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Unveiling Women's Needs and Expectations as Users of Bike Sharing Services: The H2020 DIAMOND Project

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Abstract: Within the objectives of the H2020 DIAMOND project, the paper investigates women's needs and expectations as users of the bike-sharing service managed by Syndicat Mixte Autolib et Velib Métropole in the territory of Paris Region-Petite Couronne (France). The paper presents a thematic literature review focused on gender inclusion in bike-sharing schemes. The proposed methodological approach is based on (*i*) Geographic Information Systems for the analysis of geolocated open datasets related to land, sociodemographic and mobility characteristics of the areas surrounding each docking stations. This was aimed at identifying a short list of suitable bike-sharing docking stations, which were further characterized through: (*ii*) structured proprietary data focused on travel demand; (*iii*) onsite observations focused on universal design indicators; (*iv*) survey questionnaires focused on women's concerns, needs and expectations; and (*v*) social media data from Twitter focused on the opinion of the end-users. Results showed that women use the VELIB's bike-sharing service much less than men (about 30% of the total number of users), since they are more concerned about the following issues: accessibility (e.g., availability of bikes at the docking stations, distance to the nearest station, type and quality of the cycle paths); safety and security (e.g., perception of danger and insecurity while cycling and using the current bicycle infrastructures); social constraints (e.g., perceptions and cultural stigmatization associated with cycling and bike-sharing); weather and topography (e.g., impact of weather and the urban terrain on cycling and bike-sharing). The final aim of the H2020 DIAMOND project is to support the definition of guidelines and policies for the inclusion of women's needs in the design of future bike-sharing services.

Keywords: gender and mobility; bike-sharing service; data analytics; inclusive transport system

1. Introduction

Encouraging the shift towards sustainable mobility strategies based on public transport, shared micromobility and active modes of travel is one of the main challenges of European cities [1], since they are increasingly facing problems of traffic congestion, road safety, energy dependency and air pollution. In this context, advanced urban planning activities are shifting towards a focus on active modes of transport [2], among which is the development of strategies and design elements which enhance the accessibility, comfort and safety of the urban setting for cycling.

This has become even more crucial considering the unprecedented effects of the COVID-19 pandemic on urban mobility. The European Commission [3] has recently provided ad hoc guidelines for implementing short-term transport planning interventions to face the current critical situation. Among the principles included in the document, the section '*Active Mobility*' has a specific focus on cycling:

> "*Many European cities are taking steps to make active mobility (e.g., walking and cycling) a safe and more attractive mobility option during the COVID-19 outbreak. Urban areas could consider temporary enlargements of pavements and increased space on the road for active mobility options to facilitate the needs of the population to move in a safe and efficient way, while reducing speed limits of vehicles in increased active mobility areas*" [3], p. 15.

In this regard, the activities of urban transport planners and decision makers are projected ahead towards investigating sustainable future mobility solutions taking into account the need to effectively plan the city in order to ensure public health but also to enhance social, environmental and economic resilience [4]. This includes both interventions on road network and public transport services (e.g., temporary cycling paths and sidewalk infrastructures, queue management in transit infrastructures), to guarantee the possibility to access public transport, services retail and goods within a comfortable distance from home [5].

Despite recent efforts towards universal design in mass transportation [6], the measures currently in place to design and manage public transport do not sufficiently consider women's needs as vulnerable users of the service. As highlighted by the European Charter for Women Rights in the City [7] and by the 2030 Agenda for Sustainable Development adopted by all United Nations Member States [8] (i.e., SDG 11.2-Sustainable Transport for All), public transport should be designed to be gender-inclusive:

> "*By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons*" [8], p. 24.

Women, in fact, experience and use transport systems differently than men, since they are more concerned with economic, accessibility and security issues [9]. In particular, statistical facts and figures showed the low use of bike-sharing schemes by women and the need to increase their participation [10–12], given that men cycle on average three times as often as women and travel more than four times as far. One of the barriers reported by women users of bike-sharing schemes are the unsafe driving conditions and the need of more traffic rules and speed limits on public roads, with many claiming they prefer cycling in zones with lower traffic [11,13].

In this framework, the H2020 DIAMOND research project (see: https://diamond-project.eu, accessed on 30 March 2021) aims at transforming data from various sources into actionable knowledge for ensuring the inclusion of women's needs and expectations in transport systems. The research follows a gender-sensitive approach that brings together urban and mobility experts, transport authorities, computer and data scientists, mobility economists and social scientists. The project focuses on four Use Cases: (*i*) Public Transport Infrastructures (Railways); (*ii*) (Emotion in) Autonomous Passenger Car; (*iii*) Vehicle (Bike) Sharing Fleet Management; (*iv*) Employment of Women in Rail Industry and Freight/CSR Protocols. Within the objectives of the third Use Case of the DIAMOND project, the paper proposes a data driven approach for investigating the level of accessibility, comfort and security for women of the bike-sharing service that is managed by Syndicat Mixte Autolib et Velib Métropole (VELIB) in the territory of the Paris Region-Petite Couronne (France).

The methodological approach that sets the current research work is based on the use of Geographic Information Systems (GIS) for the analysis of several geolocated structured open data focused on: (*i*) land characteristics (e.g., urban fabric of land use, points of interest); (*ii*) sociodemographic characteristics of the inhabitants (population density, gender, age and nationality of the inhabitants); (*iii*) mobility characteristics (e.g., transport services;

cycling infrastructures). This was aimed at identifying and characterizing a short list of suitable bike-sharing docking stations, as characterized by high and low levels of accessibility for women. Results of GIS-based analysis were merged with VELIB's proprietary data related to the travel demand of the selected docking stations. Then, the selected docking stations were further investigated through onsite observations focused on universal design indicators, survey questionnaires and social media data focused on women'concerns, needs and expectations related to the bike-sharing services. The disaggregated data was used to understand and trace the mobility patterns of women as users of the bike-sharing services, to ask their opinion and to identify the factors important for them, in order to plan and design a fair, gender equitable and integrated bike-sharing schemes.

First, the paper proposes a thematic literature review focused on gender inclusion in bike-sharing schemes (Section 2), in order to provide a preliminary assessment of women's needs and barriers (i.e., *Fairness Characteristics*). Then, it presents the methodology which sets the current work (Section 3) and the results of the analyses (see Section 4) with reference to: Structured Open Data, Travel Demand Data, Onsite Observations, Users' Satisfaction Index Questionnaires and Social Media Data from Twitter. The paper concludes with final remarks about the achieved results and future work.

