considering the limited-transport capacity

and the different types of contracts and business models that need to be arranged for operators to make viable customized packages.

These three elements combined are the necessary ingredients for a platform/app to be labelled as MaaS. This app should allow their subscribers to plan, book, access and pay for their mobility services as bundles, just like they pay for their phones or Netflix accounts (Mulley, 2017). Hence, after reviewing the concept, in this thesis we are going to stand with the definition proposed by (Smith & Hensher, 2020) as it involves the three elements identified as core for MaaS (single app, multiple mobility services and mobility packages) defining it as:

“A type of service that through a joint digital channel enables users to plan, book and pay for multiple types of mobility services” (Smith & Hensher, 2020, p. 56).

10.4. MaaS research, history and stakeholders

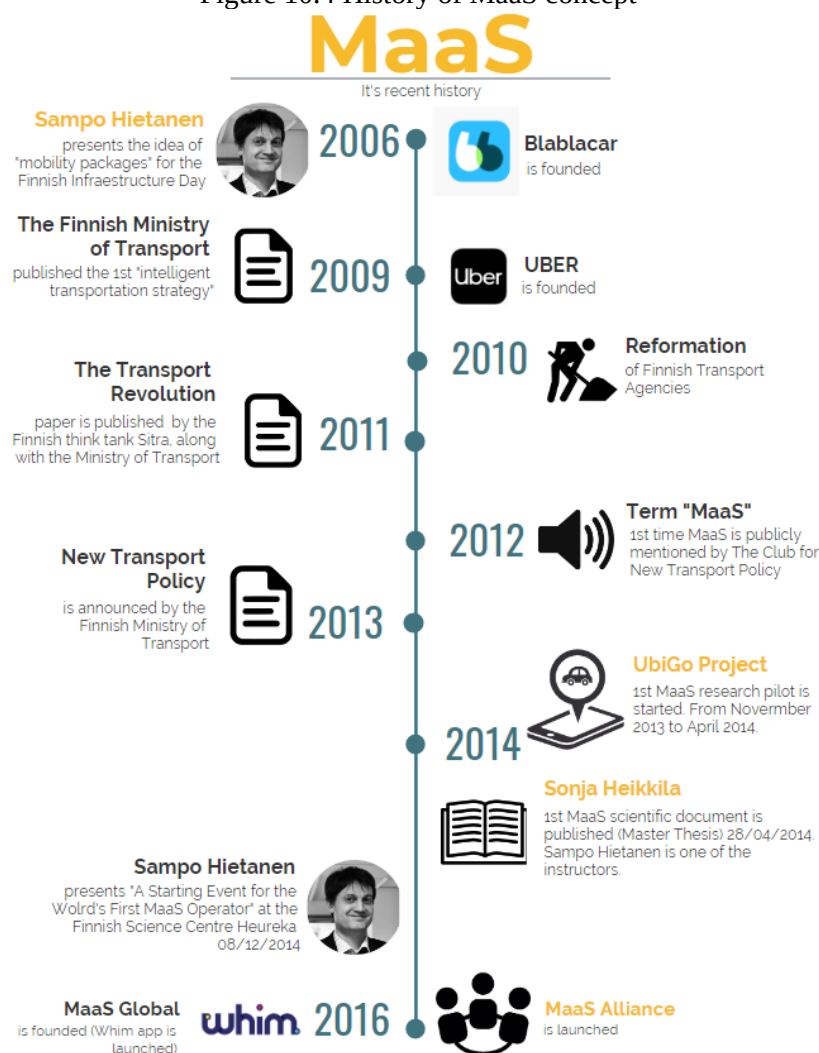
MaaS literature is relatively recent, but rapidly growing. We can identify three main lines of research according to the perspective of the three main actors involved in MaaS: (1) Users: MaaS modelling (demand-supply matching systems), which covers all articles related to MaaS pilots and their results or modelling approaches, as well as studies that analyse users' willingness to pay for MaaS, their preferences, or the importance given to different services (Ho et al., 2018; Lopez-carreiro et al., 2020; Lyons et al., 2019; Matyas & Kamargianni, 2017; Sochor et al., 2016; Strömberg et al., 2018); (2) Operators: MaaS business models, which include the stakeholders' perspective, revenue models, integration with different actors or the MaaS ecosystem (Cottrill, 2020; Hensher, 2017; Wong & Hensher, 2020); and (3) Authorities: Governance issues on MaaS, with authorities' perspectives, analysing governance issues, regulation, conditions needed and possible impacts (Audouin & Finger, 2018; Docherty et al., 2018; Fenton et al., 2020; Hirschhorn et al., 2019; Y. Li & Voegelé, 2017; Pangbourne et al., 2020; Sochor et al., 2015c).

Additionally, the MaaS-related topics are diverse. A first line of research is focused on the architecture of the concept (Jittrapirom et al., 2017; Liimatainen & Mladenovic, 2018; Utriainen & Pöllänen, 2018) and classification of MaaS (Kamargianni et al., 2016; Lyons et al., 2019; Sochor et al., 2017). Other studies address the organisational structures and business models to implement MaaS (Hensher, 2017; Jittrapirom et al., 2018; Merkert et al., 2019; Polydoropoulou et al., 2018; Wong et al., 2019). A third research path explores demand and travel preferences from recent MaaS pilots in urban areas (Sochor et al., 2016; Strömberg et al., 2018), as well as rural or suburban areas (Aapaoja et al., 2017; Eckhardt et al., 2018; Geurs et al., 2018; Mulley et al., 2018; Wright et al., 2020). Last but not least, scholars have also studied governance issues for MaaS to be feasible, identifying barriers and enabling factors (Smith et al., 2019), in an attempt to anticipate some of its possible impacts (Becker et al., 2020; Jittrapirom et al., 2017; Pangbourne et al., 2020; Smith, Sochor, & Karlsson, 2018), exploring regulation challenges (Hirschhorn et al., 2019; Karlsson et al., 2016; Y. Li & Voegelé, 2017; Mukhtar-Landgren & Smith, 2019; Surakka et al., 2018) or stakeholder viewpoints (Audouin & Finger, 2018; Jittrapirom et al., 2018; Polydoropoulou et al., 2018; Sochor et al., 2015c).

In regard to the scientific literature available, the first MaaS article was published in 2015 (Sochor et al., 2015a). Up until 2019, there were around 41 journal articles published; however, just in 2020 (only one year), 49 new papers have become available. This means that in only one year, the number of MaaS articles doubled, in comparison with the ones available for a four-year period. Most papers (60%) were written by authors who attempted to fill the research gap by suggesting a definition while others (40%) adopted previously proposed definitions; most of them made reference Heikkilä's and Hietanen's MaaS-related documents (Heikkilä, 2014; Hietanen, 2014), as well as Kamargianni's different papers, especially (Kamargianni & Goulding, 2018) and also the MaaS Alliance's definition (MaaS Alliance, 2017).

Being an emergent concept, the history of MaaS begins with Sampo Hietanen, which is often referenced as the father of the concept as he proposed the mobility packages to the Finnish Transportation Ministry in a global conference held back in 2006 (Hietanen, 2019) (see Figure 10.4). Soon after, in 2009, the Finnish Ministry of Transportation and Communication published the first “Intelligent Transportation Strategy” and in 2010, all transport agencies were reformed. In 2011, a paper called “The Transport Revolution” was published by the Ministry, promoting what was known as transport as a service. By the end of 2013 (November), Sweden had developed the first MaaS-pilot called UbiGo, within the Go:Smart project (Holmberg et al., 2016). Later in 2014, the notion of MaaS gained widespread publicity through the development of the “Helsinki Model” in Finland, proposed by Sonja Heikkilä in her master thesis, the first academic publication (master thesis) regarding MaaS (Heikkilä, 2014). In 2016, Sampo Hietanen launched the MaaS Global project to start the Whim app (Polydoropoulou et al., 2020). In 2016, a MaaS International Alliance was created to promote MaaS around the world.

Figure 10.4 History of MaaS concept

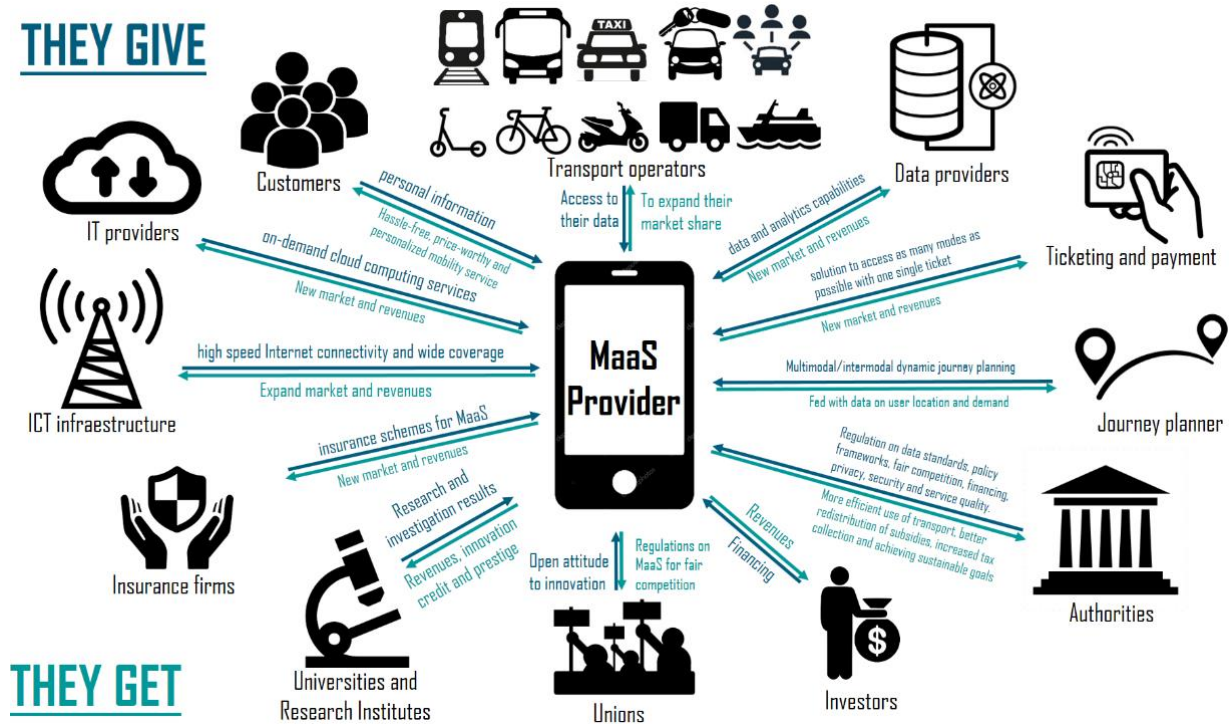


Source: own elaboration.

Since then, many new actors have become involved in MaaS, defining what is often called as the MaaS ecosystem (MaaS Alliance, 2017). This Ecosystem is the wider network of organisations that influences how a MaaS Provider creates and captures value (Kamargianni & Matyas, 2017). Actors involved include transport operators, data providers, technology and platform providers, ICT infrastructure, insurance companies, regulatory organizations, universities and research institutions, and other media, marketing and advertising firms. Based on their interactions, value

is captured, and benefits are obtained as seen in Figure 10.5. Besides customers, which are the main reason for the service, transport authorities also play a key role as they promote collaboration with different stakeholders (Chang et al., 2019) and they also tend to have a societal focus, a dominant influence on public transport operators (which are the backbone of the MaaS offer), and the potential to enable MaaS through various policies and incentives (Audouin, 2019).

Figure 10.5 The MaaS ecosystem.



Source: own elaboration.

All actors have different interactions with the MaaS Provider. Transport operators offer their service and data, and they are able to expand their market due to more users being exposed to their mobility services. In the case of ICT infrastructure, data, ticketing, and payment firms, they provide their cloud capacity, high speed connectivity, data analytics and single-payment solution services while opening a new market for new revenues. Companies that developed journey-planning applications are also involved, and must create multimodal planners, promoting intermodality, while being easy-to-use and flexible for customisation. Unions are also considered, because they will most likely demand fair competition regulations. Universities and research institutes play a key role, as well, because they will develop knowledge based on pilots' evidence in order to obtain tools and strategies for decision-making regarding MaaS. Finally, there are a few other actors, like insurance companies that may find new business possibilities (Kamargianni & Matyas, 2017). Entertainment-related companies may also be interested in offering subscription packages for free Wi-Fi access while travelling, free access to newspapers and magazines, movies, music and gaming services, and even discounts to coffeehouses and restaurants to buy food for the trip, especially in the self-driving vehicle era, as it is expected that travellers would have freed time while not driving (Giesecke et al., 2016). The MaaS ecosystem should integrate both, public and private operators with the MaaS provider in the centre, managing demand and supply and offering mobility services to end users, as well as dispatching/assigning daily trips to several operators (Kamargianni, Yfantis, et al., 2018). Intermodal trips made within MaaS could be complementary suggesting public transport for dense areas, and private shared mobility for last mile trips (Aapaoja et al., 2017). Anyhow, the public transport system is going

to be the backbone of MaaS, but new shared mobility services should increase the transport coverage of those areas less served by public transport.

10.5. MaaS pilots and findings

With MaaS being a topical subject, many ongoing pilots are being developed worldwide as tools for “learning by doing”, especially now that the concept is still in its nascent stage and new evidence is required (Jittrapirom et al., 2020). However, it has been agreed that, as stated by (Y. Li & Voegelé, 2017), two main conditions should be in place to implement MaaS: a consolidated public transport system and a varied shared mobility offer. Hence, many of the MaaS pilots around the world are initiatives and theoretical proposals, while only few of them are actually operative. The authors (Kamargianni et al., 2016) proposed a classification of MaaS pilots according to their integration level in:

- Partial integration: MaaS pilot with basic level of integration in which a scheme not fully, but partially possesses ticketing, payment and ICT integration.
- Advanced integration: MaaS pilots that fully possess ticketing, payment and ICT integration.
- Advanced integration and mobility packages: MaaS pilots that are fully integrated and also offer mobility packages.

Considering this classification and the previously mentioned MaaS-checklist, we evaluated some of the most popular MaaS pilots that were operative until September 2020 and listed in several studies (Goodall et al., 2017; Jittrapirom et al., 2020; Kamargianni et al., 2016; Stopka et al., 2018). We also used the references to initiatives and projects presented on the MaaS Alliance website. The results are summarised in Table 10-2. We can infer from the table, that only Ubigo and Whim cover the most elements to be labelled as MaaS. From the evaluation, we can also observe that the most common elements covered are having an available application with real-time information, intermodal journey planners and booking and ticketing functions (app-related features). The most uncommon elements are offering mobility packages (only Ubigo, Whim and Citymapper offer them, the rest only have the pay-as-you-go option) and the possibility for users to make up their own mobility package.

Table 10-2 Revision of 21 MaaS pilots and evaluation with MaaS-checklist.

MAAS-LIKE SCHEMES	You are able to plan, pay and access with the app	The app offers real-time information	The app offers an intermodal journey planner	The app offers booking function	The app offers ticketing functions	The app allows you to buy public transport tickets	The app allows you to buy shared mobility tickets	The app has mobility packages
UBIGO (Stockholm, Sweden)	●	●	●	●	●	●	●	●
WHIM (Helsinki, Finland)	●	●	●	●	●	●	●	●
WIENMOBIL (Vienna, Austria)	●	●	●	●	●	●	●	
CITYMAPPER (London, United Kingdom)		●	●	●	●	●		●
JELBI (Berlin, Germany)		●	●	●	●	●	●	
ZIPSTER (Pulau Ujong, Singapore)		●	●	●	●	●		
MY CICERO (Milan, Italy)		●	●	●	●	●	●	
MOOVEL (Berlin, Germany)		●	●	●	●	●		
SBB MOBILE (Zurich, Switzerland)		●	●	●	●	●		
GVH MOBILITY SHOP (Hannover, Germany)		●	●	●	●	●		
TRANSITAPP (Montreal, Canada)		●	●	●		●		
QIXIT (Berlin, Germany)		●	●	●	●	●		
RTA DUBAI (Dubai, United Arab Emirates)		●	●	●	●	●		
MAAS MADRID (Madrid, Spain)		●	●			●		
MYDVG (Duisburg, Germany)		●	●	●	●	●		
MOOVIT (San Francisco, United States)		●	●			●	●	
BEELINE SG (Pulau Ujong, Singapore)		●		●	●	●		
URBI (Milan, Italy)		●	●				●	
STIB-MIVB APP (Brussels, Belgium)		●	●			●		
MOBIPALMA (Palma de Mallorca, Spain)		●				●		
TRIP GO Skedgo (Sydney, Australia)		●	●					

Source: own elaboration.

The characteristics of the six more advanced MaaS-like schemes are summarised in Table 10-3. In general, all of them integrate public transport and some of them shared-mobility services. The ones that combine a more varied offer of transport modes are Whim, Wienmobil and Jelbi, which offer car sharing, bike sharing and scooter sharing.

Table 10-3 Most advanced MaaS-like schemes and their characteristics.

MaaS-like scheme	Company behind	Operating since	Cities where the app operates	Mobility services included	Google play information			Mobility Packages
				Name	Abs.	Downloads	Score	
UBIGO	Ubigo Innovation AB	2013-2014 six-month trial in Gothenburg (Sweden)	Stockholm (Sweden)	Bus, subway, tram, light rail, ferry, bike- SL Taxi- Cabonline Rental cars- Hertz Carshare- Move About	9	500	No info	Large 380.85 €/month Medium 201.38 €/month Small 95.08 €/month Custom 54.33 €/month
		2019-actuality operating in Stockholm (Sweden)						
WHIM	MaaS Global	2016-actuality operating in Helsinki (Finland)	Vienna (Austria) Birmingham (United Kingdom) Helsinki (Finland) Antwerp (Belgium)	Bus, tram, subway, light rail, ferry- HSL and HKL Bike- Citybike Taxi- Helsinki Taxi, Lähtäksä Car rental- Sixt, Hertz, Toyota Carshare- ALD car sharing Scooter-TIER	10	100.000	3.8	Whim Urban 30, 59,70 €/month Whim Weekend 249 €/month Whim Unlimited 499 €/month Whim to Go (pay-as-you-go)
		2019-actuality operating in Helsinki (Finland)						
WIENMOBIL	Wiener Linien	2015 Smile Project pilot in Vienna (Austria)	Vienna (Austria)	Bus, tram, subway, light rail, Westbahn- Wiener Linien Bike-Citybike, Nextbike Carshare-ÖBB Rail&Drive Stationäres, SHARE NOW Taxi-Taxi 31300, 40100 Scooter-Circ, Tier Motoshare-ÖAMTC easy way Parking -WiPark Car rental- Europcar, Sixt	11	500.000	1.6	Pay-as-you-go
		2017-actuality operating in Vienna (Austria)						
ZIPSTER	Mobility-X	2019- currently operating in Singapore Island (Singapore)	Singapore Island (Singapore)	Bus, trains Carshare- Grab, Gojek, BlueSG Bike-Anywheel	4	10.000	2.4	Pay-as-you-go
JELBI	Berliner Verkehrsbetriebe	2018- currently in Berlin (Germany)	Berlin (Germany)	Bus, Tram, Subway, rail, ferry- Berlin's Public Transport System Scooter- TIER, Emmy Taxi- BVG BerlKönig Carshare- Miles Bike- Deezer	9	50.000	3.9	Pay-as-you-go
		2019-actuality operating in Berlin (Germany)						
CITYMAPPER	Citymapper Limited	No information	Worldwide (several countries)	Bus, subway, rail, tram, ferry- London Public transport system Bike- Citybike	6	10.000.000	4.5	Pay-as-you-go

Source: own elaboration (information up to September 2020).