2. Literature Review

A bicycle-sharing system, or public bike share (PBS) scheme is a transport service in which bicycles are provided for a shared use on short term basis to individuals for a fee or free. Bicycle-sharing contributes towards achieving sustainable and inclusive transport services in urban centres. Women make more shorter and multipurpose or multistop trips and complex trips than men, due to the constructed normative gender roles in most societies [14,15]. The complex mobility pattern of women due to caring and parenting responsibilities makes the use of traditional public transportation time consuming and inconvenient [14–16]. Cycling or bicycle sharing services provide a better alternative to meet the complex urban mobility needs of women. Existing evidence suggest that traditionally, women cycle less than men [17]. However, recent evidence from the UK suggest a narrowing gender split of bike-share usage compared to general cycling [18,19].

The aim of the H2020 DIAMOND project is to investigate the mobility needs and challenges of women in relation to bike sharing services in order to produce guidelines for providing more inclusive infrastructure, improve planning and distribution of docking points, engender fair inclusion for women and address the social imbalance within the domain of transport. Therefore, the final goal of the research is to identify and reduce the barriers preventing women from using bike sharing services and, then, to increase the percentage of women using bike sharing services to meet their mobility needs.

Bicycle-sharing services is fraught with several barriers and limitations, which prevent women from using the services. Taking advantage of a preliminary work already presented by the authors [20], the review of extant literature focused on identifying pertinent issues and challenges bothering on women mobility experience as users of bike sharing service and barriers preventing women from using bike sharing services. Literature review was conducted through several academic database (e.g., Web of Science, Scopus, Google Scholar, ResearchGate, etc.) and organized in a tabular structure (see Table A1 and Figure A1). Overall, the process allows the identification of about eighteen *Fairness Characteristics* (FCs) influencing women participation in bike-sharing systems, which were validated through the execution of several focus groups and semistructured interviews. The FCs have been grouped into four *Cluster of Fairness Characteristics* (CFCs):

1. CFC-*Accessibility & Spontaneity* (e.g., availability of bikes at the docking stations, distance to the nearest station, type and quality of the cycle paths, etc.);
2. CFC-*Safety & Security* (e.g., perception of danger and insecurity while cycling and using the current bicycle infrastructures, etc.);
3. CFC-*Social Constraints* (e.g., perceptions and cultural stigmatization associated with cycling and bike-sharing, etc.);

4. CFC-*Weather & Topography* (e.g., impact of weather and the urban terrain on cycling and bike-sharing, etc.).

The availability of bikes at the stations when needed, the distance to the nearest station and the type and quality of the cycle paths available are some of the issues users have to take into consideration when planning a trip involving bike-sharing services. CFC-*Accessibility & Spontaneity* is defined in terms of those characteristics of the service related to the ease with which all women groups can access and use the bike-sharing services for a trip. Significant differences are reported between women and men cyclist and bike-share users due to their respective normative gender roles [17,21]. The fairness characteristics for this CFC include the following:

- According to TfL [22], there is poor awareness of local walking and cycling routes among low-income and minority groups. Similarly, Stredwick [21] found a low-level of awareness of practical cycling (such as cycling with children or carrying luggage or shopping on a bike). This observation is described in FC-*Public awareness*. Public awareness campaigns of bikes sharing schemes, promoting cycling/bike-share as a legitimate form of transport and offering lessons on practical cycling amongst women and minority groups could ramp-up women interest in cycling and using bike-sharing services.
- Majority of the bike-sharing services rely on the use of credit/debit card, smart phones and require internet access to sign-up for membership and for rental. This requirement prevents potential users of bike-sharing services from using the services [23]. This is highlighted in FC-*Sign-up and booking process*. McNeil et al. [24] found that some individuals from minority and low-income background and the elderly are less likely to have smart phones, reliable internet access or credit/debit cards.
- Accessibility in terms of FC-*Membership cost*, includes entry cost, rental charges above a stated threshold, the cost of other essential cycling accessories (such as helmet, clothing etc.) and a possible liability cost resulting from the theft or damages of the bike. Bikeplus [25] found the entry cost of bike-sharing services to be lower than the cost of owning a bike; however, entry costs and rental charges above a stated time limit of some schemes are observed to be higher [26], which come as a major barrier to the full adoption of the services, particularly, by commuters from minority and low-income groups [27].
- FC-*Spontaneity of accessing bike/dock* relates to the possibility of finding a bike at the station and finding a vacant docking point at the trip destination station to return a bike after the trip in a traditional dock-based bike-share systems. This relates to the reliability of the service and significantly influence trip makers decision on whether or not to include bike-sharing as an option in their daily travel plans [28]. This has been reported to be one of the major barriers to cycling. The inability to guarantee a bike at the station or an empty docking point to return a bike after the trip when needed has resulted in many users giving up on using the schemes or using them for important trips [18].
- FC-*Proximity of docking station* relates to how far a user has to walk to pick-up a bike or walk to the trip destination after returning a bike. Some users report travelling further from their trip destination to return a bike after their trip because the station at their destination did not have an empty dock to return the bike. The spatial distribution of docking stations is seen as a critical factor influencing bike-share usage; the proximity to members as well as to low-income and minority neighbourhoods promotes membership [26].
- Women are mostly encumbered due to their parenting and gender role; this significantly affects their mobility options [29]. FC-*Travelling with children/carrying things*, describes the lack of child seat and good-sized carry baskets on most bike-sharing services limits the use of such services for shopping trips and trips involving children by women. This raises gender and social justice concerns since women make more 'escort' trips with children, and more shopping trips, than men.

- FC-*Insufficient infrastructure* focuses on the lack of protective Infrastructure (segregated cycle infrastructure), discontinuity of the cycle infrastructure including cycle path and cycle facilities. This raises safety concerns particularly for users with dependants who considers the infrastructure unsafe for cycling with kids and identified as barriers to women in the use of bike-share services [21,30]. Similar to road network improvement, cycling infrastructure makes cycling and bike-share attractive to users and potential users [23,31].