Next, we can describe with more detail the three most advanced MaaS pilots. On one hand, the UbiGo project is one of the most oft-mentioned pilots. It began in 2013 as a six-months trial in Gothenburg being the first MaaS pilot deployed in the world, although it was a research project. Their results showed behavioural changes in modal choices, pre-trip planning, trip chaining, destinations and travel time (Sochor et al., 2015a). The app demonstrated to influence in the reduction of car usage, and many subscribers reported to be walking more frequently. The most valuable finding from the trial was that the app served as a management tool, because presenting various travel options every day made participants reflect on their mode choices. In this regard, MaaS was acting as habit intervenor, and over time, made them more aware of the ‘smorgasbord’ of transport choices (Strömberg et al., 2018). After the research trial, the service relaunched for Stockholm after the public transport company, the Storstockholms Lokaltrafik (SL), opened up to digital reselling and bundling of their services. This allowed them to resell tickets in the app and be able to offer different mobility packages. Another important aspect of UbiGo is that their subscribers could be individuals or families (as households), and the customisation of mobility packages is allowed.

The second pilot is the Whim app which is also one of the most-advanced MaaS schemes. It is owned by MaaS Global and has been continuously operative since it was launched in 2016. They have now grown their market to other cities, being the only company that offers services in more than one country. They aggregate many partners, including the public transport operator called Helsinki Region Transport (HSL). Their recent official report states that 73% of their trips are being made with public transportation, as opposed to 48% of trips made by the average citizen (Hartikainen et al., 2019; Whim, 2018). It also describes that 42% of all Whim users’ city bike trips are combined with public transportation, demonstrating that active modes are used for solving the last-mile problem. The business model in Whim is similar to UbiGo’s, as they buy transport tickets from different operators and assembled them in different mobility packages with a charge for revenues. Thirdly, the Wienmobil app is the third most-advanced MaaS scheme. It began in 2015 as a pilot project called Smile and was relaunched in 2017 in its commercial phase. It operates only in the city of Vienna, with eight private partners. As a positive feature, it offers the WiPark service, a parking operator for parking spaces in the city. The most critical aspect of Wienmobil is that it does not offer (at least, not until September 2020) any mobility packages, only the pay-as-you-go option.

As findings from these and other pilots, we can highlight the key role of public transport services and the importance to integrate multiple and varied shared mobility services (the more operators and modes, the better) and real-time information (Hahtela & Viitamo, 2017). Other requirements as seats for children or allowing pets in car-sharing services or specialised services for collecting others and travelling to hard-to-reach locations have been reported as relevant (Kamargianni, Matyas, et al., 2018). In relation to the initial segmentations of MaaS customers, we can highlight the first one done by (Sochor et al., 2015a) categorising them in: a) car shedders, b) car accessors, c) simplifiers and d) economisers. Car shedders were users with a car that wanted to attempt to live without it for economic reasons and parking hassles. Car accessors are those with plans to buy a car in the future, exploring whether they need one. Simplifiers and economizers did not have a car; the former used many mobility options, and the latter were mostly public transport users. At the end of the trial, they all drove less than expected. Some stated that they will delay purchasing a car, and others started using public transport after they found out it worked well. Similarly, (Lopez-Carreiro, Monzón, Lois, et al., 2021) found that potential MaaS users could be classified in four groups: technological pro-cars, unimodal travellers, MaaS fans and sustainable travellers. The study concluded that MaaS fans were the population with higher willingness to pay for MaaS and most of them were highly educated and very aware of the many micromobility options in the city. Tech-lovers and the degree of knowledge related to different mobility apps proved to positively influence the willingness to use MaaS, supporting what was found in previous

studies (Ho et al., 2020; Karlsson et al., 2016; Matyas & Kamargianni, 2018a; Sochor et al., 2015a, 2016; Zijlstra et al., 2020). In another MaaS pilot, (Robinson, 2018) identified that males, high-income earners, and families with children were socio-demographic factors that decrease willingness to join MaaS, while the contrary occurred with the low-income earners, that did not own a car, were young with no children, and had environmental awareness. When analysing the results from different studies that estimated MaaS users profiles we observe that some authors stand for the young early adopters (Jittrapirom et al., 2020; Polydoropoulou et al., 2018), while others show scepticism, arguing that young people do not have such complex mobility patterns and that they have limited budget (they care for affordability), whereas business travellers or tourists could be more interested (Johansson, 2017; Y. Li & Voege, 2017). The fact is that different users may have different requirements: business travellers, for example, may value reliability, timeliness, exclusiveness and privacy, whereas a student may seek affordability and the social/environmental qualities of ride sharing (Chang et al., 2019; Sochor et al., 2016). This potential conflict of interest in MaaS attributes highlights the need to develop a service that combines choices for targeted groups, in accordance with their age, reason for travel, and present travel behaviour. Prior behaviour has also proven to be important, meaning that customers are more willing to choose the modes they have tried before; this becomes important when considering strategies to promote active modes (walking, bikes and scooters) (Matyas & Kamargianni, 2018a).

Therefore, from the revision of the 21 apps we can conclude that only three of them (Ubigo, Whim and Wienmobil), accounting for 14% of the services, are in an advanced stage, covering the elements most important to be labelled MaaS. Most of the ongoing MaaS pilots constitute mere service information aggregators, some include intermodal journey planners that consider all modes, but few of them really allow users to pay and have a mobility package, which has become the key function to differentiate a MaaS service. Our results show that, even though there are many schemes claiming to be MaaS, three of them cover the main elements that intrinsically define MaaS. Most schemes cover the app-related functions or features while few of them offer mobility packages, which yields that the path to MaaS may not be hindered by technology development but rather by governance issues. In conclusion, most schemes that are claiming to be MaaS today, are not essentially covering the elements related to this concept yet, however the majority of them have paved the way covering the essentials for the app services. This revision of pilots sheds light on the importance of governance and stakeholders' courage to enable MaaS, for example in the case of Ubigo and Whim with their public transport systems' authorities deciding to open up to digital reselling and bundling of their services. From the Whim app, we also outline the ICT integration achieved in order to launch the app in different countries. In any case, the revision of these MaaS pilots and their preliminary findings give a broad idea of MaaS as a concept that is still developing and that needs further exploration.

10.6. MaaS challenges, benefits and impacts

In order for MaaS to scale up and continue its development, there is a need to overcome some barriers and challenges outlined by the literature. First, technological aspects include the needed interoperability and sharing of data between the different stakeholders and centralised payment solutions. From the governance approach, new regulations and policies should take place to support the concept. Regarding the latter barrier, some authors are even stating that, rather than technological obstacles, which are being solved at a very fast speed, MaaS urgently requires the establishment of a governance framework or, in less words: the rules of the game (Hensher, Mulley, et al., 2021a; Pangbourne et al., 2020). The close coordination between transport authorities, public transit and micromobility operators is necessary in order to enable MaaS, and this is one of the hardest tasks in many cities, especially those metropolitan areas with several multilevel authorities and institutions. A strong data privacy policy and MaaS regulation is needed

to allow third-party ticket selling, fair competition aspects, re-arrangement of benefits and fundings and finally, the willingness of the citizens to join the MaaS offer (Kamargianni & Goulding, 2018).

One of the main MaaS obstacles oft mentioned in the literature is that public transport operators might try to cling to their current operational models and their monopoly positions because they are afraid of losing control/influence and brand exposure when participating in MaaS (Jittrapirom et al., 2020; Kamargianni et al., 2015; Lyons et al., 2019; Smith, Sochor, & Karlsson, 2018; Sochor et al., 2015c). The brand-exposure problem is that transport operators who decide to join MaaS are not going to handle the MaaS front-end, but rather the MaaS Provider. The same occurs with users' primary relationships with Facebook, Google or Amazon, and not with the computer manufacturers or the networking companies that power their data centres (Smith, Sochor, & Karlsson, 2018). Others argue that opposing objectives in private and public organisations may also be a barrier for collaborating; public entities wish to decrease pollution and private vehicle usage and increase public transport (PT) patronage, while the private sector aims to increase revenues, even if this is achieved by increasing the use of private vehicle (especially car-sharing and rental, which is more profitable than PT) (Smith, Sochor, & Karlsson, 2018; Smith et al., 2019).

Another challenge for MaaS mentioned by the experts, is public transport funding, as it will be the backbone of MaaS, and it is a subsidised service, thus, it would not allow the MaaS Provider to make profits from selling public transport tickets (Gaudó Labarta, 2017; Y. Li & Voegelé, 2017; Smith, Sochor, & Karlsson, 2018). In this regard, financial support from MaaS could involve different business models. (Hensher, 2017) proposes a MaaS business model called the "Three Bs": bundles, budgets and brokers. By bundles, he means that mobility packages could enable providers to cross subsidies between mobility options. With budgets, he emphasizes the need to understand end-user preferences and willingness to pay for MaaS when setting prices. And lastly, brokers highlight the importance of considering potential new stakeholders and hybrid multi-modal contracts to allow as many investors as possible. Besides these initial principles, a MaaS scheme could be arranged in three different ways: market-driven development (entirely private), public-controlled development (entirely public) and public-private development (mixed). The general rule seems to be: "too much regulation might impede the private sector's ability to participate and innovate, leading to unattractive MaaS while too little regulation might lead to not serving the public interest" (Smith, Sochor, & Karlsson, 2018).

For MaaS to be economically profitable, many authors recommend offering the service not only to customers, but to administrations and other companies (Business-to-Administration and Business-to-Business services) who desire a more sustainable commute for their employees (Kamargianni & Matyas, 2017; Sarasini et al., 2017). To earn revenue, (König et al., 2016) describes that the MaaS Provider could purchase a significant amount of public transport tickets (bulk or volume purchase), receiving discounts and obtaining a marginal profit by reselling the tickets at the normal price. On the other hand, with private shared mobility services, they recommend charging commissions to transport operators for reselling tickets. And finally, third party advertisements, selling data on customers' preferences (considering the privacy with anonymised data) and other fees in transactions (Sarasini et al., 2017).

Despite all these barriers and challenges, MaaS also promises to offer some benefits. With the growing mobility ecosystem and new players arising, it is becoming more necessary to transition towards a MaaS model. As a centralised platform, MaaS is envisioned to manage the transport supply and understand the demand at all times which could help transport authorities to influence more positively in modal choices, reducing car-dependency and thus, congestion and pollution (Strömberg et al., 2018). Another expected benefit is the possibility of achieving higher service

quality and competitive pricing, since transport operators will gain detailed data from user travel preferences and profiles, resulting in a wider service offer and prices that are adapted to each individual. From the users' point of view, a single platform eliminates the hassle in accessing mobility information, ticketing or payment through multiple apps. Having mobility expenditures centralised, pre-planned, and being exposed to different modes of transport every day, could make users' travel behaviour change positively toward more active modes, working as a continuous informational campaign (Kamargianni, Yfantis, et al., 2018; Ratilainen, 2017).

Environmental benefits may include the reduction of private vehicle usage, and thus congestion, although this is still uncertain as MaaS may be unsustainable if it competes against active modes and public transport rather than private vehicles (Pangbourne et al., 2020). One of the most oft-mentioned MaaS negative possible effect is having a low percentage of car drivers joining MaaS and, consequently, MaaS becoming a potential competitor of public transport (public transport users may shift to taxis or car-sharing; cyclists and walkers may shift to public transport, taxis or car-sharing) (Jittrapirom et al., 2020; Kriukelyte, 2018; Smith et al., 2019). Hopefully, MaaS will contribute to a more sustainable mobility as Ubigo's trial version showed, where 36% of non-car owners stated that they will delay purchasing a car, and 35% of regular car users stated they will shift to public transport, 17% to bicycle, and 17% to walking (Kamargianni, Yfantis, et al., 2018). If MaaS really takes down car trips, the reduction of car possession could lead to an increase in freed parking spaces and infrastructure that could be used to promote active modes (constructing bikeways, public spaces, etc.) (Aapaoja et al., 2017). Social benefits are the extent to which this concept is inclusive is still highly uncertain as many people do not own bank accounts and may be digitally-illiterate with smartphones and different applications (which is the case for many elderly/disabled people) (Pangbourne et al., 2020). All these impacts need to be further analysed with new research contributions. Nevertheless, city planners and transport authorities have adopted many solutions oriented to the promotion of MaaS, with mobility hubs being one of the most successful strategies.

We have revised 21 MaaS schemes worldwide, and our findings yield that only three of them covered the basic elements necessary to be labelled as MaaS (Whim, Ubigo and Wienmobil). The majority of services are still mere information aggregators and do not offer mobility packages. These results point to the fact that the main obstacle for implementing MaaS may not be technology, but rather the necessary governance frameworks.

10.7. Catching up with MaaS literature (findings from 2021-2023)

As previously mentioned, we conducted the MaaS literature review to set the theoretical base of the thesis up until 2020. As MaaS-related literature is continuously growing, we have conducted a second search in Scopus during February 2023 (up until 27/02/2023) to update and summarise more recent findings from new contributions. Our search was carried in Scopus selecting those open-access, English-written, journal scientific articles, published from 2021 until 2023, with the words "MaaS" or "Mobility as a Service" in their title, obtaining 28 new documents. We discarded seven of them as MaaS was not the central topic of interest but rather a tangent matter, obtaining a valid set of 21 documents to analyse. This section summarises the most relevant findings from this literature update.

Overall, the most recent literature on MaaS is now focusing on its governance issues and the challenges and obstacles that the concept is facing. As stated by some experts, MaaS seems to be transitioning by the Gartner hype cycle, as it was at the "peak of inflated expectations" a couple of years ago and now is going somewhere in the "trough of disillusionment" (Hensher, Mulley, et al., 2021b, p. 153). From the 21 documents reviewed, nine of them focused on MaaS' near

future and the revision of literature to find gaps while 12 of them are more oriented to summarise MaaS trials' findings and offer methodological approaches to study MaaS' preferences.

On the first group of studies, we find (Hensher et al., 2022; Hensher, Mulley, et al., 2021b) that opened the discussion based on current literature to critically point out that new trials are needed in order to get pass the debate around MaaS' concept. Furthermore, they invite the readers to realistically start recognising that cars will not disappear, especially in rural environments, and that the challenge is to find better ways of integrating electric cars in MaaS to be able to achieve sustainability goals. In addition to the short-discussion papers, some other studies focused on the revision of literature, with the majority of them resulting in the identification of MaaS challenges/obstacles (Alyavina et al., 2022; Butler et al., 2021; Enoch & Potter, 2023; Muller et al., 2021), but also some others that delved into niche topics like the inclusion of freight transport in MaaS (le Pira et al., 2021), vulnerable groups (Dadashzadeh et al., 2022) or preferences for mobility packages (Ho et al., 2021; Kriswardhana & Esztergár-Kiss, 2023). (Butler et al., 2021) conclude that from the MaaS supply side, barriers include public-private cooperation, business support, service coverage, shared vision, and data and cyber security issues, while on the MaaS demand side the main barriers are the lack of appeal to older generations, public transport and private vehicle users, the attractiveness of the digital platform, and user willingness-to-pay for the service. Similarly, in (Enoch & Potter, 2023) the authors highlight that the major challenges for policy makers will likely relate to balancing the promised benefits offered by MaaS with issues such as safety (including bio-safety in the post Covid-19 world), data security and privacy, equity and the threat of dominant suppliers distorting the market-place, with a great deal of uncertainty around the future of MaaS, which might indicate a 'wait-and-see' approach of policy makers. Lastly, (Alyavina et al., 2022) groups in 11 diverse thematic areas the opportunities and challenges of MaaS (market visibility, centralised data gathering, vehicle utilisation, accessibility, transport affordability, digital access, modal shift, market shares, environment, health and wellbeing and financial support) offering a roadmap for policy makers.

On the second group of studies we mostly find new approaches to evaluate end-users' preferences for MaaS in general (Hasselwander et al., 2022; S. Kim & Rasouli, 2022) or focusing on particular topics like mobility packages for suburban areas (Brezovec & Hampl, 2021), tourism sector (H. Kim et al., 2023; Martinčević et al., 2022), gender (Aman & Smith-Colin, 2022) and private vehicle owners (Hensher, Ho, et al., 2021; van 't Veer et al., 2023). In (Brezovec & Hampl, 2021) they found that price was the most important attribute to choose a mobility package and most respondents preferred to have car-sharing included instead of micromobility services, supporting findings from previous research that point to the relevance of cars in peripheral contexts (suburban, rural). Moreover, on two recent studies, results suggested that having positive attitudes towards multimodal travel increases the propensity to adopt MaaS and especially multimodal tourists which required particular needs (S. Kim & Rasouli, 2022; Martinčević et al., 2022). The study done by (Aman & Smith-Colin, 2022) conducted sentiment and text analysis of 29.000 Mobility app reviews to evaluate differences across gender regarding 11 topics (schedule, plan, train, Uber, walk, pass, ticket, user interface, update, app issues and Google Map). For men, app-related features (update and app issues) as well as fare-themed features (ticket and pass) showed the most significant impacts on satisfaction while in the case of women attributes like update, app issues, and ticket and train were the most important. Only Google Map (for both men and women) showed positive correlation to satisfaction. To our knowledge, this was the first study that analysed gender differences regarding preferences for MaaS. When analysing private vehicle owners, (van 't Veer et al., 2023) identified five clusters. Their results showed that those who often use public transport and active modes are most inclined to use MaaS, whereas the

‘conservative’ passenger car owners who use the car as their main mode of transport for all their trips (e.g., commuting, leisure) show a lower intention to use MaaS.