The second CFC-*Safety & Security* relates to factors influencing the perception of danger and insecurity while cycling and using the current bicycle infrastructures. The fairness characteristics for this CFC include the following:

- FC-*Driver behaviour*: While more research is required to understand why more women experience and report more incidents than men, cyclists believed most of the near misses and scary incidences can be blamed on factors such as speed, drivers passing too close, negligent opening of a vehicle door and aggressive driving on the road, which is preventable [32]. The attitude and behaviour of drivers towards cyclists is seen as a major deterrent to cycling and the use of bike-sharing services, particularly among women [23,33].
- FC-*Separate infrastructure*: while sharing the road space with motor vehicles seems problematic for females, it is believed that the slower cycling speed of women on the road [34] could be a plausible explanation as drivers become impatient with the slow riding speeds. Developing a safe and protective cycling network separated from vehicular traffic have a positive effect on women perception of safety and could get more women cycling and using bike-share [21,30]. Segregated infrastructure, alongside interventions targeted at road culture and driver behaviour, is suggested to have stronger influence on the rate of cycling of women [35,36].
- FC-*Harassment*: Women are susceptible to harassment, verbal abuse and attacks in the public space and are more likely to report sexiest harassment from other road users when cycling than men [21,37,38]. Howland et al. [17] found the fear of harassment by men and drivers is a significant barrier to cycling and the use of bike-sharing services by women. Street harassment is one of the barriers to cycling and the use of bike sharing. Consequently, continuous public education could help address this social menace.
- FC-*Safe environment and personal safety*: The subjective safety (perceptions of insecurity) and the objective safety (measured risk level) have greater implication on the rate of cycling [36]. The likelihood that a rider was a woman is higher than a man if the cycling environment is friendly. Off-road infrastructure, on-road infrastructure without parked vehicles and residential streets are considered safer than mixed-traffic roads by cyclists [36]. The findings of our interview also suggest that the level of lighting and visibility at the stations, the presence/absence of emergency help buttons at the bikes stations and the characteristics of the lanes (width, location, lighting, etc.) have significant impact on cycling, which is consistent with the subjective and objective safety findings reported in Kumar et al. [36] and Ravensbergen et al. [38].
- FC-*Confidence/experience*: Less experienced cyclists, or those with little confidence on their own cycling abilities, see the interaction with vehicles on on-road cycling infrastructure more challenging and intimidating [34]. The fear women have of traffic results from the sense of inexperience and lack of self confidence in cycling [37]. These are barriers and possibly explain why women are more uncomfortable cycling in traffic [21]. Off-road and dedicated and enforced on-road infrastructure may encourage inexperienced cyclists and get more women cycling and using bike-sharing services.
- FC-*Traffic safety*: Road safety is a gendered issue when it comes to cycling; women report twice as many incidents of 'frightening near misses' and more concerned about cycling on the road in traffic than men [32,36,39]. Cycling on the road with vehicular traffic is very intimidating for women [21] and disproportionately impacts a woman's decision to cycle [27].

There is sociocultural dimension to barriers of cycling, and this is more pronounced in women than men. This is presented in the third CFC-*Social Constraints*. The perceptions and cultural stigmatization associated with cycling and bike-sharing is fuelled by gender stereotyping in society and the perception that cycling is for the poor. The fairness characteristics for this CFC include the following:

- FC-*Subjective norm (peer influence)*: Important others have significant influence on behaviour and on the decision to cycle or otherwise; peers and coworker normative beliefs on cycling can influence women's participation in cycling to and from work [40].
- FC-*Sociocultural constraint (negative perception)*: There exist culturally embedded perceptions about the symbolic value of cycling. Cycling is perceived as a transport mode reserved for people of low status, with evidence of poverty and the inability to afford a car [22,37]. The stigmatisation of cycling in most communities serves as a major barrier to the desire to cycle and use bike-sharing services. Campaigns to promote cycling as a legitimate form of transport for all income groups and encouraging all income groups to cycle could help overcome this myth, encourage cycling and the use of bike-sharing services [37]. Additionally, the appearance of women (the wearing of skirts, high heeled shoes, hair style and the likelihood of carrying a purse) constrains and limits the rate at which women cycle [41]. End-of-trip or workplace facilities and the design of bikes are suggested to address this barrier.
- FC-*Family responsibilities*: The constructed normative roles of women including childcare prevent women from cycling and using bike-sharing services because of the complexity of cycling with children and for shopping [41]. Education on practical cycling and the possibility of cycling with children and for shopping could help address this barrier and encourage more women to cycle and use bike-sharing services.

The fourth and last CFC-*Weather & Topography* relates on the impact of weather and the urban terrain on cycling and bike-sharing. The fairness characteristics for this CFC include the following:

- FC-*Weather*: The impact of weather on cycling is emphasised in literature. The demand for cycling and bike share is subject to seasonal variation and weather such as humidity, temperature, wind and rains [33,42].
- FC-*Topography*: The presence of hills along cycle routes have negative impact on cycling and a barrier to women urban cycling and bike share [33,43]. The development of electric assisted bikes has overcome this barrier and further makes long distance trips possible [25].

3. Enabling Data and Methodology

Within the scope of the H2020 DIAMOND project, the objective of the proposed analysis was to investigate the women's needs and expectations as users of bike-sharing services managed by VELIB in the territory of Paris Region-Petite Couronne (1358 docking stations in total). This was aimed at supporting the development of EU policies and guidelines for gender-equitable bike-sharing fleet management, focusing on the Clusters of Fairness Characteristics defined through the proposed thematic literature review (see Section 2): (*i*) Accessibility & Spontaneity; (*ii*) Safety & Security; (*iii*) Social Constraints; (*iv*) Weather & Topography.

In this framework, the methodology which sets the current work was based on a series of (geolocated) Structured Open Data, which were retrieved, sorted and filtered from open data repositories, national geoportals and census databases (see Section 4.1). In analogy with a previous work already presented by the authors [44], preliminary structured open data analysis was based on GIS (all GIS-based analyses presented in this paper have been performed by using the software QGIS v.3.16.1) in order to identify and characterize a short list of relevant docking stations, in which to perform further data collection activities. A series of thematic maps related to the localisation and density distribution of datasets were designed to assess the level of accessibility of the bike-sharing docking stations managed by VELIB, focusing on the following:

- *Territorial Data*: density distribution of urban fabric on land use (including continuous urban fabric, discontinuous dense urban fabric and isolated structures) and points of interest (e.g., commercial activities, schools, facilities, public services, attractions, etc.);
- *Sociodemographic Data*: density distribution of total population, female population, elderly population and foreigner population per census section;
- *Mobility Data*: density distribution of public transport services (e.g., metro and commuter railway stations, bus stops, tram stops, etc.) and cycling infrastructure.