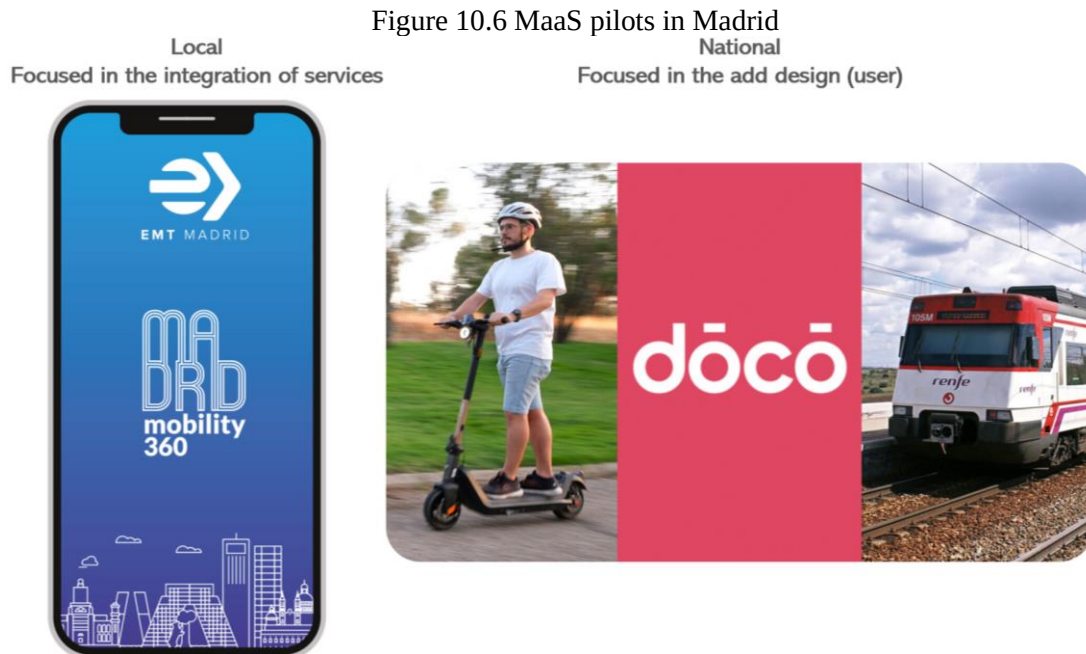
More related with the topic of this thesis, two recent studies are found. The first one done by (Cho & Shin, 2022) analysed the route choice behaviours of bike-sharing users for the first/last mile of trips and how they connect with metro stations to evaluate this kind of intermodality in the framework of MaaS. Their results showed that distance was a critical variable for users who depart/arrived at metro stations and the authors recommended to extend bike facilities to ease the access/egress stages. Lastly, (Narayanan & Antoniou, 2023) develop a mode choice model for Madrid, capable of capturing the demand for bike-sharing, car-sharing and ride-hailing services simultaneously (simulating a MaaS offering). Their results showed that gender and household car-ownership influenced both bike-sharing and car-sharing. While males have a higher likelihood to use bike-sharing and car-sharing, a significant difference between males and females is not observed for ride-hailing. Young (20-44 aged) and highly educated individuals are more likely to use all the three types of shared mobility services. Having license or public transport monthly ticket negatively influenced on the use of ride-hailing service, although the latter improves the odds of using bike-sharing and car-sharing services. Moreover, they found that households with higher number of cars are less probable to use bike-sharing, while a positive impact is seen for car-sharing. Their recommendations include the design of bike-sharing and car-sharing as complementary services to public transport, while ride-hailing could substitute the car in areas where public transport is weak. They also recommend subsidies, discounts and special offers to attract young age groups and free-ride promotions to make older groups accustomed to the use of shared mobility. Gender-related measures include the offer of special rates for females or caregivers around daycares to attract them to use shared services. And finally, the authors recommend implementing or extend cycling infrastructure (short cuts or segregated cycle lanes with green light waves) or for the case of car-sharing, the introduction of dedicated parking facilities for shared cars.

10.8. The development of Mobility as a Service (MaaS) in Madrid

As our results show, Madrid has a cluster of conditions that make the city a potential candidate for MaaS developments. The first one is having a dense, diverse and young population served with a good public transport system and many shared mobility services. Different studies have analysed the potential MaaS user for Madrid and the characteristics are similar: young people, with high environmental consciousness, technophiles, well educated (digitally literate), early adopters and that are shared mobility subscribers (with some experience) (López-Carreiro, 2021; Velázquez Romera, 2019). These are all favourable characteristics that are enabling the development of MaaS pilots and initiatives for the city.

The two most important MaaS pilots in Madrid are shown in Figure 10.6. The first one, coming from the public sector, with the Municipal Transport Company of the city of Madrid (EMT), which operates the city’s urban bus, cableway car and BiciMAD services. They have developed, with the City Hall’s support, the test prototype of an application called "Madrid Mobility 360", which aims to integrate all the services available. This application offers real-time information on different services (intercity trains, subway, urban bus and shared services) and the bus occupancy both when calculating a route and when waiting at a stop. This information can help to flattening the public transport peak hour, which seems of particular relevance today in view of users’ added concerns for the COVID-19 pandemic (López-Carreiro, 2021). In addition, payments can be made through the application to purchase single bus tickets and use the services of BiciMAD and BiciMAD-Go (additional EMT Madrid services). So far, it has achieved 3.000 subscribers that have agreed to have their mobility behaviour patterns studied. Nevertheless, for now, the app is

just an information aggregator, with developments needed in the payment integration. The second one, coming also from the public sector, is the company Renfe, which operates the primary rail network of Spain. They have developed a MaaS prototype called “DOCO”. The train operator is envisioned itself as a mobility service provider in the future, expanding its revenues by involving the emergent concept in their core essential activities. The app was tested during months with around 500 people and is now available to download from Google Play. These two main initiatives are differentiated by two main aspects: their reach and their focus. The Madrid 360 app is a local initiative (Madrid’s municipality) pushed by the City Hall and it is currently more oriented to add or integrate as many mobility operators as possible. On the other hand, the DOCO app has national coverage as it is managed by the national rail company involving light and interurban trains as well as interurban buses. This app is mainly focusing on the user-centric perspective and the design of a robust application. Therefore, we have different scales (local and national) and different main focuses (integrating operators and a well-design app). From a positive perspective, we could highlight that having two very different initiatives can result on interesting findings and comparisons. For now these two main stakeholders are trying to become the MaaS operator in Madrid by offering the best MaaS pilot.



Source; own elaboration.

From private initiatives, we can highlight two pilots. On one hand, the Wondo app, which a service aggregator with real-time information regarding all mobility operators in the city (public transport and shared mobility). This initiative has established partnerships with several shared mobility services to do a volume purchase of tickets and resell them through their MaaS app. In November 2019, the Wondo team announced that they were partnering with Moovit (which had more subscribers) just before being purchased by the organisation MaaS Global, which increases the chances to be the most consolidated private pilot of Madrid (Ferrovial, 2021). On the other hand, we can mention the Chipi app. This application integrates public transport and the majority of shared mobility services available in the city. One of the most interesting functionalities of the app is that it compares distances, travel time, prices and calories for each modal chain, being one of the few multimodal journey planners available in the market.

All these initiatives, at present, are mainly in their early stages and have a partial level of integration (Kamargianni et al., 2016), which is still far away from covering all the elements

required to be labelled as a MaaS. Additionally, there are scarce regulation frameworks for MaaS to work, and collaborations between public transport and shared micromobility operators are just starting to take place (especially promoted by the City Hall with the Madrid 360 app). Advances have been announced from the Consorcio Regional de Transportes, Madrid's public transport authority, regarding the development of payment and ticketing ICT infrastructure that could allow users to buy tickets with only the use of their smartphone and a single app, which is a basic requirement to integrate the public transport systems (which includes services managed by different operators) as the backbone of MaaS (CRTM, 2019).

However, although there are at least two ongoing MaaS initiatives in the city, there is no collaboration between them. After the COVID-19 pandemic, public transport and micromobility operators are more focused on retaining or recovering their market share and ridership levels. Consequently, we could state that the MaaS topic in Madrid after the pandemic has become less topical. However, important advances are observed from micromobility operators. On the first hand, their willingness to share data (which is one of the most important elements to enable MaaS) is very high compared to other cities. The operators want to establish collaboration agreements with academic institutions in order to extract value out of their raw trip datasets and publish findings that could leverage their status and image when asking for licenses to the City Hall. In other words, micromobility operators want to be linked with academic to look better when negotiating with the City Hall for permissions/licences and regulation issues. On the other hand, they believe that becoming part of the MaaS app of Madrid could increase their exposure to citizens that are not yet clients, which could result in an increased market share. To that end, many of these micromobility operators are willing to make discounts and arrange convenient prices of their services in order to gain more exposure through the MaaS app. This is highly relevant for the configuration of MaaS packages to be price convenient as demonstrated by (Awad Núñez et al., 2020). Hence, the current state of cooperation supports what other authors have established as one of the main challenges to MaaS' feasibility: poor governance frameworks for MaaS.

10.8.1. Exploring MaaS packages for Madrid

One of the most important concerns related to MaaS governance is the design of a profitable and attractive business model. When planning for MaaS business models, researchers need to consider the "MaaS package" design. As we have seen in section 10.5, many of the ongoing MaaS pilots do not offer mobility packages yet, which indicates the presence of a research gap related to studies that delve in the exploration of the willingness to pay for MaaS. To explore this topic, research must be oriented to the exploration of potential subscribers' travel preferences and lifestyles. In other words, an 82-years old grandmother will not have the same preferences as an 18-years old student, and theirs will be very different from a 40-years old businessman. The price that they will be willing to pay would probably vary considerable according to multiple factors, including their geographical context and socio-demographic characteristics (e.g., gender, age and income). Therefore, exploring attitudes and preferences for a future possible MaaS offering could be highly relevant as it could offer insight on the viability of MaaS and the potential that it brings to enable a sustainable modal shift in travel behaviour, especially now that the concept is just beginning to arise. In other words, analysing the "price issue" may be highly relevant in an early stage of MaaS implementation (which is Madrid's case) in order to have a basic idea about willingness when designing for MaaS bundles and business models.

Very few contributions are found in this topic. For example, (Matyas & Kamargianni, 2019) explored preferences regarding MaaS mobility packages for London, proposing three MaaS plans that included public transport systems, bike-sharing, car-sharing and taxi rides. Additionally, this study offered the opportunity for the respondents to configure their own plan if they did not feel attached to any of the proposals. Through a mixed multimodal logit model, findings yield that

people were interested in having public transport integrated more than any other service. Their results showed that 38% of respondents will buy the MaaS plan offered or designed by them. For the case of Madrid, (Lopez-Carreiro et al., 2020) conducted a survey to analyse MaaS preferences using focus groups. The authors identify the key elements that need to be considered in the MaaS app to make them adopt the service. These elements were an easy registration process, being able to make reservations, real time information, having mobility packages and being able to pay for them in the same app. Other elements that were considered less important were having parking at destinations, knowing the environmental impact and the calories burnt of the selected route, information regarding pollution levels, vehicle condition and points of interest in the city. On both studies, researchers yield the inevitable: the need to develop further research to understand the perspectives, expectations and behaviours of potential MaaS subscribers. The acceptance, adoption and the willingness to pay for MaaS is a basic knowledge needed to successfully implement a MaaS pilot. For the case of Madrid and to the author's knowledge, there is only one intent to explore this topic (Tinelli, 2021; Tinelli et al., 2022), despite being one of the world cities with the most shared mobility services. Hence, this section will describe the main results obtained from this study in order to offer even more context for the topic of MaaS in the particular case of Madrid.

The data used for this study was obtained through an online survey (December 2020) with 182 valid responses. Four initial MaaS packages were configured (see Figure 10.7) based on the price of the services diagnosed in 2020 (Arias-Molinares & García-Palomares, 2020a) and mobility patterns resulted in the last Mobility Survey (Comunidad de Madrid, 2018). This initial proposition of MaaS packages for Madrid was developed thinking of a particular targeted user.

Figure 10.7 Configured MaaS packages for the exploration of willingness to pay for MaaS in Madrid

	ESTUDIANTE Hasta 25 años	URBANO	METROPOLITANO	PREMIUM
	40 € / mes	80 € / mes	100 € / mes	200 € / mes
Transporte público	Abonos todas la zonas	Abonos zona A	Abonos zonas A, B1, B2 y B3	Abonos zonas A, B1, B2 y B3
Taxi	Pago por uso	1 viaje (5 km)	Pago por uso	2 viajes (10 km)
VTC / Uber / Cabify	Pago por uso	2 viajes (5 km)	Pago por uso	10 viajes (5 km)
BiciMad	200 min	120 min	100 min	120 min
Bicis sin estaciones (Ej. MoBike)	40 min	30 min	50 min	120 min
Moto compartida (Ej. Acciona, Movo)	30 min	30 min	50 min	50 min
Patinete compartido (Ej. Lime, Bird)	30 min	30 min	40 min	40 min
Coche compartido (Ej. Zity, Sharenow)	Pago por uso	Pago por uso	Pago por uso	100 minutos
Alquiler de coche (Ej. Hertz, Sixty)	Pago por uso	Pago por uso	Pago por uso	1 fin de semana

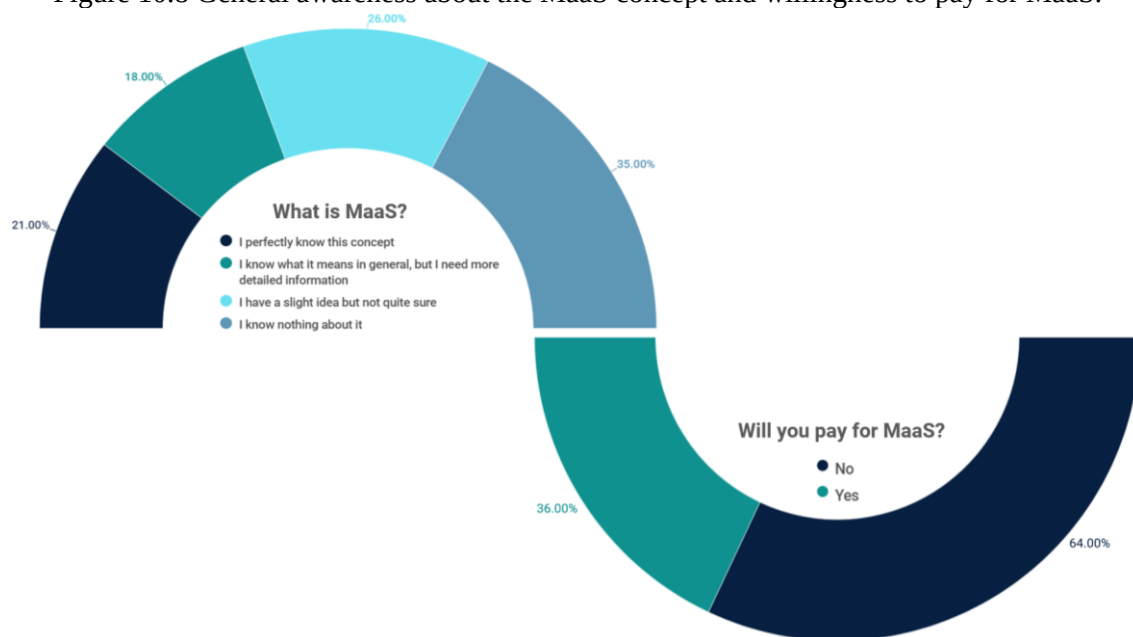
Source: (Tinelli et al., 2022).

The student plan was the cheapest one (40€/month) as it was designed for the population up to 26 years old. It included the 20€ monthly ticket for public transport systems in all zones but also new shared mobility services like bike, moped-style and scooter-sharing as they (young population) are expected to be more familiar with these new travel options as supported by previous findings (Johansson, 2017). The most expensive choices like car-sharing, ride-hailing and taxi services were configured as pay-per-use. The next plan (urban) was designed for adults who live in the central districts of Madrid (Zone A). It included the monthly public transport ticket (Zone A- 54, 6€) as well as all the shared mobility modes with the exception of car-sharing and car rentals. The third plan ("Metropolitan") was targeted for residents of peripheral areas. In considers all the areas of the city in the public transport monthly ticket (Zone B3- 82€) as well as shared mobility options.

The configuration of this particular plan responds to the intention to encourage the use of public transport to access Madrid and the use of shared mobility for the first/last mile of trips. Finally, the Premium Plan includes all modes of transport, it is designed for people who have high mobility demands and need more coverage and options. This plan is structured for high income employees that do not want to lose time and appreciate the solution of bundling all the services together. This plan included 100 minutes of car-sharing and a weekend of car rental. Apart from the four pre-designed plans, the option to configure their own was offered. Hence, each person had the opportunity to select the preferred services and associated costs. This was relevant as respondents were aware of how much each service costs and we could evaluate the willingness to pay for each service.

The sample base was characterised mainly by contemporary male adults with middle-high income and high education level. The majority of them were multimodal users as they also have subscriptions to shared mobility services and 42% of them have used a journey planner like Google Maps on daily basis or at least three times per week. When exploring the general knowledge about the MaaS concept, 65% of them reported to have at least heard about the term, while only 35% knew nothing about it. After showing a brief and general definition of the concept, respondents declare whether they will be willing to pay for a MaaS service in Madrid, with 36% stating they will (see Figure 10.8). Even though the majority of the people would not pay for the MaaS service just yet, 35% is a considerable amount of people that will try it, considering similar findings (38% willingness to pay for MaaS) from (Matyas & Kamargianni, 2018a).

Figure 10.8 General awareness about the MaaS concept and willingness to pay for MaaS.



Source: own elaboration.

When exploring preferences for the four pre-configured plans, we observed that the “Student” (16%) and “Urban” (15%) plan stood out as preferred ones. The majority of respondents did not find any of them attractive (61%), with Metropolitan (6%) and Premium (2%) being the least preferred. Results point out to the importance of pricing when choosing a plan and especially after COVID-19 as many people started teleworking and reduced their weekly trips. When configuring their own plans, most of them included public transport which supports previous findings indicating that it is the backbone of MaaS (Strömberg et al., 2018). Having access to taxi/ride-hailing services was also noticed as relevant as well as having unlimited minutes of BiciMAD service. These preliminary results should not be considered definitive or exhaustive as it consisted

of a first attempt to generally explore this topic in Madrid. A relaunch of the survey is recommended to evaluate the post COVID-19 behaviour (evaluating if telework-related behaviour persists) and the impact of the recently introduced price reduction for public transport system monthly tickets (they were reduced to 50% due to the Ukrainian war). Even though further research on this topic is still needed, this first exploration offers a general and helpful idea that could begin to orient transport authorities in the task to understand potential users' opinions related to MaaS and their willingness to pay for it. This knowledge is of great relevance when MaaS implementation processes are beginning (as is the case of Madrid), so that stakeholders could better target their market share, and better business models and pricings schemes could be designed to be competitive and attractive.

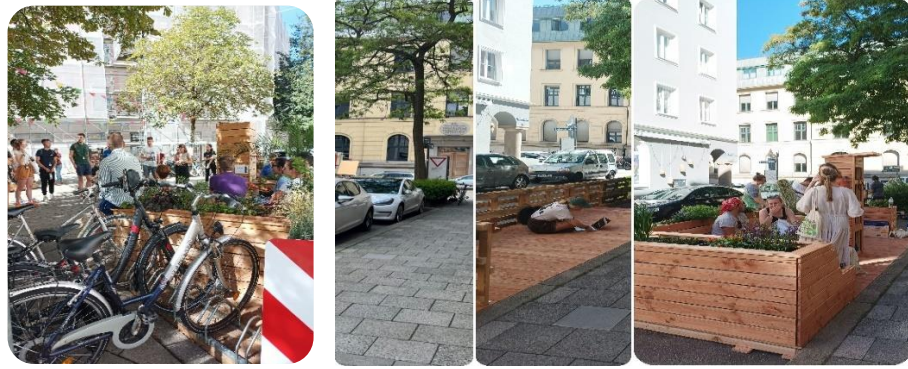
10.8.2. Practical strategies to promote MaaS in Madrid

Building upon the revised literature and our practical findings, we have described a general diagnosis of Madrid's current perspectives towards MaaS. To translate all of this gained knowledge into practical solutions for MaaS in Madrid we elaborate a brief list of strategies and their implications. At this point it is important to note that we do not intend to offer an exhaustive and static "one-fits-for-all recipe" type of solution, but rather provide a basis for discussing and exploring new ones. These strategies could include:

- **Create a MaaS target profile:** several studies, including our results have indicated that MaaS early adopters would probably be young, multimodal and tech-lovers (Lopez-Carreiro et al., 2021; Lopez-carreiro et al., 2021; Sochor et al., 2014; Strömberg et al., 2018). Therefore, efforts should be oriented to attract these profiles by understanding their particular needs and offering them flexible solutions, instead of trying to achieve a one-fits-for-all MaaS app that would unrealistically cover all needs for all kinds of people (older population, tourists, rural, business people, family groups, etc.). By this statement we do not intend to close the possibilities of MaaS for different groups, but rather concentrate and focus on the "pro-MaaS" target in the initial phases of the pilot while the app gains strength and then progressively include features and services for other groups of people, just as any other marketing product does. Our results from chapter 4 and the literature revised supports that for Madrid, young students and young/middle-aged workers that are highly educated and multimodal users could be the most prone to adopt a MaaS service. Furthermore, from section 10.8.1 we have learnt that the majority of Madrilenians could adopt a future possible MaaS service only if it is price-attractive and with mobility packages that include taxi/ride-hailing services and unlimited BiciMAD. Overall, the consideration of end-users preferences and expectations from the MaaS service is a key point to start the fruitful MaaS-related discussions in Madrid.
- **Create a MaaS Hub for Madrid:** creating a MaaS hub that integrates all the stakeholders related to or interested in MaaS. All public transport operators should be present as many studies and also our results suggest that the public transport system is considered the backbone of MaaS. In regard with shared mobility operators, they should be invited to participate to the greatest extent in order to achieve a coverage of most of the transport operators in the city. This hub could provide the space and time to discuss about MaaS concept, implementation, and obstacles and specially their role in the MaaS ecosystem. However, workshops and meetings should be solution-oriented, meaning that they should result in products or improvements of the current apps to promote MaaS, rather than being a space where people meet and talk about MaaS, but nothing really happens next. Compromises and solutions should be obtained, especially related to the data sharing structures, data privacy concerns, business and revenue models and governance issues related with conflicts on stakeholders' respective interests and expectations.