The proposed approach for structured open data collection allowed the identification of a short list of twenty heterogeneous and nonadjacent docking stations, characterised by positively and negatively relevant characteristics related to the objectives of the analysis. In order to further characterise the shortlisted stations, structured open data were merged with:

- *Travel Demand Data* (see Section 4.2): to distinguish the selected docking stations in regard of utilisation patterns, such as trips related data (e.g., number of started and ended rentals, trip distance and duration, etc.) and users segmentation data (e.g., number of unique users, number of female users).
- *Onsite Observations* (see Section 4.3): to characterise the selected docking stations focusing on universal design indicators;
- *Users' Satisfaction Index Questionnaires* (see Section 4.4): to characterise the sociodemographic characteristics and mobility patterns of the end-users and to correlate their level of satisfaction with the characteristics of the selected docking stations;
- *Social Media Data from Twitter* (see Section 4.5): to get insights on women's and men's concerns related to the bike-sharing service, as emerging from online conversations.

4. Results

4.1. Structured Open Data

The proposed methodological approach is based on analysing and merging a series of geolocated structured datasets (see Table 1), in order to assess the level of accessibility for the women using the bike-sharing service managed by VELIB (1358 docking stations in total, see Figure 1), to identify and characterise a short list of twenty suitable stations (ten docking stations characterised by high levels of accessibility and ten stations characterised by low levels of accessibility). The indicators were analysed to design a multilayer map of Paris Region-Petite Couronne (France) and to estimate the spatial distribution of each dataset considering the localization of the VELIB's docking stations (see Table A2, Figures A2–A4). From a general point of view, the analysis was based on various attributes and characteristics of the urban area surrounding each docking station. To do so, raw data related to the urban scale were extracted about surrounding areas of each docking station, namely by considering the boundaries of census sections as catchment areas. A preliminary data validation phase aiming at checking any missing and/or not relevant values allowed us to filter 1297 valid docking stations distributed on 914 census sections, containing at least one docking station.

Data were postprocessed through: (*i*) density-based calculation on census section areas; (*ii*) normalisation of values (z values in a range between 0 and 1); and (*iii*) weighted formulas of normalised values to calculate the Territorial Data Index (TDI), Socio-demographic Data Index (SDDI), and Mobility Data Index (MDI). Quintile frequency distribution of results made possible the identification of the docking stations characterised by high levels of accessibility for the women (belonging to the highest quintile, $\geq$80th percentile) and the docking stations characterised by low levels of accessibility for the women (belonging to the lowest quintile, $\leq$20th percentile). A group of 76 docking stations belonging to three out of three highest quintiles among the TDI, SDDI and MDI was identified (distributed on 32 census sections). Then, a group of 80 docking stations belonging to three out of three lowest quintiles among the TDI, SDDI and MDI was identified (distributed on 47 census sections). The list was further shortened considering the localisation of each station in order to identify a group of twenty heterogeneous and nonadjacent docking stations characterised by positively and negatively relevant characteristics related to their level of accessibility.

Table 1. List of retrieved Structured Open Data that were analysed and merged for the identification and characterisation of a short list of relevant bike-sharing docking stations managed by VELIB.

Data Typology	Indicators	Data Source	Year
Preliminary Data	Paris Region (Petite Couronne) Census Sections of Paris Region VELIB docking stations	Copernicus Land Monitoring Service National Institute of Statistics Open platform for French public data	2012 2019 2019
Territorial Data	Land Use (Urban Fabric) Points of Interests and Amenities	Copernicus Land Monitoring Service OpenStreetMap-Geofabrik DB	2012 2019
Socio-demographic Data	Total Population per Census Section Age of Inhab. per Census Section Gender of Inhab. per Census Section Nationality of Inhab. per Census Section	National Institute of Statistics National Institute of Statistics National Institute of Statistics National Institute of Statistics	2011 2011 2011 2011
Mobility Data	Public Transport Services Cycling Infrastructure	OpenStreetMap-Geofabrik DB OpenStreetMap-Geofabrik DB	2019 2019

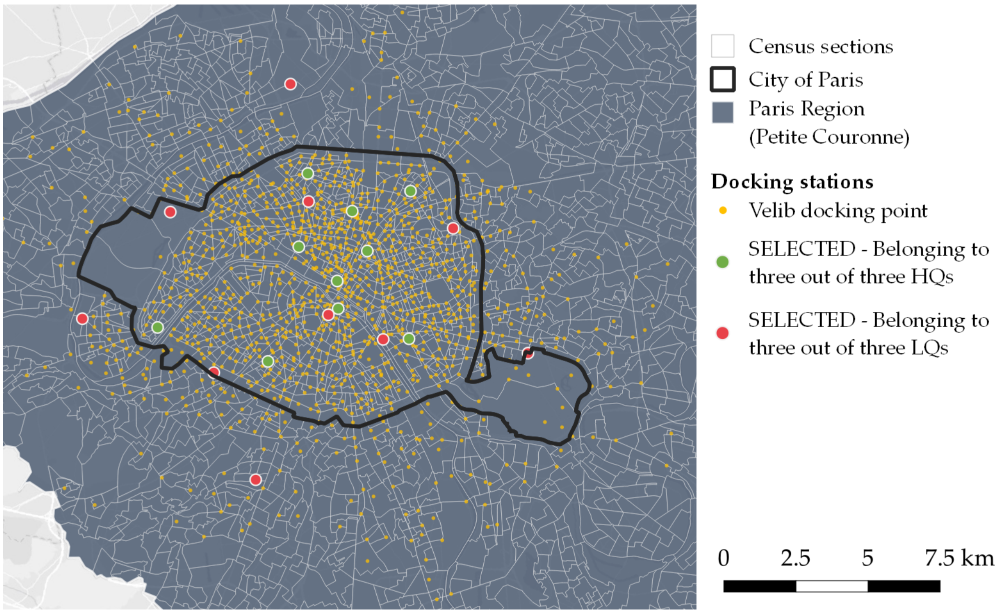

Figure 1. The map shows the total number of bike-sharing docking stations managed by VELIB and the group of twenty heterogeneous and nonadjacent docking stations, which were selected through the proposed GIS-based analysis of Structured Open Data.