- **Convincing through the eye:** as highlighted by (Lopez-Carreiro, Monzón, Lois, et al., 2021) and supported by previous studies, public acceptance of MaaS is a pre-requisite for its success. With the recent nature of the MaaS concept, it is still quite unknown whether the general population will adopt the service and shift their travel behaviour, especially car-owners. In order to gain acceptance of the concept, policy makers could “convince by the eye”, meaning that they can implement real-world physical infrastructure that could serve as showrooms for what MaaS “looks like” in the real world, being important infrastructures that could influence in people’s acceptance of the service and promoting intermodality more than unimodality. This opportunity for people to see and begin to grasp the MaaS concept by experiencing with physical infrastructure is key to change their minds. In this regards we recommend three types of initiatives:
 - **Mobility hubs:** the progressive implementation of different types of mobility hubs is highly recommended. With Madrilenians showing a high modal share of private cars, we recommend that these hubs include free parking to make facilitate intermodal chain (e.g., car-bike, car-moped, car-public transport). From our results from Chapter 9, we also recommend starting the allocation of mobility hubs near the most important intermodal stations in Madrid where many of the transport services are concentrated and high demand is observed. To this end, this thesis offers a methodology to efficiently allocate these infrastructures. Mobility hubs can be seen as the physical-world materialisation of MaaS as citizens can find in a single spot a mix of public transport, shared mobility, and other services. They could begin to understand and experience the concept through this kind of infrastructures.
 - **Street experiments:** street experiments could also be introduced, as they are temporary interventions to improve the quality of public space. These “try-out” interventions are a result of different urban actors coming together to give the street a new and potentially radical set-up that offers more space to soft, active mobility and a healthy and liveable public realm, *moving away from “streets for traffic” and towards streets for people*” (EIT Urban Mobility, 2022). Many cities have begun to implement temporal street experiments, substituting parking spaces or closing particular streets to install people-oriented services and activities (see Figure 10.9). Some interventions could be implemented only during the spring and summer months when the climate is more convenient to spent time in the public space. In the case of Madrid, our results yield that spring and autumn seasons constitute the best time to use micromobility, as temperatures are not as extreme (extremely hot in summer and cold in winter), and thus this could be the perfect timeframes to implement these kinds of experiments.

Figure 10.9 Street experiment in Munich



Source: pictures taken by author on July 15th, 2022. Two parking spaces were substituted by public seats, a library and bicycle parking. This intervention was temporary (during summer season) from July to October.

- **Attractive and competitive service bundles:** include gamification and discounts for people to start using the service and experiencing their benefits. We have seen the introduction of many apps that started as free services offering great benefits for its users and gaining fidelity. Once these apps achieve the target market desire, they switch to a paid-type service. This could be an approach viable for MaaS, including different services' discounts (e.g., for movies or cultural events, shopping cards or trip giveaways) or benefits that could attract new citizens to adopt the service. As previous studies suggest (Hensher, 2017; López-Carreiro, 2021; Lopez-carreiro et al., 2020), the incorporation of non-transport services might be key for engaging end-users, as MaaS should be conceive as a multi-service scheme (rather than just multimodal), and hence, the MaaS packages could combine mobility options with other services such as a mobile phone contracts, utilities or other household related services (television packages, music subscriptions, etc.).
- **Normalising data-sharing schemes:** a topic of great concern in MaaS is the data-sharing policy between different operators to enable the service. In this regard, cities can adopt the scheme used in other contexts (e.g., San Francisco or Washington DC) where operators are "obligated" to publicly share their aggregated data if they want to obtain a permit license, allowing authorities and researchers to gain findings from it. In order to become a licensed operator, the service providers offer an open API (Application Programming Interface) for authorities and researchers to have access to the anonymised and aggregated data for mobility studies. The transparency of data and its availability are key to extract knowledge and improve mobility and this should be a common practice adopted and spread throughout different contexts. In Spain, and in Madrid particularly, shared mobility operators seen to be willing to hand out their data and hence, the initiative should be taken and put forward by public authorities.

10.9. Conclusion

Our study conducted an extensive literature review related to the MaaS concept, then translated the main findings into a three-bullet point checklist, and finally applied this MaaS-checklist to assess the level of development of 21 MaaS-like schemes. Our main conclusion after carrying out this study is that after five years of research contributions published, the research community is close to finding a standardised concept of MaaS as there are more agreeing than disagreeing points. When analysing the 90 articles, we observe that there are many small variations in the MaaS definitions, but in general, scholars understand it as a mobility service offered through an application with a model that manages the whole trip chain. Some authors prefer to prioritise the

technological innovation of MaaS defining it as a model, system, app (Hietanen, 2018; Kamargianni & Goulding, 2018) while others put in the forefront different aspects like the transport modes offer (Becker et al., 2020; Hesselgren et al., 2020; Sochor et al., 2017) or the actors involved in the MaaS ecosystem (Docherty et al., 2018; Pagoni et al., 2020; Pangbourne et al., 2020).

Our review shows that MaaS is topical and will continue to be, especially regarding governance issues and new findings from pilots around the world as the impact of MaaS has yet to be measured. While MaaS continues to generate hype among the scientific community, we must reach a common understanding of the term as soon as possible, in order to develop clearer and better interactions between different stakeholders. Our study contributes to the literature as it offers a clear and summarised three-point MaaS-checklist based on scientific definitions that could help the MaaS ecosystem of actors, especially those outside the research community, to have a minimal basic common understanding of MaaS in order to establish fruitful conversations and efficient cooperation to clear the path for MaaS in different cities. As we know that the concept is still developing and new contributions will be expected, we stand for the definition proposed by (Smith & Hensher, 2020), since it involves the three main elements identified in the review: MaaS as ‘a type of service that through a joint digital channel (A) enables users to plan, book and pay (C) for multiple types of mobility services (B)’ (Smith & Hensher, 2020, p. 56).

Previous works have classified MaaS-like schemes. A good example is (Sochor et al., 2018) that classified MaaS according to their integration level. However, our analysis does not intend to fit schemes into a set classification, but rather describes their functionalities and analyses whether they cover or not some elements identified as important to be labelled as MaaS. This was a basic exploration of the market in order to count how many of the schemes are really covering the MaaS checklist and not just using the term as a ‘buzzword’ (Pangbourne et al., 2020). Some of the revised schemes are just customised journey planners at this stage, and they still lack some of the most important features like being able to do everything in a single app (not just information aggregators) or offering mobility packages. The MaaS Alliance website has shown more than 70 initiatives of MaaS-like schemes around the world, but as we have observed, only 21 MaaS-like schemes have an application available (only 30% of the initiatives). Furthermore, of the 21 apps selected, only three of them (Ubigo, Whim, and Wienmobil), accounting for 14% of the services, are in an advanced stage, covering the elements most important elements identified in the review. Our results show that even though there are many schemes claiming to be MaaS, three of them cover the main elements that intrinsically define MaaS. While most schemes cover app-related functions or features, few of them offer mobility packages, which yields that the path to MaaS may not be hindered by technological development but rather by governance issues on MaaS as stated also by (Pangbourne et al., 2020; Smith, 2020; Smith & Hensher, 2020).

In conclusion, most schemes that claim to be MaaS today are not essentially covering the elements related to this concept yet, however the majority of them have paved the way covering the essentials for the app services. Reviewing the advanced MaaS schemes’ characteristics has shed light on the importance of cooperation between different stakeholders in order to enable MaaS (e.g. in the case of UbiGo, after the public transport company decided to open up to digital reselling and bundling of their services). Based on the Whim app, we also outline the ICT integration achieved in order to launch the app in different countries. From our results as mentioned previously, we infer that governance issues regarding MaaS are a recurrent topic in the literature, because the elements that must be urgently addressed are related to it. For example, offering mobility packages, which only three services do, is an urgent need, but this will also spring from the new governance frameworks for MaaS that must be developed. Technology-based issues are seen to be secondary as our results show that most applications have all the app-related features covered (ICT technology advances that allow information, booking and ticketing

integration). This is particularly important for targeting the most urgent actions related to MaaS (governance and cooperation to offer mobility packages), based on the evaluation of the current MaaS-like schemes in operation.

Limitations of this study include the fact that our evaluation of apps is basic and is restricted to the applications available. However, the identification of the three main elements necessary for MaaS, based on the available scientific research body, makes an important contribution for planners and the research community to differentiate advanced schemes from others still on the path to MaaS. Future research lines could be oriented toward completing the MaaS checklist by directly interviewing MaaS providers, reducing the subjectivity in the authors' evaluation. However, in this recent stage of the concept, with MaaS pilots still under development and with limited empirical evidence, we believe this is a clear approach for comparing schemes

11. Conclusions

11.1. Conclusions regarding the research specific questions and objectives

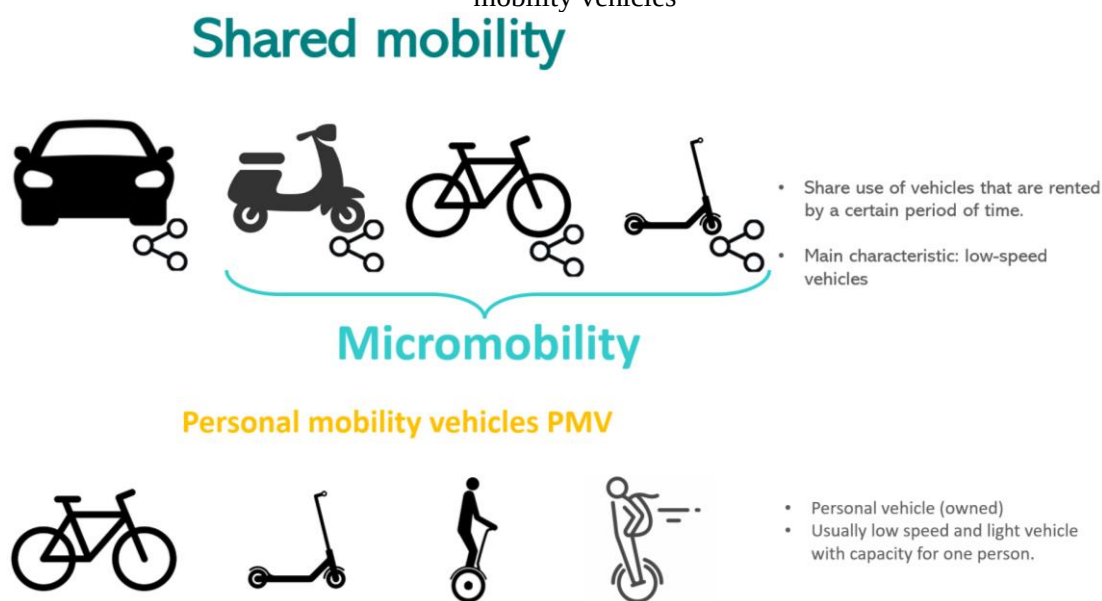
The thesis is composed of several research papers including their corresponding conclusion sections. Hence, the aim of this chapter is not to repeat those conclusions, but to provide more general ones from a perspective that understands the research as a whole. The conclusions are provided in relation to the specific research questions and objectives defined and then some general conclusions related to the main objective of this research are also derived.

Six research questions to address were defined when this thesis research was planned. We described them in the introduction section, and, in addition, we defined a number of research objectives, derived from and related to these research questions. The aim of this section is to provide the main conclusions that can be drawn based on the research conducted. These conclusions are provided next, in relation to each specific objective. We have also added an infographic for each research question summarising the main findings on the study addressed to make results more illustrative.

RQ1. What is the new mobility paradigm and the elements that characterise it?

Several shared mobility companies have been developed over the last years and are operating in multiple cities around the world. The burst of these initiatives, and especially micromobility services has been the main motivation of this research. For this reason, we have delved into the recent literature on micromobility and its definitions. Definitions vary quite often, but most of the studies agree that micromobility is *a low-speed type of shared mobility*. In other words, micromobility is all shared mobility with the exception of car-sharing, as cars allow high speeds. Thus, micromobility involves the shared use of vehicles like bike-sharing, moped-style scooter-sharing (also known as moto-sharing) and kick-style scooter-sharing services (also known as scooter-sharing). Moreover, micromobility is different from personal mobility vehicles (PMV) as the vehicles are owned by a company that offers their fleet through an app for customers to rent them for a certain period of time. Thus, two differentiations have been grasped with this research question. The first of them related to the ownership of the vehicles: micromobility vehicles are owned by companies while personal mobility vehicles are owned by people. Secondly, micromobility is differentiated by the vehicle's speed capacity, being a type of shared mobility that only involves low-speed vehicles (see Figure 11.1).

Figure 11.1 Micromobility's differentiation with respect to shared mobility and personal mobility vehicles



Source: own elaboration.

Additionally, we conducted a review of the current literature available on the topic of micromobility to set the theoretical framework of the thesis. Our findings show that these services are mostly operated by private initiatives from start-ups or big companies, usually from the car industry. We have also found that they offer their fleet through applications where their customers register and book and pay for their trips. Studies that addressed spatiotemporal travel patterns of micromobility services have found that they mostly operate in city centres where the majority of the entertainment and cultural activities are offered, but also where employment concentrates. The mix of activities and high population density are outlined by studies as key factors for micromobility to thrive. Lastly, we have described the approaches taken in the study of the micromobility topic: most of them analyse only one or two modes and few of them use new data sources, different from surveys. We agree with other authors who state that survey findings are useful and insightful, but it is also necessary to complement them with new data sources (i.e., trip data with GPS records) (Romanillos, 2018). In our thesis we have used surveys and trip data to conduct a holistic study of not only one, but the three shared modes that involve micromobility (shared bikes, mopeds and scooters). The analysis of multiple and diverse shared modes and the inclusion of new data sources that complement surveys constitute the line of research in which this work aims to contribute.

RQ2. How does the mobility ecosystem in Madrid look like, and what are the current initiatives towards sustainable mobility?

As was mentioned before in the introduction section, it was highly relevant to describe the scenario and current situation of the shared mobility ecosystem in Madrid, as we did not find any previous contributions in this regard. The city has been known as one of the most important European living labs for shared mobility with many companies implementing their services, but a clear and detailed diagnosis was inexistent. We have delved into each one of these companies and describe their characteristics in order to understand the actual *burst* of micromobility services in the city. As our diagnosis suggests, from the summer of 2018 until the end of 2019, there were more than 20 thousand vehicles offered as shared mobility fleet (see Figure 11.2). Car-sharing and scooter-sharing services lead the fleet count, followed by shared mopeds and bikes. We also witnessed the atomisation of companies in the scooter-sharing sector, with many start-ups implementing their services impressively fast. We conclude that shared scooters were the most

RQ3. Who uses BiciMAD and other dockless micromobility services and how are their travel preferences similar/different?

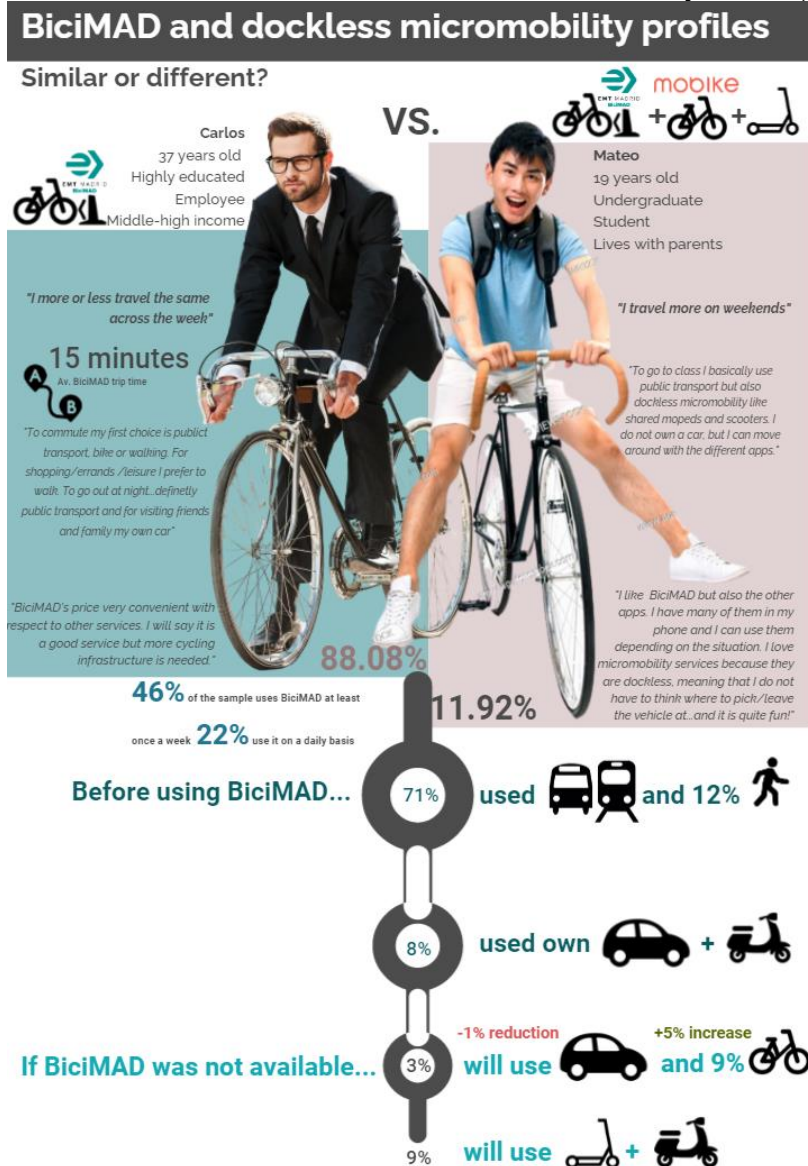
RQ3.1. Is micromobility competing/complementing with BiciMAD and/or the public transport system?

If we wanted to understand the dynamics and spatiotemporal travel patterns of BiciMAD and other dockless micromobility services, we needed to start by the basics: who uses them? This question of research was oriented to define the profiles and preferences of those subscribers to BiciMAD and other micromobility services. As was mentioned in the introduction, this is highly relevant when planning new policies as authorities need to have a clear target market defined for them. By considering the responses from the annual BiciMAD survey conducted in 2019, we have found that Madrid's results support previous studies suggesting that these kinds of services are mainly use by young generations. But if we asked, how young? In the case of Madrid, we obtain that most of its subscribers are found between the ages of 35 and 49 years old (mean = 39 years old, median = 38 years old). Hence, BiciMAD subscribers could be better described as *young and contemporary adults*. This is a positive aspect, as it supports that in Madrid, these services are adopted also by older population; something that is often hard to find in other regions. Moreover, in this survey we wanted to explore to what extent do BiciMAD users are also subscribers to other dockless micromobility services. From this exploration, we have found that *almost 12% of them have registered and used other micromobility services*, meaning that they are multimodal citizens. When delving into the characteristics of these multimodal citizens, we find that, in this case, it does hold the hypotheses of the profile being very young (in our case under 26 years old).

Hence, as described in the Figure 11.3, the profiles are quite different according to which services they have subscribed to. In one hand, we have the profile of those only subscribed to BiciMAD, which are usually males, contemporary adults, highly educated, car owners and with middle-high income jobs. These target market commutes using essentially public transport but also quite often the BiciMAD service as they see it price-convenient, and they know exactly where their origin and destination stations are (losing no time in pre-trip planning). They usually travel for shorter times as they know their best route and their satisfaction with the BiciMAD service is good, but in regards with cycling infrastructure, they tend to have low satisfaction level.

On the other hand, we have a very different profile which characterises the multimodal citizens which are mostly young males, who study at the university and live with their parents. This target market has no job and no car, but as multimodal users, they know exactly which app to use for every particular moment. These kinds of subscribers have multiple and diverse applications in their smartphones which they use for different purposes, so BiciMAD is only one of the multiple options (they are less captive). They mostly use BiciMAD for going out in the city (leisure/entertainment purposes) during weekends but also for going to the university sometimes. They like shared mopeds and scooters because they *are dockless*, which means they do not have to think previously where the origin/destination BiciMAD stations are. But they do a lot of pre-trip planning as they need to get into each of the apps to see where the shared vehicles are located at, and then determine which one is closer to them and more price convenient. They love dockless micromobility services because they are a *fun* way to move around (especially scooter users), and they appreciate travel time saved. Their satisfaction level with BiciMAD and cycling infrastructure is indifferent or high and they tend to travel for longer distances with respect to the first profiles described.

Figure 11.3 Comparison of BiciMAD profiles (left: Subscribers only to BiciMAD vs right: subscribers to BiciMAD and other dockless micromobility services)



Source: own elaboration.

Moreover, and related to the derived research question 4.1, we wanted to explore the substitution effect of BiciMAD. The substitution effect refers to the extent to which a subscriber starts using a particular mode in substitution of another one. This is highly relevant, as many authors have highlighted that micromobility services and MaaS in general, will only be sustainable if they substitute mainly motorised transport (fossil-fuelled cars and mopeds) (Hensher, 2018; Pangbourne et al., 2020; Tirachini, 2020). Based on our findings, BiciMAD and other dockless micromobility services are currently stealing travellers from public transport essentially (71% used public transport previously), and few of them from walking (12%), but also from private cars and mopeds (8% total and 4% each mode respectively). When we ask what they will use if BiciMAD stop operating, we observe more positive results as findings suggest that BiciMAD may actually be promoting other dockless micromobility services and a shift to a more multimodal profile. Our results yield a 1% reduction of car usage (from 4% previously using cars to 3% that will go back to using cars), a 5% increase in owned bike usage (from 4% previously using owned bikes to 9% that will go back to use their won bike) and a 9% that will start using other

micromobility services (see bottom part of Figure 11.3). Additionally, when analysing the home/work location of respondents, we found that a higher proportion of subscribers to dockless micromobility services live outside the city centre, which may be indicative of a complementary effect, especially for those living in the peripheries of the city. Those people living outside the city centre, have no access to BiciMAD service and have less frequent public transport system, being more captive or car dependent. By using BiciMAD, they are keener to try new travel options. With BiciMAD service being mostly offered in the city centre, dockless micromobility becomes the option for last mile trips to make intermodal chains with public transport in the peripheries.

Therefore, considering that achieving a sustainable shift is a progressive challenge, we could appreciate that BiciMAD, in its nascent stage, is substituting 8% of previously motorised trips and is promoting the use of personal owned bikes (9%) and other dockless micromobility services (9%). As main conclusion we could highlight that BiciMAD is currently doing both, competing and complementing with public transport systems, depending on where we analyse each particular effect. In the case of the city centre where most of the mobility offer is concentrated, BiciMAD is competing with public transport but also with motorised one. In the case of the city's peripheries, where BiciMAD is currently not present, and where people are usually more transport captive or car dependent, BiciMAD is promoting the use of other dockless micromobility services that do complement with public transport systems. This substitution effect should be looked further with more detail, as a future research line, and also considering the changes in modal choices and daily mobility dynamics brought by the COVID-19 pandemic. But at least for now, we can have a slight idea of how the substitution effect works in Madrid.

In general, from the survey responses, we can emphasise the role that micromobility services are having in this new mobility paradigm. As stated by (Tirachini, 2020), people are starting to see the benefits of being a multimodal citizen increasing their travel choices. These benefits include for example, being able to do more trips during the day and engage in new activities or staying at someone's place as long as wanted, without worrying about public transport schedules or the need to wait for a vehicle along the street (which may be perceived as dangerous) (Tirachini, 2020). People that drove previously, are starting to realize that their time is more worthy, and thus they prefer to use the time they spent driving or finding parking in other activities like reviewing mails, working, watching a series, talking to family, etc. (Hensher, 2017; Smith & Hensher, 2020). These benefits are well known by Madrilenians, and their awareness is part of the reasons why these services have thrived in the city.

RQ4. What are the spatiotemporal travel patterns of micromobility services and how can we visualise and analyse them?

Analysing BiciMAD and dockless micromobility spatiotemporal travel patterns is crucial to understand their particular dynamics. In this regard, we wanted to explore and describe how similar or different are these patterns according to the shared mode used. To that end, we have started analysing only BiciMAD, which is the main topic of the thesis and the most consolidated service in the city. Then we continue with a second study that analysed not only BiciMAD, but other more recently introduced dockless micromobility services (shared mopeds and scooters). These two-folded purposes of the approach allowed us to better understand the different travel patterns.

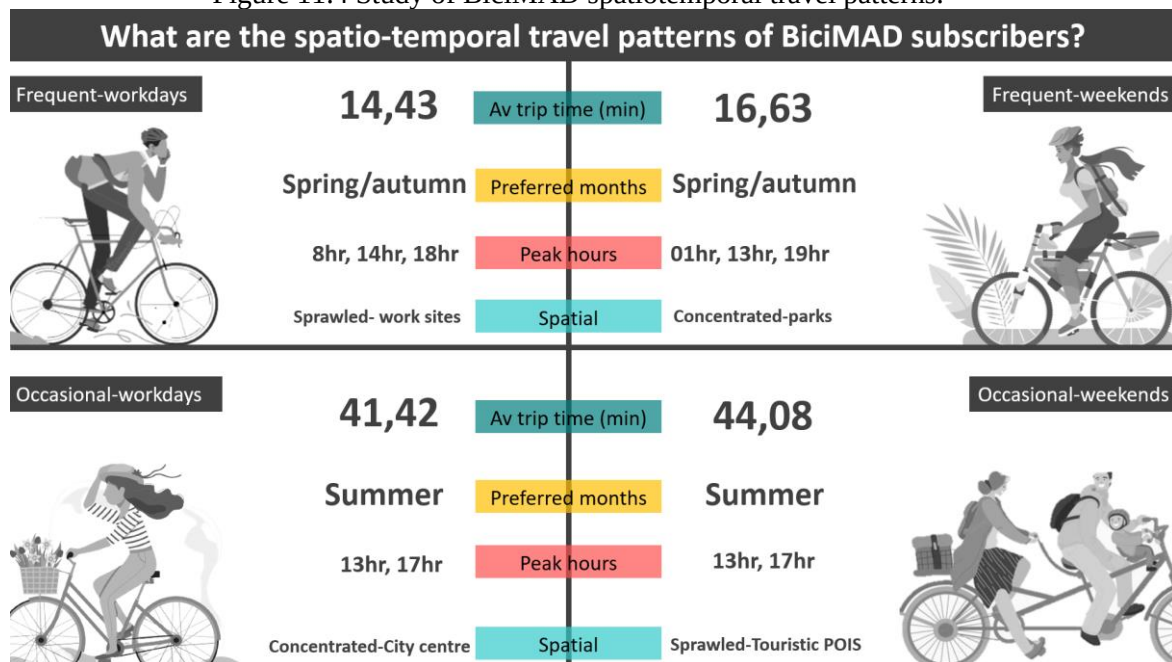
In the first study we have found four types of BiciMAD users, grouped according to the day of the week in which the trip was made, and the subscription used (see Figure 11.4). Results show very different patterns according to each type of user. Firstly, those who use the service with a frequent subscription and during weekdays, travel for shorter times (almost 15 minutes of average travel time) mostly for commuting purposes. Therefore, the temporal peaks are observed during

the warm months of the year and when no vacations/holidays are present, especially during spring and autumn season. During holidays, these users usually go out of the city. Hourly temporal patterns describe a curve with three peaks associated with morning and afternoon commuting peak hours, and midday lunch activities. Finally, spatial patterns show that these frequent users move more sprawled around the city to different places and especially work locations (north-south axe of The Castellana street). Secondly, similar patterns are observed for users that have frequent subscription but travel during weekends. They tend to travel for a slightly longer time (16,63 minutes of average travel time) and they also use the service more often during warmer months (spring and autumn). However, when analysing hourly temporal patterns, the morning commuting peak is reduced as many users do not work on weekends and instead, three peaks are observed towards the afternoon hours when most activities are conducted. Moreover, their spatial patterns are more concentrated on parks and where cycling infrastructure is located, as well as the city centre.

Regarding those users that have occasional subscriptions, we can highlight very similar spatiotemporal travel patterns with the exception of the spatial distribution of trips. Both types of users tend to travel longer times with respect to frequent users, as they mostly use the service for recreational activities in which cyclist are usually more relaxed and calmed. Their preferred months are in summer season, as it is the time when Madrid receives the majority of tourists, and the hourly peaks are concentrated in the afternoon hours increasing towards the late afternoon (17hr). Regarding their spatial patterns, during weekdays they tend to stay concentrated in the touristic points of interest of the city centre. On the other hand, during weekends they tend to go farther away from the city centre and have a more sprawled distribution of trips, especially visiting other points of interest outside the city centre (for example, the Bernabeu stadium).

From this study, we obtained a map (see Figure 5.3) illustrating the different spatiotemporal dynamics of BiciMAD and the parts of the city that are more attractive depending on the day of the week and the type of subscription used. We can highlight that BiciMAD is more used by Madrid's residents, with few occasional users as they mostly use other travel options like taxis/ride-hailing or micromobility services. Nevertheless, this study allowed us to visualise in a very graphical way the travel patterns of the bike-sharing service.

Figure 11.4 Study of BiciMAD spatiotemporal travel patterns.



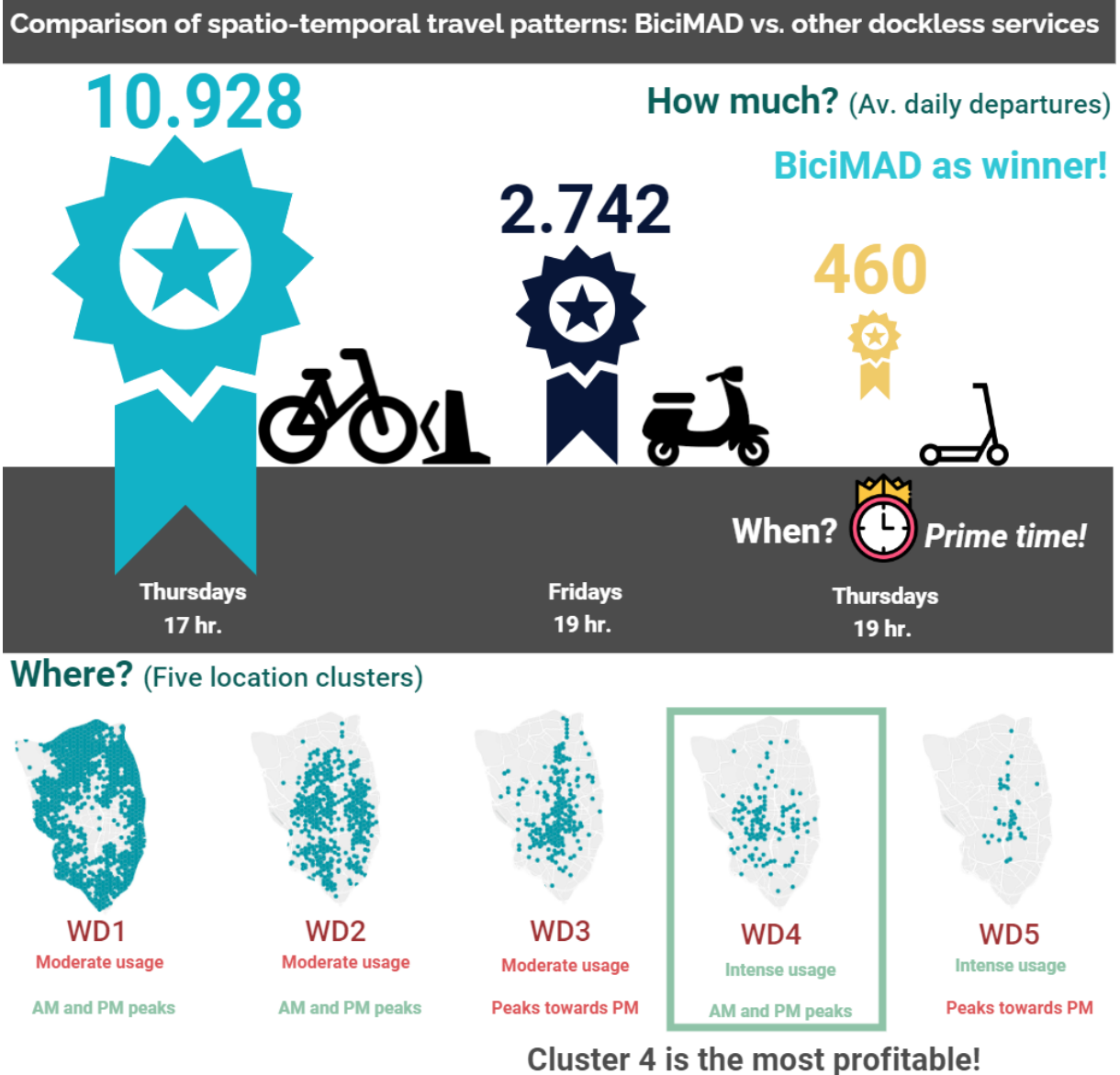
Source: own elaboration.

In the second study derived from this research question, we did not only analysed BiciMAD, but also other recently introduced micromobility services (see Figure 11.5). This study also involved more updated data in comparison with the first study (2017 vs 2019). Therefore, this study contributed to the analysis in several ways: 1) the inclusion of other shared modes that allowed comparisons, 2) updating trip data to a more recent year (2019) and 3) introducing a new visualisation technique by using the Time Geography constructs.

By using space-time cubes, we were able to visualise spatiotemporal travel patterns according to the day of the week but also according to each hour of the day. Our results yield the expected: *BiciMAD is the most important micromobility service in Madrid*, tripling mopeds' average daily departures, which followed in the second place of importance. Regarding the most preferred days and hours, we observe that the prime time for BiciMAD is Thursdays and earlier, at 17hr, while in the case of other dockless services, they are preferred on Fridays (mopeds) and Thursdays (scooters) at 19hrs respectively. Hence, dockless micromobility is preferred for later hours, supporting previous findings which outlined recreation as the main trip purpose when using a moped/scooter (McKenzie, 2019b, 2019a; Zhu et al., 2020). These recreational trips made in the late afternoon are also consistent with the increased number of trips observed in early morning hours (00-05hrs). *This may indicate that BiciMAD bikes, mopeds and scooters are travel alternatives for nightlife when the public transport systems are closed, highlighting the complementary effect of these services.* Another important finding from the cubes (see Figure 7.5) are the hot spot areas of the city in terms of micromobility departures. We found that during morning hours, the hot spot areas were mostly residential zones where people are leaving to work. In the middle hours of the day, we see trips more homogeneously distributed around the city centre and working sites for lunch activities. And in the afternoon hours we clearly noticed more departures occurring from office hubs (leaving work to go home). During the weekends, the morning commute from residential areas is considerably reduced with many people work-free. On the weekends we could also noticed high departures in early morning hours due to nightlife activities. All of these dynamics were visualised in detail which helped us understand how patterns change over the course of a day and according to each mode. Finally, we conducted a time series clustering to group together those locations that share a similar spatiotemporal behaviour in terms of micromobility departures along the course of the day. The five resulted clusters are mainly differentiated by the intensity and temporality of trips. We conclude that cluster 4 (high intensity and departures consistent throughout the day) were the most profitable for micromobility operators. These locations of the city have high trip departures all day long, which characterises areas of the city with mixed land uses, high employment and diverse activities.

In general, these two studies offer a detailed description of how people move using BiciMAD bikes and dockless shared mopeds and scooters. The descriptive analysis offers high resolution in the visualisation of different dynamics along weekdays and hourly patterns. Moreover, the comparison of the three shared modes helps us to realise that *bikes are mostly used for commuting by residents of Madrid, while mopeds seen to have a mixed profile of residents (commuting) and tourists (enjoying the city) and finally scooters seen to attract more younger and tourists profiles.* The use of different visualisations techniques as OD matrices and space-time cubes offers complementary and insightful information. This information is highly crucial when designing new mobility infrastructure and when planning strategies to promote a more sustainable modal shift.

Figure 11.5 Comparison of BiciMAD and other dockless micromobility services



Source: own elaboration.