4.1.1. Territorial Data Index

The calculation of the Territorial Data Index (see Figure 2 and Table 2) was based on the density distribution of the urban fabric (UF_cs) and Points of Interest (PoI_cs) on the census sections surrounding the VELIB's docking stations. Land-use dataset include the localization of continuous urban fabric, discontinuous dense urban fabric and isolated structures. Data analysis was aimed at estimating the level of urbanisation of the catchment areas since the level of accessibility of bike-sharing service for women greatly differs based on the urban or periurban characteristics of the surroundings. Points-of-interest datasets include a series of heterogeneous services and facilities (e.g., commercial activities, bars, supermarkets, playgrounds, sport facilities, nightclubs, university facilities, public services, tourist attractions, etc.). Data analysis was aimed at assessing the level of attractiveness of the catchment areas surrounding each docking station, considering the needs of different users' profile (e.g., commuters, students, tourists).

$$\sum_{k=1}^{0} = {}_{\mathrm{KUF}}UF\_cs + {}_{\mathrm{KPoI}}PoI\_cs \quad (1)$$

TDI was calculated through the weighted summation of normalised density distribution values of urban fabric and points of interest on catchment areas (see Equation (1)). The constant parameters KUF and KPoI were equally balanced (∑ constant parameters = 1).

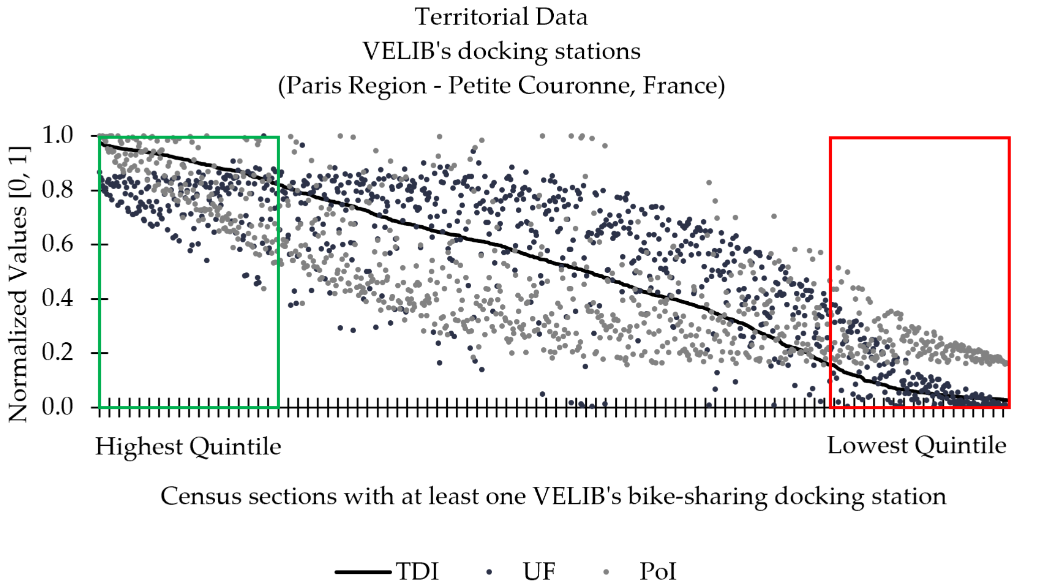

Figure 2. Results of Territorial Data Index (TDI) related to the VELIB's docking stations. Highest Quintile and Lowest Quintile respectively refer to the 80th and 20th percentile of quintile frequency distribution of TDI.

Table 2. Quintile frequency distribution of TDI values and indicators related to the VELIB's bike-sharing docking stations.

Parameter	Indicator/Index	Highest Quintile	Lowest Quintile
UF	Km^2 urban fabric on census section area	0.093 (±0.077)	0.116 (±0.095)
PoI	No. PoI on census section area	1079.129 (±433.167)	132.375 (±108.582)
TDI	Territorial Data Index	0.905 (±0.043)	0.071 (±0.038)

4.1.2. Sociodemographic Data Index

The calculation of the Socio-demographic Data Index (see Figure 3 and Table 3) was based on the density distribution of the Total Population (TP_cs), Female Population (FeP_cs), Elderly Population (Elderly population dataset includes the spatial distribution of the inhabitants being over 64 years old.) (EP_ca), and Foreigner Population (FoP_ca) on the census section of the Paris Region-Petite Couronne (France). Data analysis was aimed at estimating the density distribution of the population and the age, gender and nationality characteristics of the inhabitants living in the catchment areas surrounding the docking stations managed by VELIB, as potential users of the bike-sharing service. The calculation of the SDDI relies on the density distribution of the population on the urban fabrics of the catchment areas surrounding the VELIB's docking stations, to balance the population density between urban and periurban areas.

$$\sum_{k=1}^{0} = {}_{\mathrm{KTP}}TP\_cs + {}_{\mathrm{KFeP}}FeP\_cs + {}_{\mathrm{KEP}}EP\_cs + {}_{\mathrm{KFoP}}FoP\_cs \quad (2)$$

SDDI was calculated through the weighted summation of normalised density distribution values of total population, female population, elderly population and foreigner population on urban fabric of catchment areas (see Equation (2)). The constant parameters KTP (corresponding to 0.3), KFeP (corresponding to 0.3), KEP (corresponding to 0.2) and KFoP (corresponding to 0.2) were weighted to accentuate the impact of the density distribution of the total and female populations on SDDI (∑ constant parameters = 1).