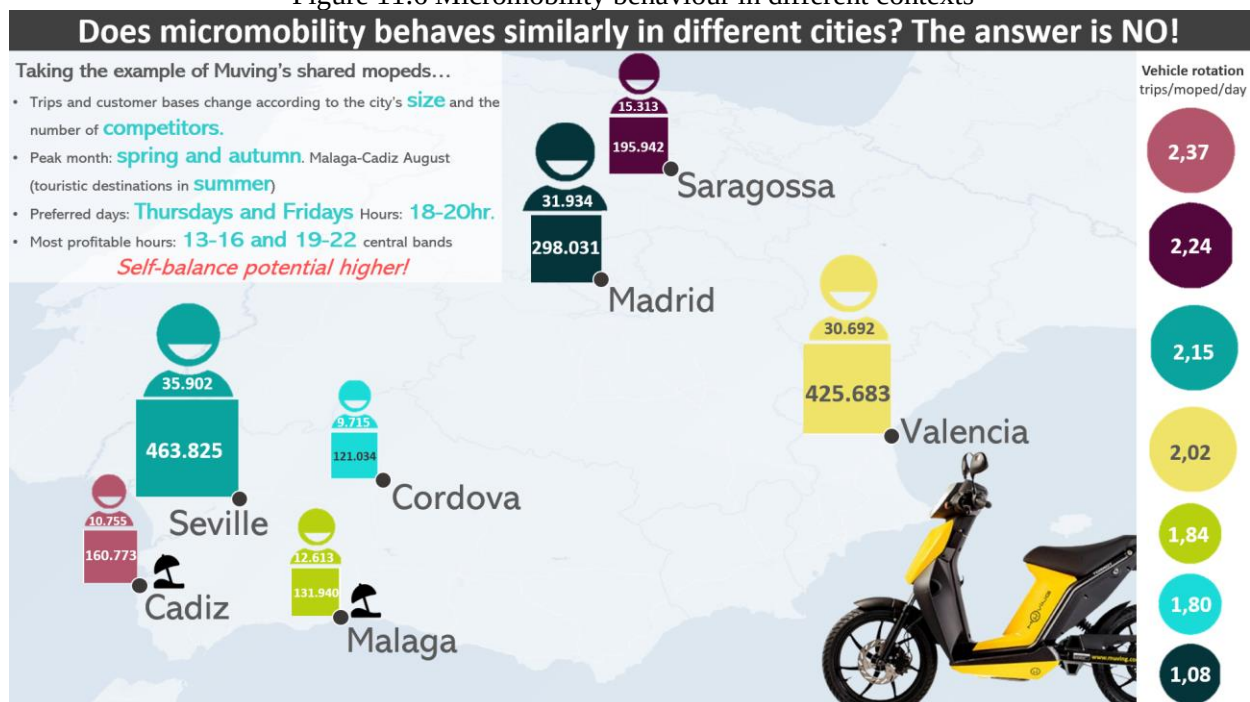
RQ4.1. Does micromobility behaves differently depending on the context and what could operators learn from micromobility trip data?

In this derived research question, we intended to analyse spatiotemporal travel patterns of micromobility services in different cities. To that end, we considered the trip data from Muving, a moped-style scooter sharing service present in seven Spanish urban areas. Our results demonstrate that in fact, *micromobility does behave differently according to different contexts* (see Figure 11.6). The size of the city, its form or urban structure, being a coastal city or if it has a hilly topography are all factors that facilitate different dynamics. We have also seen that the main cities like Madrid, Barcelona and Valencia have many shared micromobility services, with competition being also an important factor to interpret the described results (i.e., vehicle rotation being lower for Madrid). In general, the preferred days for these services are Thursdays and Fridays from 18-20hrs. We have also seen the different temporal patterns, as some cities have higher usage during summer (touristic regions like Cadiz and Malaga) while others lose population over summer vacations or other holidays (for example, Madrid). Spatial patterns have shown one similarity: *the concentration of micromobility services along the city centre where*

they are highly profitable as there is more mixed land use and diverse activities, supporting previous findings from our studies. Contrasted spatial and temporal patterns are complemented with insights for mobility operators. To this end, we aimed to add value to operators' trip data by exploring the extent to which each service can self-distribute its fleet according to the daily demand (what we called self-balance potential). As hypothesised, findings suggest that the self-balance potential is higher in the central bands (midday and afternoon peaks) while it is lower in the beginning and end of the day. This dynamic is related with the imbalance resulting from trips' origins and destinations varying over the course of the day. For example, during morning hours, departures are happening mostly in residential areas, with many people leaving for work/study purposes. On the contrary, employment and activity areas increase arrivals as they are receiving people. In the afternoon commuting hours, the contrary occurs. Thus, during the beginning and end of the day, vehicles are concentrated in some neighbourhoods and scarce in others, forcing operators to redistribute vehicles in vans, with the consequent increase in operating costs. During midday and early afternoon (central bands), vehicle rotation is higher and thus, less fleet redistribution is required, as users are leaving the vehicles where others are taking them. This dynamic was observed in all seven cities with slight variations. Lastly, we analysed also the relationship between vehicle fleet and spatial patterns observing that in some cities (e.g., Valencia and Malaga), the highest vehicle supply is used at a time band when vehicle rotation is not necessarily in its highest peak. This knowledge could help operators increase their vehicle supply at the exact time band when vehicle rotation is in its highest peak, which consequently could lead to increased profits.

From this particular study the main conclusion is that having a clear knowledge of how micromobility behaves in different contexts helps operators when expanding their services to new cities as they could have a slight idea of how the service will function, saving time and effort. The different travel patterns along the day also showed to be related with land use activities, which facilitates to predict or anticipate demand hubs when expanding. All these insights offer an added value to a mere raw trip dataset as operators can leverage their performance on the cities where they already operate and also obtain new information of cities where they want to expand.

Figure 11.6 Micromobility behaviour in different contexts



RQ4.2 How did the COVID-19 pandemic affect BiciMAD and other micromobility services?

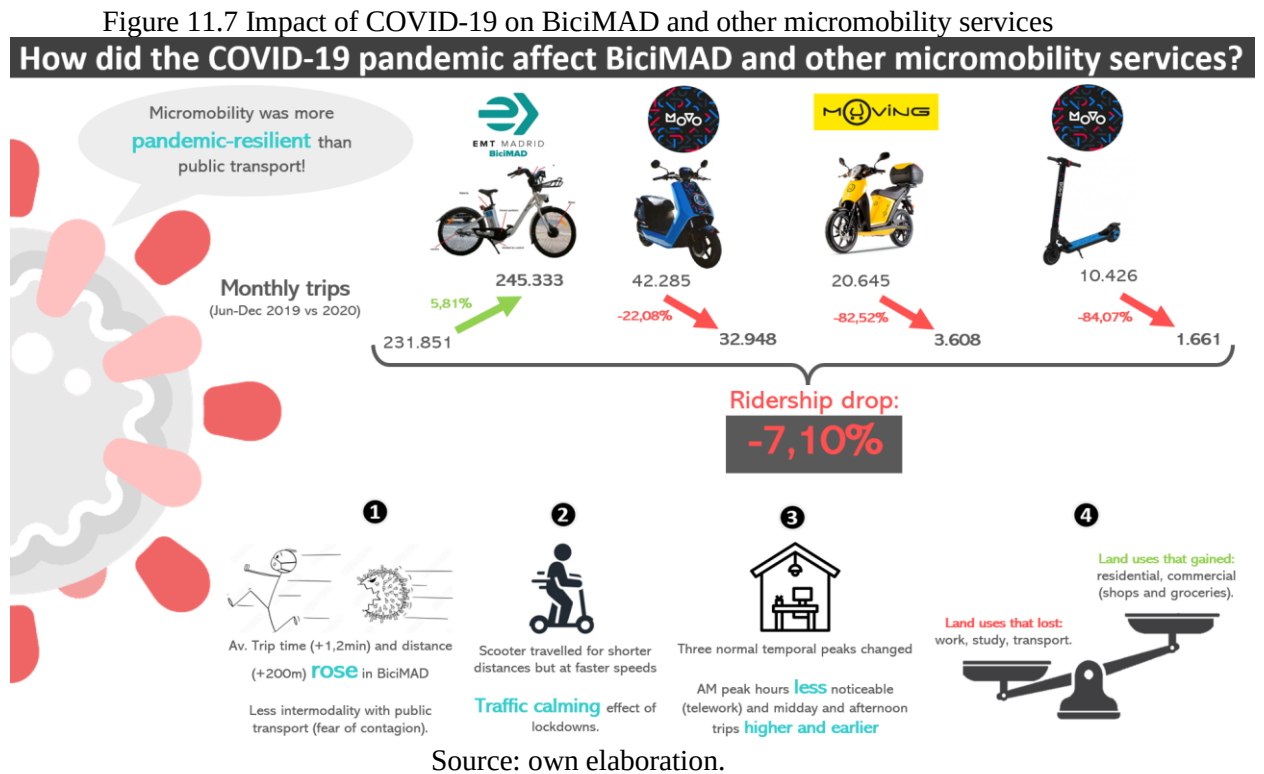
The second derived research question aimed to explore how a global extreme event, like the COVID-19 pandemic, affected spatiotemporal travel patterns and dockless micromobility services as well as the lessons to be retained if possible future events like this occurred. As previous studies have found (McKenzie & Adams, 2020; Teixeira & Lopes, 2020), we have demonstrated that the pandemic helped to increase awareness on the potential of micromobility services during these extreme events, as it allowed users to maintain social distancing (avoiding crowded public transport systems) while also conducting a healthy physical activity (Dias et al., 2021).

Our results showed that BiciMAD bikes, shared mopeds and scooters usage was affected after the pandemic. However, *this impact was much lower (10% and 7.10% if only considering last semester) compared to the ridership drops observed in public transport systems (80%)*. When only considering the last semesters of 2019 and 2020, when the services started to recover, we even noticed a positive impact in BiciMAD (rise in ridership of almost 6%), meaning that the service gained subscribers and surpassed its trip records in July 2020, when lockdown measures were relaxed, and people did not feel comfortable enough to travel for summer vacations due to restrictions (travel bans) and the pandemic status. Therefore, with most Madrilenians being in the city and prone to make some physical activity, BiciMAD was seen as a good travel option for recreational purposes. This phenomenon was known as “the boom of bicycles” around Europe as it was shown in several cities, Madrid being one of them (Asenjo, 2021; Porcel, 2021).

In general, four trends were clearly observed after the pandemic. Firstly, increased trip times and distances, which could be related to people using only micromobility to move around, without connecting with public transport for fear of contagion. Secondly, scooter trips were shorter in distance but faster in speeds which could indicate that without cars on the streets, there was a general traffic calming effect in the network, being safer for scooters to travel at higher speeds. Thirdly, the three usual peaks along the course of the day were maintained after COVID-19 with two main changes: 1) a reduced usage during morning commuting hours as many people stayed at home teleworking/studying and 2) a curve shift to earlier hours meaning that people conducted their activities earlier. We also noticed higher usage in the mid-morning hours and towards the late afternoon, which supports the recreational purpose that BiciMAD gained after lockdowns were relaxed. And lastly, we analysed the relationship between micromobility usage and land uses in order to explore which activities gained/lost relevance after the pandemic. Residential and commercial land uses gained relevance, especially local shops and supermarkets as people depended only on their groceries, as many restaurants were closed. On the contrary, worksites, education facilities and entertainment/leisure facilities lost importance as people were teleworking or online studying and all entertainment activities were cancelled. These general patterns were expected, but our study offered more detail and resolution in regard to different morning and afternoon peak hours.

Our results contributed to describe and measure the changes resulted from a pandemic in order to learn how people behaved and the role and relevance of micromobility services during this period. From this experience many researchers are delving into a new research line oriented to explore cities' resilience to these extreme events. According to POLIS (2021), city resilience focuses on increasing, or at least securing, the performance of urban systems in the face of multiple hazards

in crises, rather than preventing or solely mitigating the loss of assets due to a specific event. When applied to transportation systems, resilience can be seen as *the ability to resist, reduce, and absorb the impacts of disturbance, maintaining an acceptable level of service, and restoring the regular and balanced operation within a reasonable time and cost* (Gonçalves & Ribeiro, 2020). Therefore, BiciMAD and dockless micromobility services have showed to be more pandemic-resilient than public transport, especially BiciMAD. New policies oriented to increase cycling infrastructure, to promote attractive pricing schemes and to maintain hygiene measures implemented during the pandemic may be all key factors to retain what was gained during the pandemic.



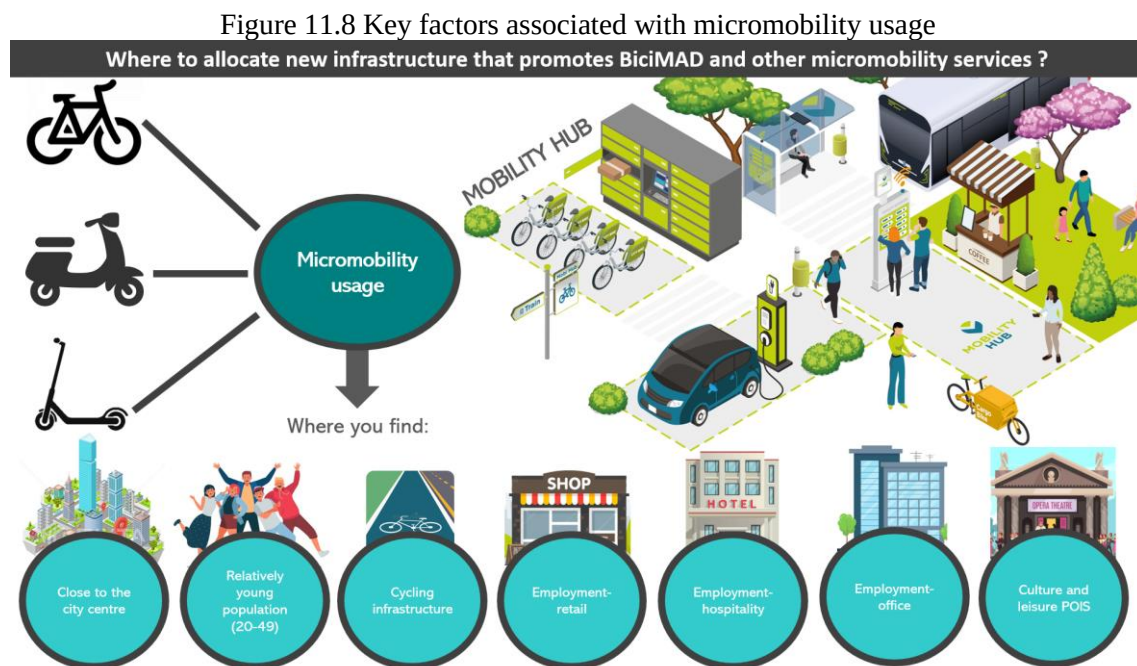
RQ5. Based on the understanding of micromobility spatiotemporal travel patterns, how can we estimate its potential usage to allocate new mobility infrastructure?

Up until this point, all we have done in the thesis is to use different sources of data to *describe* BiciMAD and other dockless micromobility spatiotemporal travel patterns. From this point on, what we try to assess is the understanding of the factors that increase micromobility usage. From that understanding we finally propose a model to estimate potential usage in new areas of the city. Therefore, the last research questions of the thesis regard the analysis of the common factors associated with micromobility usage and how these factors can be considered when modelling micromobility potential demand. As was mentioned in the introduction, most current modelling approaches in transportation lack the consideration of the new forms of mobility. Hence, our aim in this part of the thesis was to contribute to the studies that *do consider* these new shared services when planning and modelling mobility.

In general, previous studies often apply statistical methods to conduct demand modelling, for example by using Multiple Ordinary Least Square (OLS) regression. However, as stated by (Zhang & Zhao, 2022), these models usually have heterogeneity issues, in which spatial statistical models perform better. Nevertheless, one major issue of the statistical models is that they are restricted to the predefined model structure (e.g., linear or log-linear) and only allow specific

assumptions for parameters and error term distributions (Zhang & Zhao, 2022). To tackle this problem, machine learning algorithms have gained increasing popularity, and has been widely accepted to solve mobility and transportation problems. These machine learning algorithms are able to capture patterns behind the data, achieving significantly higher prediction accuracy than statistical models. Therefore, in this study we have a mixed methodology by using OLS models to identify the key factors associated with each micromobility service and then we use the Principal Component Analysis (PCA), one of the most commonly known unsupervised machine learning algorithms, to create a “combined model” to estimate micromobility potential usage as a whole. Consequently, one of the main contributions of this part of the thesis is introducing different and more advanced methodologies for the analysis of micromobility services.

Our results helped us to identify the key factors associated with each service (bikes, mopeds and scooters) and the common ones between all of them (see Figure 11.8). The main findings point to centrality measures (closeness to the city centre), proximity to cycling infrastructure and available commercial shops (commercial and retail land use) as the variables that are more significant for increasing micromobility usage. Hence, those centric areas of the city with cycling infrastructure and surrounded with commercial activities have more vitality in terms of micromobility services. This is highly relevant for policy planners and transport authorities in order to promote these services in areas with mixed land use and diverse activities over the course of the day to increase the probability of people using them. We have tested and validated our different models (OLS and PCA combined model) in the Chamberi District identifying the areas that could be prioritised to implement mobility infrastructure, like mobility hubs. Mobility hubs has gained recent popularity as they are designated areas aimed at increasing intermodality between public transport systems and shared mobility services. These solutions try to attract more people to use shared mobility while also enhancing public space. Our methodology is transferable to other parts of the city where currently no BiciMAD nor shared mobility service is offered, which could help policy planners in their decision-making processes for their expansion processes (creating new bike stations, offering shared fleets in new areas, creating cycle lanes, parking places or mobility hubs).



RQ6. What is the future of the mobility paradigm and what's the role of micromobility services in it?

As was mentioned in the introduction section, mobility is being transformed each day due to new innovations oriented to tackle the climate crisis and the reduction of car-dependency. To this end, new forms of mobility have thrived, and new applications have emerged to satisfy a growing demand for shared services. With mobility options and travel apps growing every day, the need to have them integrated in a single app is becoming relevant as citizens may find it difficult to navigate through all the information sources, applications, tickets, and journey planners. Mobility as a Service (MaaS) is the promise to solve this issue. MaaS has multiple definitions. Based on an exhaustive review of a robust 5-year-old literature, we stand by the definition offered in (Smith & Hensher, 2020, p. 56). They defined MaaS as *a type of service that through a joint digital channel enables users to plan, book and pay for multiple types of mobility services*. Therefore, to be properly labelled as a MaaS, an application should have multiple features, like real-time information of all services, intermodal journey planner and payment integration that allows them to plan, book and access all the mobility offer. It should also include as many services as available in the city and finally it should offer a mobility package or a subscription plan to pay for all mobility services at once. Our review of MaaS pilots shows that only few of the MaaS initiatives really cover the elements necessary (i.e., Whim app). We have also found that many of the apps available cover the technological features required in the app (real time information, intermodal journey planners and in some cases payment integration), but they lack the mobility package subscription which is essentially the “new thing” or most characteristic innovation of MaaS. When delving further into the reasons why many of these initiatives do not have mobility packages, one of the main conclusions of this thesis is revealed. *The main obstacle for the implementation of MaaS is not a technological aspect, but rather a governance one*. In order to offer adequate mobility packages, different mobility operators and MaaS stakeholders need to communicate, discuss and agree who is going to be the MaaS operator and what “the game rules” are going to be. Contracts describing how the profit is going to be distributed, how brands and marketing is going to be handle, the role of each stakeholder, the business model to make MaaS profitable, etc. All these aspects are the main obstacles of MaaS as they need further collaboration and high cooperation between the actors involved. However, in this nascent stage of the concept, and for the case of Madrid, this is not happening yet. Each stakeholder is trying to consolidate their market and communication and agreements are lacking.