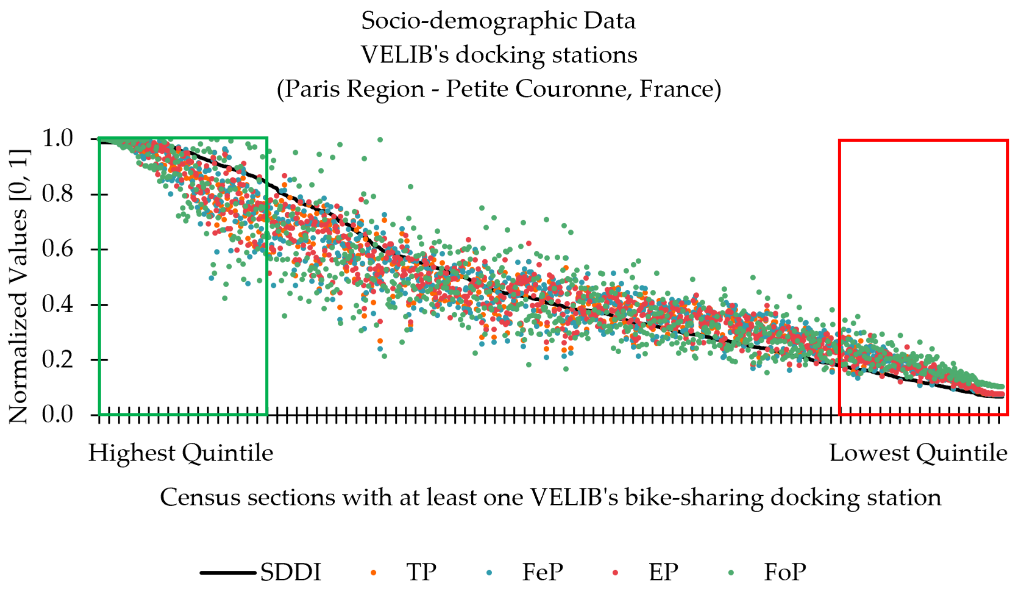

Figure 3. Results of Socio-demographic Data Index (SDDI) related to the VELIB's docking stations. Highest Quintile and Lowest Quintile respectively refer to the 80th and 20th percentile of quintile frequency distribution of SDDI.

Table 3. Quintile frequency distribution of SDDI values and indicators related to the VELIB's bike-sharing docking stations.

Parameter	Indicator/Index	Highest Quintile	Lowest Quintile
TP	Inhabitants per km^2 on UF/census section	4667.953 (±1657.834)	695.479 (±389.921)
FeP	Female inhabitants per km^2 on UF/census section area	2449.051 (±892.744)	367.511 (±211.022)
EP	Elderly inhabitants per km^2 on UF/census section area	3752.781 (±1362.851)	549.440 (±299.566)
FoP	Foreigners inhabitants per km^2 on UF/census section area	711.794 (±285.861)	91.672 (±56.511)
SDDI	Socio-demographic Data Index	0.933 (±0.053)	0.127 (±0.039)

4.1.3. Mobility Data Index

The calculation of the Mobility Data Index (see Figure 4 and Table 4) was based on the density distribution of Public Transports (PT_cs) and cycling Road Infrastructure (RI_ca) on the catchment surrounding the docking stations managed by VELIB. Public transport datasets include the spatial distribution of metro and commuter railway stations, bus stops, tram stops and taxi stations. Data analysis was aimed at estimating the level of connectivity of the bike-sharing docking stations with other transport services. Data analysis of cycleway road infrastructures dataset was aimed at analysing the level of accessibility of the docking stations.

$$\sum_{k=1}^{0} = {}_{\mathrm{KPT}}PT\_cs + {}_{\mathrm{KRI}}RI\_cs \tag{3}$$

MDI was calculated through the weighted summation of normalised density distribution values of public transports and cycling infrastructure on catchment areas (see Equation (3)). The constant parameters KPT (corresponding to 0.4) and KRI (corresponding to 0.3) were equally balanced ($\sum$ constant parameters = 1).

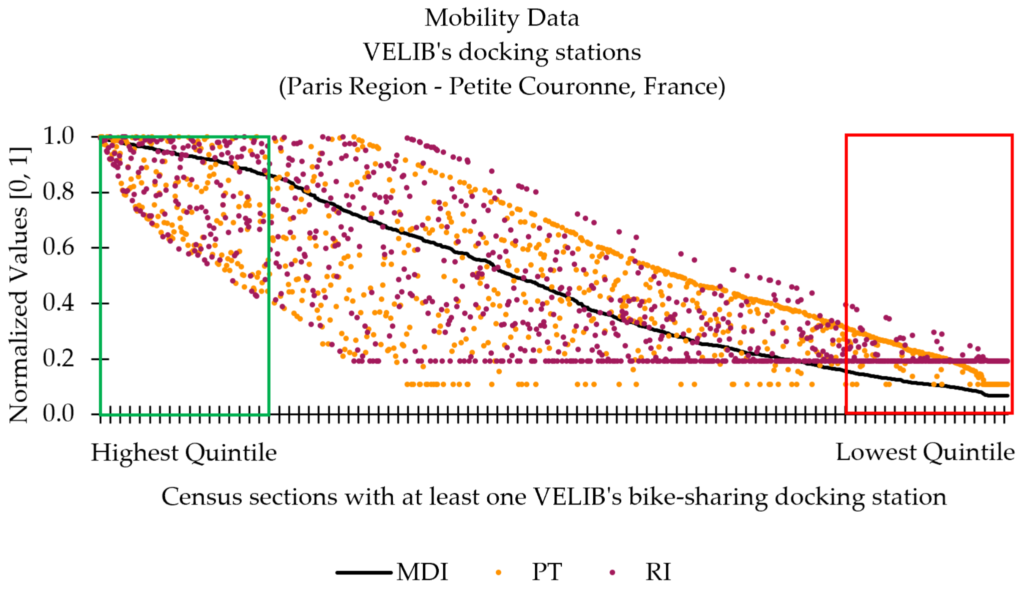

Figure 4. Results of Mobility Data Index (MDI) related to the VELIB's docking stations. Highest Quintile and Lowest Quintile respectively refer to the 80th and 20th percentile of quintile frequency distribution of MDI.

Table 4. Quintile frequency distribution of MDI values and indicators related to the VELIB's bike-sharing docking stations.

Parameter	Indicator/Index	Highest Quintile	Lowest Quintile
PT	No. Public Transport services on census section area	70.569 (±36.484)	11.524 (±7.155)
RI	Km cycling infrastructure on census section area	13.064 (±5.499)	0.383 (±0.807)
MDI	Mobility Data Index	0.927 (±0.041)	0.115 (±0.030)

4.2. Travel Demand Data

The list of bike-sharing docking stations shortlisted through the proposed GIS-based analysis (see Section 4.1) was further characterised through the analysis of Structured Proprietary Data (see Table 5), namely Travel Demand Data: number of bikes, started rentals (e.g., total number, e-bikes), ended rentals (e.g., total number, e-bikes), average distance and time duration per trip and unique users (e.g., total number, female users).