However, even though the concept is still being developed, MaaS is promising to reduce the need for private cars and thus, CO2 emissions. In the new mobility paradigm, MaaS is visualised as the linkage or connection between the existing traditional public transport systems and the new emergent shared mobility services, offered to citizens with the payment of a mobility package subscription (see Figure 11.9). In this context, micromobility’s role in a MaaS offering is key as it will be the shared services included in the app along with the public transport systems offer. Thus, shared mobility and especially micromobility services constitute the “new thing” or “the new leg” of the mobility offer. Public transport systems will continue to cover the dense and most important corridors, while micromobility services could cover the first/last mile of trips, being offered on those low/uncovered areas by the public transport. This link between public transport and shared mobility services could be the alternative for the car, covering a door-to-door trip demand. In other words, micromobility will be highly relevant in a MaaS offering, as it will facilitate the demand for last mile trips, complementing public transport systems and allowing the substitution of door-to-door car trips. As stated by (Tirachini, 2020), these new forms of mobility are generating profound social and equity effects because the inability to pay full costs of owning a car (capital, maintenance, insurance and parking costs) is no longer a barrier for easy access to a car or other shared mobility services needed.

Figure 11.9 The role of micromobility in a MaaS future



Source: own elaboration.

11.2. General conclusions and considerations regarding the research as a whole

11.2.1. With regard to the main research objectives and in relation to other similar studies.

As stated in the introduction section, the main research goal of this thesis was, essentially, to describe micromobility services' spatiotemporal travel patterns. However, although this goal condenses the main intention, the real purposes were better unfolded when formulating the general objectives: to diagnose the shared mobility ecosystem in Madrid, to characterise BiciMAD and other micromobility user profiles, to understand and visualise their spatiotemporal travel patterns and to model their usage to identify common associated factors. Even though many of the research questions could and should be further explored, we consider that the main objectives of this thesis were achieved:

- This thesis has made, as far as we know, the first scientific and more comprehensive diagnosis of the shared mobility ecosystem in Madrid. This diagnosis served us to set the geographical context of the work and begin to understand why Madrid is usually known as “the living lab of shared mobility”.
- We have clearly identified different profiles for those subscribed only to BiciMAD and those subscribed to more services. Similar research involves the study by (Munkácsy, 2017) which explored potential user profiles for BiciMAD, without considering those who use dockless micromobility services, as they were recently introduced. In the case of (Aguilera-García et al., 2020) the authors only addressed shared moped users. Hence, one of the main contributions of the thesis is to characterise profiles for shared bikes and other dockless micromobility services simultaneously, to compare differences and similarities.
- To our knowledge, this is the first thesis that uses real trip datasets provided by different micromobility operators for the city of Madrid. From my personal point of view, it is one of the main achievements of the thesis as we could signed collaboration agreements with different companies to have real trip data of their services (GPS records). Similar studies that used real trip datasets are only found on other regions where it is obligated for micromobility operators to offer their data publicly through APIS for authorities and researchers to study mobility issues. This is the case of the city of Washington DC (McKenzie, 2019a) and San Francisco (Forest, 2019; Lazarus et al., 2020). In Europe we have only found the case of (Degele et al., 2018) which established a collaboration agreement for trip data, but only for shared mopeds and just for the case of a German city and the study by (Durán-Rodas, 2021) that obtained trip data by using scrapping tools and again for a German city and only for one shared mode (bikes). We have obtained trip

data for Madrid, for a timeframe of two years (2019 and 2020) and with the three modes involved in micromobility studies (shared bikes, mopeds and scooters). These agreements set a new precedent of collaboration between academic institutions and micromobility operators.

- We have described, visualised and understood from a dynamic point of view the different spatiotemporal travel patterns of BiciMAD and other dockless micromobility services. As a general strength of the research, we have exploited trip datasets to extract as much information as possible by using different visualisations techniques, methodologies and timeframes (see Table 11-1). We have chosen to present this summary table in the conclusion chapter, as it constitutes a recap of all the methods/techniques used in the research (as a research strength point), which changed several times along the course of the doctoral programme, especially due to the COVID-19 pandemic outbreak. From our research we can have a clear idea of how BiciMAD and dockless micromobility operates in the city identifying the hot spots and the areas of the city that are more attractive.

Table 11-1 Different approaches taken for each study of micromobility data.

Study	Main data source	Mode studied	Timeframe	Temporal aggregation (days)	Temporal aggregation (hours)	Spatial aggregation	Unit considered	Unit aggregation	Methods
BiciMAD and dockless micromobility user profiles and preferences	BiciMAD 2019 survey	Bikes, scooters	2019	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	• Online survey
Visualising the spatiotemporal travel patterns of BiciMAD	Trip data (GPS records)	Bikes	Sept 2017- Sept 2018	Weekdays: Monday- Thursdays Weekends: Saturday- Sunday	Hourly	None	OD pair	OD count	• Visualisation • Main map
Comparing BiciMAD travel patterns with emergent dockless micromobility services	Trip data (GPS records)	Bikes, mopeds, and scooters	Jun-Dec 2019	Weekdays: Monday- Fridays Weekends: Saturday- Sunday	Hourly	250m-sided hexagonal grid	Origins	Average daily departures	• Space-time cubes • Spatial statistics (Getis Ord) • Time Series clustering
Micromobility behaviour in different contexts	Trip data (GPS records)	Mopeds	2019	Weekdays: Monday- Thursdays Weekends: Saturday- Sunday	07-10 13-16 19-22 23-02	200m-sided hexagonal grid	Origins Destinations	Total count	• ESDA tools (Moran's I and LISA)
Impact of COVID-19 pandemic on BiciMAD and other dockless micromobility services	Trip data (GPS records)	Bikes, mopeds, and scooters	Complete pre-COVID: Jan 2019- Feb 2020 Complete COVID: Mar- Dec 2020 Shorten pre-COVID: Jun-Dec 2019 Shorten COVID: Jun-Dec 2020	None	06-10 16-20	Transport zones	Origins Destinations	Total count	• OLS • Spatial Lag model
Allocating infrastructure to promote the use of BiciMAD and other dockless micromobility services	Trip data (GPS records)	Bikes, mopeds, and scooters	Jun-Dec 2019	None	None	400m service areas around BiciMAD's stations	Destinations	Average daily arrivals	• OLS • PCA- Machine learning

Source: own elaboration.

- We have identified the key factors that are associated with micromobility usage and based on our findings we have propose a methodology to model these services and estimate potential usage for new areas of the city. Our main contribution is to approach the modelling process with a mixed methodology that includes more advanced techniques like using machine learning algorithms.

- Lastly, our work has analysed BiciMAD in the context of the new mobility paradigm. This means that we have left behind the analysis of BiciMAD by itself, which we called in the introduction section our web 1.0, and we have furtherly analysed it along with new competitors that have appeared in last few years and that seem to be here to stay (our web 2.0). Not only that, but we have also started to visualise and outline BiciMAD in the web 3.0, or future of the mobility paradigm, by describing its possible role in a future MaaS offering for Madrid. Hence, this work pretends to be like a video of the process of BiciMAD passing through the different stages of this paradigm. Policy implications have been derived in each of the studies which are also one of the main contributions of this thesis. Just to emphasise some of them, we have found that mixed land use and areas that have multiple activities throughout the day have the more vitality in terms of micromobility usage. We have also seen that cycling infrastructure and being close to intermodal transport stations could also lead to the promotion of these services. We have underlined the highly important effect that new infrastructures could cause in the use of these new forms of mobility. Thus, policy planners should regulate and plan accordingly to increase these infrastructures and to generate strategies that attract more users (especially car drivers) to start trying new forms of mobility. Transport authorities should also make an effort to promote the discussions and governance talks that need to take place in order for a MaaS to be possible in Madrid. In the case of micromobility operators, we have also derived important insights from their data that could leverage and improve their performance and logistical tasks to increase profit.

In summary, we could briefly state that the main theoretical, methodological, and practical contributions of the Thesis are:

- The consideration of a new mobility paradigm.
- The presentation of Madrid's micromobility ecosystem as of 2019-2020.
- The identification of user profiles for different micromobility services in the same period of time.
- A novel set of methods and techniques to capture spatiotemporal patterns of micromobility usage.
- And the general conclusions extracted from all the above topics.

12. Limitations of the thesis and future research lines

Although we consider that the main objectives of this thesis have been essentially achieved, many of the research questions addressed can and should be further explored. Each of the studies have described its own limitations, however we will do a brief summary of them in this section and considering the research as a whole. Then we will outline new lines of research that we found interesting, but out of the scope of this thesis. These limitations and future research lines are listed and briefly described next.

The main limitations of this thesis are related to two main aspects. One of them is the sample representation capability. In the case of the BiciMAD survey results cannot be representative for the whole population of Madrid and a more detailed survey should be conducted to dockless micromobility services in order to capture their particular users' preferences. In the case of the trip datasets, for the analysis of different cities, we need to have in mind that for some cities we had the complete sample of shared mobility services, as only few of them are operating. But in the case of big cities like Madrid, Barcelona and Valencia we only had one part of the sample of all micromobility services. This should be considered when analysing the results obtained. The

second aspect that constitutes a general limitation of the thesis is the timeframe of the data obtained.

Further research should focus on obtaining new and more recent data and from more micromobility operators in order to see the extent to which the trends observed are maintained. One of the most interesting lines of research is the evaluation of possible impacts from the COVID-19 pandemic with the consolidation of telework. New studies can delve into the dynamics and new behaviours caused by the pandemic and if they are maintained in time (from 2021). Future research lines should analyse the role and impact that food delivery riders using micromobility services are having in the city dynamics (14% of BiciMAD users reported to be using the service for delivery purposes). This is something also found in with bike messengers (Romanillos, 2018). Another future research line is the study with more detail of the sustainable impact that BiciMAD is having with the substitution effect. This study made a first attempt to measure it, however, is it a topic that needs further development. Related to this previous line of research, future studies could also investigate the role of micromobility services in the city's peripheries and how could policy regulate to promote the expansion of shared mobility to areas with low or non-existent public transport systems. New contributions should also delve into the topic of MaaS governance as it is being the main obstacle found for the majority of cities to implement this concept. Hence, future studies can evaluate stakeholders' opinions regarding MaaS and other studies can furtherly explored end-users' preferences and willingness to pay for MaaS. And lastly, the development of new MaaS pilots in Madrid should allow the availability of new datasets to analyse with more detail how individuals use the app and the different modes (not analysing trips but individual's behaviour) delving furtherly into the topic of the role of micromobility services in MaaS for tackling the first/last mile of trips.

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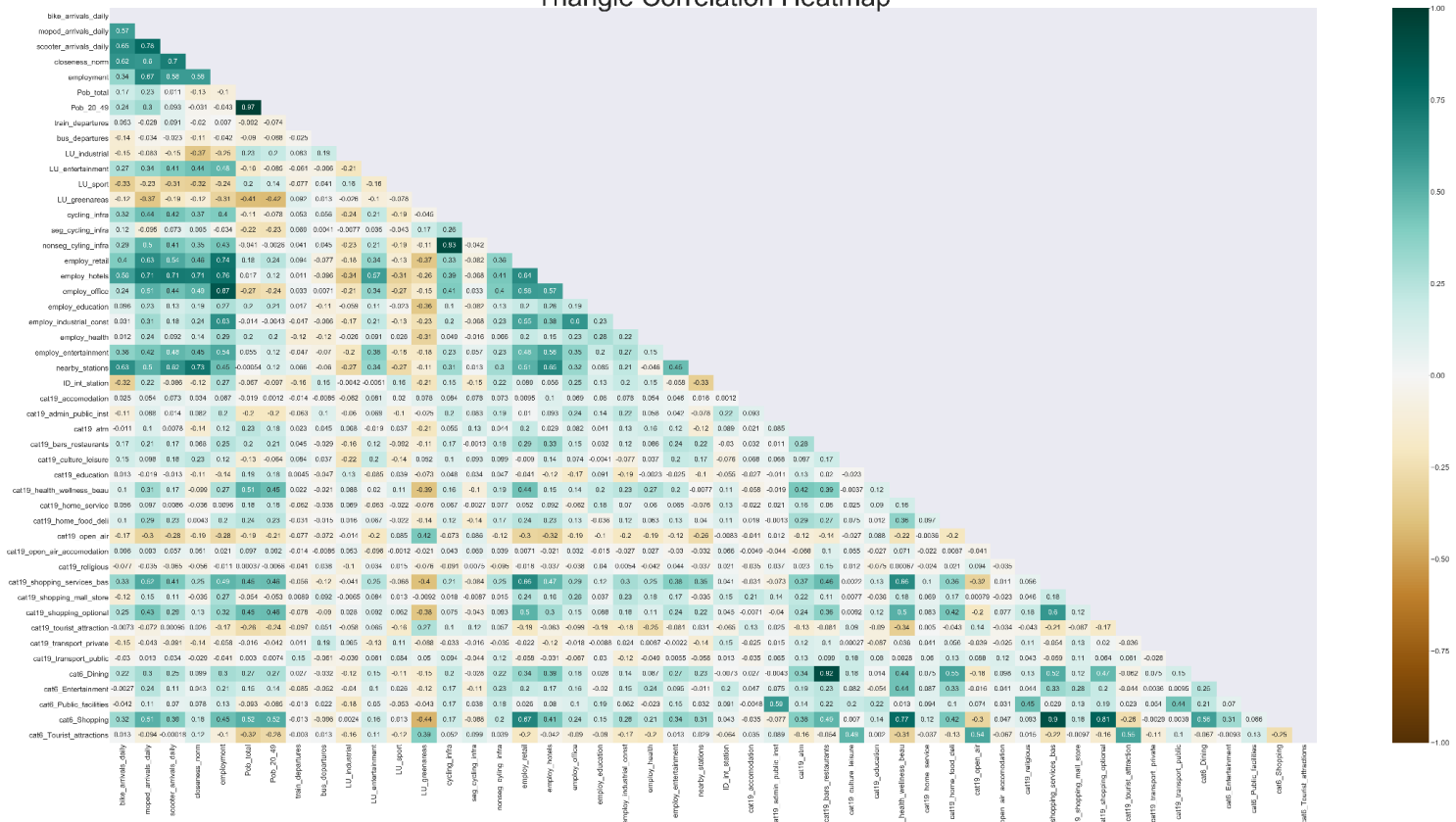
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Appendixes

Appendix 1. Correlation Matrix (Pearson's coefficient) for the three different modes (Reference to chapter 9).

Triangle Correlation Heatmap



Source: own elaboration.

Appendix 2. List of systematic review of the most important papers related to MaaS (Reference to chapter 10).

#	Author(s)	Origin*	Scope	Objective	Findings
1	(Heikkilä, 2014)	Finland	Conceptual	Identify the main factors that are enabling MaaS and propose a road map for the case of Helsinki.	Factors enabling MaaS include: social change, urbanization and globalization, servicing and sharing, scarcity of resources, technological advances and paradigm change.
2	(Sochor et al., 2014)	Sweden	Preferences	Discuss insights from the UbiGo pilot regarding motivations and deterrents for adopting MaaS.	78.8% said they would be interested in becoming a UbiGo customer, 18.1% said yes but under certain conditions, and 3.1% said no.
3	(Rantasila, 2015)	Finland	Conceptual	Study the impact of MaaS in land planning.	Two scales of MaaS impact: macro as a new transport paradigm and micro as operational regulations and new legislation will be needed.
4	(Sochor et al., 2015b)	Sweden	Preferences	Explore how user, commercial and societal expectations are met when using MaaS.	Differences appear in how the reduction of car use is estimated and the proposition of various business models and MaaS platforms.
5	(Sochor et al., 2015a)	Sweden	Preferences	To discuss changes in users' travel behaviour and mode choice.	Differences in travel behaviour allowed the identification of four type of users: shedders, keepers, car-sharing and car accessors. In general, all four groups shifted to a more sustainable mobility patterns after the pilot.
6	(Kamargianni et al., 2015)	UK	MaaS scheme model	Conduct a feasibility study for MaaS in London.	MaaS for London was proved feasible for having: public transport as backbone, ICT integration for information and payment, one single platform, cooperation between different stakeholders and tailored packages.
7	(Holmberg et al., 2016)	Sweden	Conceptual	Create a comprehensive framework to understand MaaS concept.	Identified barriers for MaaS include: public transport subsidizing, brand-exposure of transport operators, regulation issues and technical matureness.
8	(Kamau et al., 2016)	Japan	MaaS scheme model	Introduce a MaaS model.	The MaaS research pilot decreased waiting time by 25% compared to current public transport in Dhaka.
9	(Giesecke et al., 2016)	Finland	Conceptual	Identify key aspects for consideration when implementing MaaS.	Introduced the sustainable perspective of MaaS by identifying four main components to be consider: 1) the nature of travel, 2) interoperability, 3) end-user perspective and 4) sustainability.
10	(Sochor et al., 2016)	Sweden	Preferences	Discuss UbiGo results and describe changes in users' travel behaviour and mode choice.	All participants reduced automobile usage. Factors influencing travel choices include: cost, convenience, discovery/rediscovery of other modes and personal reflection.
11	(Karlsson et al., 2016)	Sweden	Preferences	Analyse barriers that can be found within the service itself, focusing on stakeholders' rather than users' willingness for joining MaaS, which could be as important.	Stakeholder's cooperation is needed for issues regarding infrastructure, information, and payment systems but also in <i>service-related</i> issues like the lack of trust between them, unequal distribution of power and resources, differences in goals, larger political commitment and regulatory context.
12	(Kamargianni et al., 2016)	UK	Methodological	Review the existing MaaS schemes and develop an index to evaluate their level of mobility integration.	A MaaS index is proposed and applied: only one (Whim) out of the 15 schemes analysed, has total integration, 8 have intermediate integration and 6 have basic integration.
13	(Datson, 2016)	UK	Conceptual	Explore the opportunity MaaS offers UK.	Focus on a brief conceptual introduction to MaaS and the future role of transport policy and possible market growth scenarios.
14	(Nemtanu et al., 2016)	Romania	Conceptual	Introduce a MaaS model.	The model has 2 components: users and MaaS providers. The platform has 8 functions: profile builder, security, transport offers, negotiation, financial, trip planning, urban conditions and the interface.
15	(Ambrosino et al., 2016)	Italy	MaaS scheme model	Introduce a MaaS model.	From a MaaS business model perspective, the authors identified B2A (administration), B2B(companies) and B2C(users) services that MaaS can offer to be sustainable.
16	(König et al., 2016)	Belgium	Conceptual	Identify sustainable business models for MaaS.	Two revenue sources were identified: agency (reselling) and merchant (commission). Four business models are proposed: resellers, providers, public transport operators or public-private partnerships (PPP). The latter is the most recommended (PPP).
17	(Sochor et al., 2017)	Sweden	Conceptual	Develop a topological approach for MaaS concept.	Proposed topology include integration levels: 0 no integration; 1 information; 2 booking and payment; 3 service offer, including contracts and responsibilities and 4 societal goals.
18	(Aapaoja et al., 2017)	Finland	Conceptual	Identify MaaS combinations for urban, suburban, rural and national/international areas.	Each area has different objectives and services combinations. In the short run, urban areas are most fitted for MaaS with the aim of reducing congestions with public transport and shared mobility services.
19	(Jittrapirom et al., 2017)	The Netherlands	Review	Identify MaaS core characteristics and review existing schemes.	12 MaaS schemes are reviewed. Core characteristics include: integration of transport modes, tariff option, one platform, multiple actors, use of technologies, demand orientation, registration requirement, personalisation and customisation.
20	(Mulley, 2017)	N/A	Review	To broadly introduce the hype around the MaaS topic.	MaaS definition is offered as well as Australia's approach to enabling MaaS.
21	(Ratilainen, 2017)	The Netherlands	Preferences	Explore users' preferences towards 10 designed mobility packages.	Unlimited public transport makes bundles more attractive, elderly people were found interested if offered discounts on off-peak hours. Young were eager for MaaS but they are pretty price-sensitive.