The retrieved Travel Demand Data was postprocessed to calculate the average monthly values for each of the selected docking stations (see Table A3), which were analysed to highlight the relation between demand patterns and level of accessibility for the women. The results are highlighted below and in Figures 5 and 6:

- The utilisation/capacity ratio (i.e., relation between started/ended rentals and the capacity of the docking stations) is 93% higher in positively relevant docking stations compared to negatively relevant docking stations (see Figure A5);
- Negatively relevant docking stations, while being less used, showed higher values in trip distance (+55%) and duration (+60%) in respect to the positively relevant stations. This could be caused by a location bias, since most of the negatively related stations are located in noncentral areas;

- The unique user ratio (i.e., the relation between the number of rentals and the number of unique users) is consistent between both positively and negatively relevant docking stations. However, the user ratio related to the docking stations located in the territory outside the City of Paris is lower (−14%) compared to the one of the overall docking stations (see Figure A6).
- The female user ratio (i.e., the relation between female and overall users) is consistent between both positively and negatively relevant docking stations. However, the female user ratio related to the docking stations located in the territory outside the City of Paris is slightly lower (−5%) compared to the one of the overall docking stations (see Figure A7).

Table 5. List of retrieved Travel Demand Data that were analysed and merged for the characterisation of the selected relevant bike-sharing docking stations managed by VELIB.

Data Typology	Indicators	Data Source	Year
Travel Demand Data	Number of bikes	Syndicat Mixte Autolib et Velib Métropole	2019
	Started rentals (total)	Syndicat Mixte Autolib et Velib Métropole	2019
	Started rental e-bikes	Syndicat Mixte Autolib et Velib Métropole	2019
	Ended rentals (total)	Syndicat Mixte Autolib et Velib Métropole	2019
	Ended rental e-bikes	Syndicat Mixte Autolib et Velib Métropole	2019
	Average distance per trip [m]	Syndicat Mixte Autolib et Velib Métropole	2019
	Average duration per trip [min]	Syndicat Mixte Autolib et Velib Métropole	2019
	Unique users (total)	Syndicat Mixte Autolib et Velib Métropole	2019
	Unique female users	Syndicat Mixte Autolib et Velib Métropole	2019

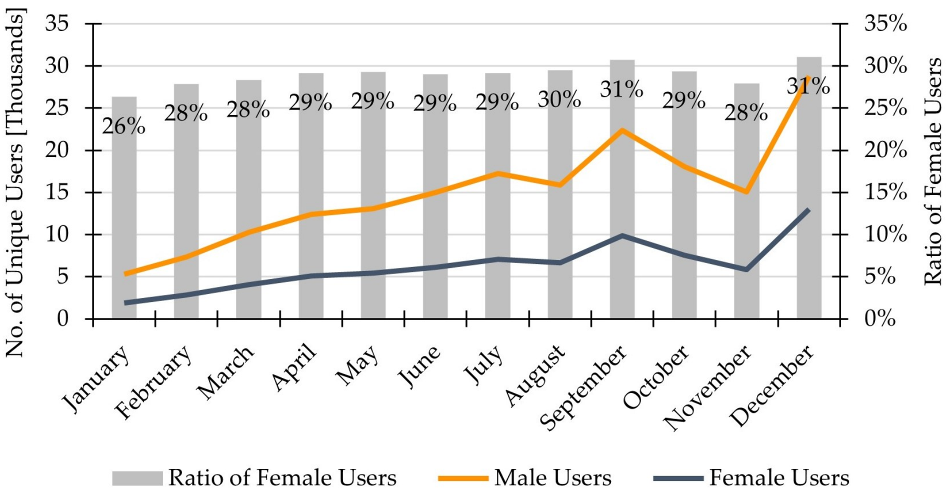

Figure 5. The ratio of female users over the overall users' number of the selected docking stations.

4.3. Onsite Observations

A list of selected bike-sharing docking stations shortlisted through the proposed GIS-based analysis (see Section 4.1) was further characterised through the execution of Onsite Observations focused on universal design indicators. In particular, an ad hoc developed checklist (see Table A4) was used for the evaluation of infrastructure design and surrounding context characteristics related to women's needs as users of bike-sharing services around the *Fairness Characteristics* identified through the above mentioned literature review (see Section 2).

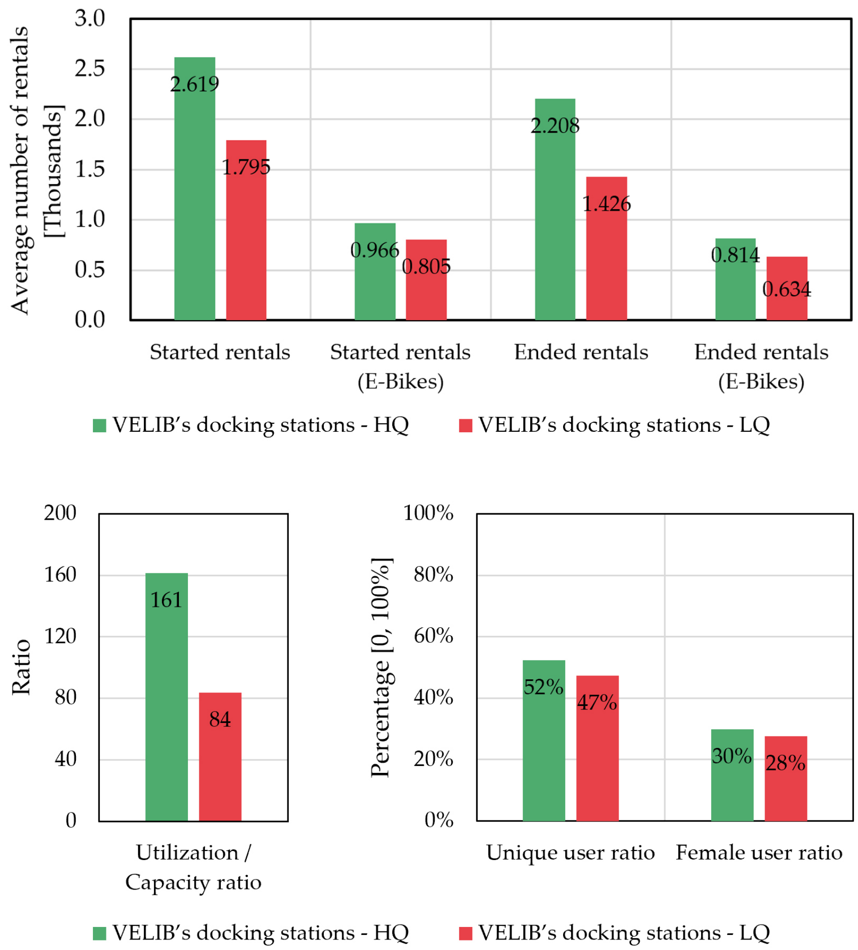

Figure 6. Results of Travel Demand Data related to the selected VELIB's docking stations. Positively relevant docking stations (i.e., *Highest Quintile*) are highlighted in green colour, negatively relevant docking stations (i.e., *Lowest Quintile*) in red colour.