#	Author(s)	Origin*	Scope	Objective	Findings
22	(Sarasini et al., 2017)	Finland	Conceptual	Evaluate sustainable MaaS business models.	Potential mechanisms for value capture include: bundling (buying mass volume to a cheaper price), selling MaaS data analytics, fees in transactions and advertising.
23	(Nikitas et al., 2017)	UK	Conceptual	Explore the new mobility initiatives.	Legislation improvements and cooperation will be as important as technical issues for enabling MaaS.
24	(Hahtela et al., 2017)	Finland	Preferences	Explore MaaS and commuting trips in Finland.	Only 6 % of respondents actually work when commuting, whereas most of them use their phone for leisure (27 %), reading (12 %) and calling (11 %). Nearly 80% combine shopping with commuting. Car-owners demand deliver-pick up for children as a motivation to join MaaS.
25	(Goodall et al., 2017)	N/A	Conceptual	Describe the MaaS concept and main topics related in a broad manner.	MaaS definition is offered, ecosystem, drivers, pilots and policy issues broadly described.
26	(Gaudó Labarta, 2017)	Spain	MaaS scheme model	Conduct a feasibility study for MaaS in Barcelona.	MaaS (1.188 euros/year) was proved to be cheaper than automobile ownership (6.810 euros/year). MaaS demand in Barcelona was estimated around 43,000 users, of which about 14,000 would come from private transport.
27	(Hensher, 2017)	Australia	Conceptual	Explore considerations regarding bus contracts in a MaaS context.	A hybrid multi-modal scenario is recommended. The author introduces the three Bs approach of MaaS: bundles, budgets and brokers.
28	(Johansson, 2017)	Sweden	Preferences	Explore young people's mobility demands for MaaS.	Mobility preferences are strongly influenced by parents and the reverse is also true. They are aware of environmental issues, but the sustainable option needs to also be price-convenient.
29	(Li et al., 2017)	Belgium	Conceptual	Identify MaaS core elements and implementation issues.	Pre-conditions for MaaS include: wide range of transport modes, transport operator's open data and allowing other to sell service and e-payment availability. New targets of MaaS are introduced: elderly and tourists. Tax policy and fair competition issues are important.
30	(Kamargianni et al., 2017)	UK	Conceptual	Identify MaaS ecosystem.	MaaS ecosystem composed of: transport operators, data providers, technical backend and IT providers, ICT infrastructure, insurance companies, regulatory organizations, universities and research institutions and customers.
31	(Kamargianni & Goulding, 2018)	UK	Methodological	Measure cities' readiness for MaaS implementation.	MaaS maturity index is created. It considers: transport operator's openness and data sharing, citizen's familiarity and willingness, policy, transport services and ICT infrastructure.
32	(Matyas & Kamargianni, 2018c)	UK	Preferences	Explore how MaaS can serve as a mobility management tool to promote currently underutilized modes.	64% of respondents indicated they will start using the shared modes, 12% would definitely use them, demonstrating MaaS bundles could change travel behaviour towards an increase of sustainable modes.
33	(Kamargianni, Matyas, Li, & Muscat, 2018)	UK	Preferences	Explore citizens' attitudes towards owning and using a car in London.	59% think owning a car is a hassle. 18% stated that they would not buy a car in the future. 36% of non-car-owners stated they will delay purchasing a car. 14% of public transport users stated they would use more bike sharing. 35% of regular car users stated they will shift to public transport, 17% with bicycle and 17% with walking.
34	(Kamargianni, Matyas, Li, Muscat, et al., 2018)	UK	Conceptual framework	Create a MaaS dictionary.	Concepts around MaaS are gathered in a single document.
35	(Matyas, 2018)	UK	Preferences	Explore barriers for trying out new modes in a MaaS scheme.	Respondents classify the modes into 3 categories: essential (mainly public transport), considered (mainly car and bike sharing) and excluded. Barriers relate to safety, special needs (children seats and pet-friendly), hard access to vehicles and bad experiences.
36	(Matyas & Kamargianni, 2018a)	UK	Preferences	Explore users' preferences for MaaS plans.	Public transport was the most important mode for users (backbone of MaaS), regardless of socio-demographic variables. When choosing plans, habits and travel patterns play a key role (people select modes according to their experience with them). Bike and car sharing were less selected due to still lacking facilities.
37	(Matyas & Kamargianni, 2018b)	UK	Methodological	Offer a methodological guideline for stated preferences surveys regarding MaaS.	Guidelines offered.
38	(Kriukelyte, 2018)	Sweden	Conceptual	Investigate the process of the institutionalization of MaaS in Stockholm.	Process involve: explaining MaaS drivers, the emergence of new challenges and the impact of MaaS in public organisations. Challenges ahead: ticketing, lack of pilots, and physical and technical infrastructure.
39	(Robinson, 2018)	Belgium	Preferences	Exploring MaaS users' preferences.	Eight user profiles were identified. The author highlights the importance of studying users' preferences to achieve attractive mobility bundles (importance of segmentation).
40	(Utriainen & Pöllänen, 2018)	Finland	Review	Review on MaaS scientific publications.	Publications are mainly from Europe and North America. They amount of papers rapidly grew from 2016.
41	(Ho et al., 2018)	Australia	Preferences	Identify MaaS users' preferences for mobility packages.	Sydney travellers are willing to pay \$6.40 for an hour of car-sharing (one-way preferred over station-based schemes), and \$5.90 per day for unlimited public transport (which is much lower than the current daily cap).
42	(Strömberg et al., 2018)	Sweden	Preferences	Identify MaaS potential users.	Four profiles are identified: car shedders, car accessors, simplifiers, and economizers. The transport smorgasbord concept being a continued reminder of travel options was acting as a transport campaign, helping users to think deeply about their travel patterns.

#	Author(s)	Origin*	Scope	Objective	Findings
43	(Stopka, Pessier, & Gunther, 2018)	Germany	Preferences	Identify the price users are willing to pay for joining MaaS.	People without a fixed income prefer mobility services that are charged according to the pay-as-you-go principle. The accepted price corridor is between 85-100 euros.
44	(Melis et al., 2018)	Italy	MaaS scheme model	Introduce a MaaS model.	Highlights the importance to broaden MaaS targets, designing a model for tourists and blind people.
45	(Smith et al., 2018)	Sweden	Conceptual	Explore possible organisation schemes for MaaS.	Three scenarios are identified: market-driven (all private), public-controlled (all public) and public-private (mix). The mix approach is recommended.
46	(Kamargianni, Yfantis, et al., 2018)	UK	Conceptual	Propose an innovative integrated transport modelling and simulation framework for MaaS.	A model for MaaS is proposed.
47	(Jittrapirom et al., 2018b)	The Netherlands	Preferences	Identify which topics are experts agreeing and disagreeing on regarding MaaS.	Agreed aspects: youth, current public transport users, and flexible travellers to be early adopters of MaaS. The implementation of MaaS as a pilot project is considered the most preferred policy in the next phase. Disagreed aspects: MaaS providers (if public or private) and implementation strategies.
48	(Durand et al., 2018)	The Netherlands	Review	Review of MaaS documents that focused on people's travel preferences and behaviour.	Young to middle-aged people residing in urban areas are likely to be the first group to join MaaS. Users generally are price-sensitive.
49	(Polydoropoulou et al., 2018)	Greece	Preferences	Explore key stakeholders' preferences and opinions about MaaS.	United Kingdom's barriers are related to APIS availability while in Budapest are stakeholder's willingness for cooperation.
50	(Mulley & Kronsell, 2018)	Australia	Preferences	Explore community transport organisations' willingness to join MaaS.	They are willing to join. They propose public subsidy is given to users directly not operators, in order to be sustainable. They recommend specialized services in MaaS (for elderly and disabled).
51	(Jittrapirom, Marchau, van der Heijden, & Meurs, 2018a)	The Netherlands	Conceptual	Propose Dynamic Adaptive Policymaking for MaaS implementation.	The DAP is recommended to plan for uncertain scenarios, like the MaaS context.
52	(Mulley & Kronsell, 2018)	Australia	Review	Summarize topics from a workshop about MaaS.	Main workshop topics are described.
53	(Eckhardt et al., 2018)	Finland	Conceptual	Construct a SWOT analysis regarding the implementation of MaaS in Finnish rural areas.	The SWOT is constructed and described.
54	(Wittstock & Teuteberg, 2019)	Germany	Review	Identify MaaS core elements.	Core elements involve: unified platform, multimodality, user-centricity, cooperation, customisation and technology integration. Risk and opportunities regarding MaaS are also described.
55	(Smith et al., 2019)	Sweden	Preferences	Analyse public-private cooperation for MaaS in Sweden.	Private and public stakeholders seem to have embedded differences in their objectives being a barrier for them to collaborate.
56	(Lyons et al., 2019)	UK	Conceptual	Propose a MaaS taxonomy and a model for implementation.	The proposed taxonomy is: level 0 for no integration at all to level 5 for full operational, informational and transactional integration. A model for individual choice regarding the adoption of MaaS is proposed.
57	(Hesselgren et al., 2019)	Sweden	Preferences	Described findings from a corporate MaaS pilot.	Barriers for adoption involve: inadequate integration with external transport systems; corporate policy, culture and norms that conflict with using the services; and system limitations due to laws and regulations.

Source: own elaboration.

Appendix 3. Update on MaaS literature (2021-2023) (Section 10.7).

#	Author(s)	Origin*	Scope	Objective	Findings
1	(Muller, M. et.al, 2021)	United States	Review	Identify available methodologies for assessing the sustainability impact of potential MaaS implementations from a whole system (STEEP—social, technical, economic, environmental, and political) perspective.	The authors summarised the literature reviewed, offered a weighted ranking of relevant transportation simulation tools and identified the key gaps in the current state of the art. The gaps included capturing the interaction of demographic changes, mode choice, induced demand, and land use in a single framework that can rapidly explore the impact of alternative MaaS scenarios, on sustainable mobility, for a given city region.
2	(Brezovec, P. et al. 2021)	Austria	Preferences	Investigate consumer preferences for MaaS packages in a suburban area. Specifically, explore consumers' willingness to pay for MaaS, and their preferences to include electric vehicles in the form of e-carsharing and e-scooter sharing in MaaS packages	Price was found to be the most important factor for purchase intention (when directly asked, the average study participant would be willing to pay approx.€52 for a MaaS package that meets their preferences). Additionally, almost 70% of the respondents would choose e-car sharing while only about 43% would choose e-scooter sharing as a basic component of MaaS packages. Three different MaaS segments were identified with varying preferences for MaaS bundle features. Overall, the WTP MaaS was high 56.7%.
3	(Butler, L. et al., 2021)	Australia	Review	Conduct a systematic literature review to extract insights, and develop a conceptual framework to identify barriers and risks related to MaaS adoption in cities	(a) the desired MaaS outcomes are reduced vehicle kilometres travelled, increased trip awareness, reduced parking, reduced vehicle ownership, and improved social equity; (b) MaaS supply side barriers include public private cooperation, business support, service coverage, shared vision, and data and cyber security; (c) MaaS demand side barriers are its lack of appeal to older generations, public transport users, and private vehicle users, the attractiveness of the digital platform, and user willingness-to-pay.
4	(Ho, C., et al., 2021)	Australia	MaaS scheme model	Investigate participants' choice between PAYG and four subscription plans (or bundles). Investigate the potential for changes in monthly car use in the presence of a MaaS program. In other words, test the relationship between MaaS bundle uptake and private car use	Findings suggest a substantial market for mobility bundles, but PAYG is an option preferred by many, particularly those with varying travel needs
5	(Hensher, D., et al., 2021)	Australia	MaaS scheme model	To analyse the feasibility and sustainability benefits of integrating freight with passenger transport in a MaaS environment by proposing the MaaS for passenger and freight - MaaS4PaF - concept	Findings suggest that MaaS has the potential to change travel behaviour in a way aligned with sustainability objectives
6	(Le Pira, M. et al., 2021)	Italy	Review	Evaluate if MaaS has a future or not in a short discussion paper	The authors proposed a new concept named MaaS4PaF where freight and passenger transport could be included in MaaS. They identified relevant logistics segments, proposed service models and evaluated these from a multi-stakeholder and sustainability perspective.
7	(Hensher, D., et al., 2021)	Australia	Conceptual	Analyse citizens' readiness for and attitude towards MaaS, and how a MaaS-system could influence users' mobility behaviour.	The paper offers a discussion about the need to implement more trials of MaaS and pass the debate around the concept's definition or else, the future of MaaS could be hampered.
8	(Hasselwander, M. et al., 2022)	Portugal	Preferences	Evaluate the role of the car in MaaS in a short discussion paper	The majority (84%) of respondents stated they were likely to use a MaaS app. The main reasons for adoption appear to be reliability and cost savings. MaaS could shift users' mobility behaviour towards more sustainable transport modes (i.e., from private and low-capacity modes towards public transport)
9	(Hensher, D., et al., 2022)	Australia	Conceptual	Understand how people's lifestyles are associated with their willingness to adopt a relatively new and innovative mobility solution, Mobility-as-a-Service (MaaS).	The authors recommend recognising that cars will not disappear, especially in rural environments, and that the challenge is to find better ways of utilising the car and still achieve sustainability goals.
10	(Kim, S. et al., 2022)	The Netherlands	Preferences	Examine the relationship between a multimodal mindset and its impact on the MaaS concept service in tourism of a possible mediator effect of satisfaction with the use of mobility-related applications.	The results confirm that psychographic lifestyles play a substantial role in people's decision to subscribe to MaaS. Having positive attitudes towards multimodal travel increases the propensity to adopt MaaS, where the attitudes are moderated by values and personality traits significantly.
11	(Martinčević, I., et al., 2022)	Croatia	Preferences	Contextualise the key dimensions of MaaS and then identify, categorise, and discuss possible implications	The change in the way of thinking about mobility and types of mobility affects the choice of new ways of mobility, which is the MaaS service concept that increases user satisfaction and speeds up and facilitates the mobility in tourist destinations.
12	(Alyavina, E. et al., 2022)	United Kingdom	Review		11 diverse thematic areas resulted and mapped out the opportunities and challenges of MaaS (market visibility, centralised data gathering, vehicle utilisation, accessibility, transport affordability, digital access, modal shift, market shares, environment, health and wellbeing and financial support)

#	Author(s)	Origin*	Scope	Objective	Findings
13	(Duan, S. et al., 2022)	Australia	Methodological	Develop predictive models and identify the factors that explain MaaS use for social, general, and work trips	The study reveals different sets of socio-economic factors, the impact of Covid-19, and personal travel factors as key predictors of MaaS use for general, social, and work trips with an average prediction accuracy of 68%, 68%, and 75% respectively
14	(Cho, S. et al., 2022)	Korea	Methodological	Analyse the route choice behaviours of bike-sharing users for the first- and last-mile trips in MaaS, incorporating the connectivity to the subway stations.	Distance was a critical variable to the users who departed from or arrived at subway stations in route choice because the BSS played a crucial role in connecting the first- and last-mile trips. The extension of bike facilities on access and egress to the subway stations needs to improve to promote bike usage in MaaS
15	(Aman, J. et al., 2022)	United States	Preferences	Identify the features that impact on MaaS satisfaction across gender.	Eleven topics (Schedule, Plan, Train, Uber, Walk, Pass, Ticket, User Interface, Update, App Issues, Google Map/ Map) were extracted from online reviews, and their association with user satisfaction examined. For men, app related features (Update and App Issue) as well as fare themed features (Ticket and Pass) showed the most significant impacts on satisfaction. For women, Update, App Issues, and Ticket showed the most significant impact on satisfaction. Of all the features only Google Map (for both men and women), and Train (only significant for women) showed positive correlation to satisfaction.
16	(Dadashzadeh, N. et al., 2022)	United Kingdom	Review	Conduct a literature review on studies related to MaaS to identify research gaps with respect to vulnerable social groups	A framework and MaaS Inclusion Index (MaaSINI) are proposed to evaluate the inclusion in MaaS services, focusing on vulnerable social groups' needs at a service level.
17	(Kriswardhana, W. et al., 2023)	Hungary	Review	Conduct a literature review on the socio-technical factors related to the adoption of MaaS and the creation of mobility packages	Socio-demographic factors show inconsistency regarding their impact on user preferences (age, educational level, the number of people in households, and income vary), while travel pattern variables are found to be more solid as the effect of travel-related factors like transport modes have significant effects on MaaS adoption. Mobility packages are mainly tailored using current travel pattern data.
18	(Enoch, M. and Potter, S., 2023)	United Kingdom	Review	Explore MaaS future market scenarios	The major challenges for policy makers will likely relate to balancing the promised benefits offered with issues such as safety (including biosafety in our post Covid-19 world), data security and privacy, equity and the threat of dominant suppliers distorting the marketplace. Together, these insights suggest that the MaaS reality may be messy and difficult to manage, and that future transport systems might look very different to now. Taken together, these insights suggest a great deal of uncertainty still pervades the future of MaaS, which might indicate a 'wait-and-see' approach to policy makers.
19	(vaan' Vert, R. et al., 2023)	The Netherlands	Preferences	Explore the factors that influence the intention to use MaaS among private vehicle owners, who have until now been identified as relatively MaaS-averse travellers	Five clusters are identified. The cluster profiles show that private vehicle owners who often use public transport and active modes are most inclined to use MaaS, whereas the 'conservative' passenger car owners who use the car as their main mode of transport for all their trips (e.g. commuting, leisure) show a lower intention to use MaaS. As it can be expected that the societal benefits of MaaS will especially occur when these conservative car owners adopt MaaS, we conclude that, from a policy perspective, implementing MaaS could be less effective in reducing transport externalities (e.g. pollution and wasted time in congestion) as perhaps expected
20	(Kim, H. et al., 2023)	Korea	Methodological	Show the relationships of the tourist preference for tourism travel alternatives represented as MaaS portfolios with MaaS provision of tourism destinations.	Findings showed that tourists have different travel needs and hence should be considered as a particular target of MaaS market.

#	Author(s)	Origin*	Scope	Objective	Findings
21	(Narayanan, S. and Antoniou, C. 2023)	Germany	Methodological	Develop a mode choice model, which is capable of capturing the demand for bike-sharing, car-sharing and ride-hailing services simultaneously.	Their results showed that gender and household car-ownership influenced both bike-sharing and car-sharing. While males have a higher likelihood to use bike-sharing and car-sharing, a significant difference between males and females is not observed for ride-hailing. Young (20-44 aged) and highly educated individuals are more likely to use all the three types of shared mobility services. Having license or public transport monthly ticket negatively influenced on the use of ride-hailing service, although the latter improves the odds of using bike-sharing and car-sharing services. Moreover, they found that households with higher number of cars are less probable to use bike-sharing, while a positive impact is seen for car-sharing. Their recommendations include the design of bike-sharing and car-sharing as complementary services to public transport, while ride-hailing could substitute the car in areas where public transport is weak. They also recommend subsidies, discounts and special offers to attract young age groups and free-ride promotions to make older groups accustomed to the use of shared mobility. Gender-related measures include the offer of special rates for females or caregivers around day-cares to attract them to use shared services. And finally, the authors recommend implementing or extend cycling infrastructure (short cuts or segregated cycle lanes with green light waves) or for the case of car-sharing, the introduction of dedicated parking facilities for shared cars.

Source: own elaboration.

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