Data collection campaigns were executed from March 2020 to September 2020, by the staff of Genre et Ville (partner of the consortium of the H2020 DIAMOND project) at different time periods of the day (i.e., day and night). Onsite observations took the form of researchers visually observing the public and recording their finding on paper. In addition, some still photography of the bike sharing docking stations was carried out. Data analysis was focused on comparing data between the twenty heterogeneous and nonadjacent docking stations characterised by positively relevant characteristics (i.e., *Highest Quintile*) and negatively relevant characteristics (i.e., *Lowest Quintile*) related to their level of accessibility. The results are highlighted below and in Figure 7:

- About 60% of the docking stations displayed some negative connotations in relation to spontaneity of accessing the bike service (the index is for reasons related to the maximum number of bikes observed at the docking stations or the minimum number of bikes recorded during the observation), the percentage of bikes recorded during the observation (considering the capacity of the docking station) and the number of other public modes of transport near the docking station. In addition, no bikes were reported to have a child seat for children;
- The characteristics related to public awareness were equally distributed between positive and negative and it was simply measured as an assessment of the observed percentage of female users;

- About 90% of observed docking stations displayed some negative features related to separate infrastructure like the presence of a cycle lane nearby the docking station (approx 200 meters around) and/or the lack of a separate cycle infrastructure;
- Above 40% of docking stations had negative features related to safe environment and perceived personal safety related to features such as observation of safety of the cycle paths and lanes for cycling at night, and/or percentage of users wearing hi-visibility cycling gear, and/or percentage of worthy bikes among the fleet (e.g., well-functioning brakes, lights, etc.).

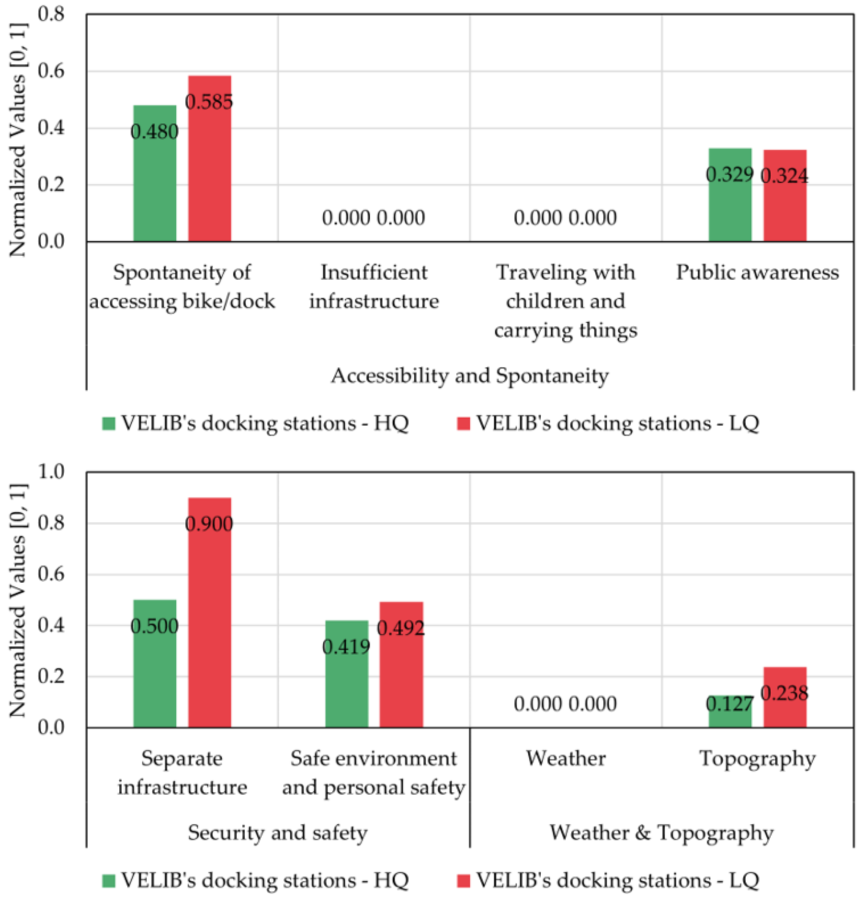

Figure 7. Onsite Observations results related to the twenty selected bike-sharing docking stations managed by VELIB. Positively relevant docking stations (i.e., *Highest Quintile*) are highlighted in green colour, negatively relevant docking stations (i.e., *Lowest Quintile*) in red colour.

4.4. User Satisfaction Index Questionnaires

The outline of the Users' Satisfaction Index Questionnaires was designed to collect data on users' experience and perception on the bike-sharing service managed by VELIB by focusing on: (*i*) bike-sharing experience; (*ii*) the four CFCs identified through literature review (see Section 2) and (*iii*) general sociodemographic information. The questionnaire assesses participants knowledge, perceived challenges and opportunities of the bike-sharing services as well as their expectation of bike-sharing schemes.

Data collection was carried out in the territory of Paris Region-Petite Couronne (France) from October 2020 to November 2020. The questionnaire was administered online and through intercept survey at the selected docking stations (see Section 4.1). In total 407 users completed the survey: 46 online and 361 in the intercept survey. The gender split of respondents was almost half for both sexes, 50.6% male compared to 49.4% for female. Respondents were aged between 18 to 74 years old, with the majority (69.3%) aged between 18 and 34 years old. Furthermore, 50.8% of respondents have at least a university degree. In addition, 99.5% of respondents are users of bike-sharing services, 47.2% uses bike sharing services one to five times in a week, 26.8% between 6 and 10 times a week and 26.0% more than 10 times a week. More than one third of respondents cycle to work (37.7%). Almost three-quarters did not live with any dependent (73.5%). As expected, more female than male respondents travel with dependants. Almost half of the respondents were in paid employment (49.9%); more than a quarter were students (26.8%) and a little over a half of respondents were in full-time employment (50.4%).

According to the CFCs and FCs identified through the proposed literature review (see Section 2), the UESI Questionnaire responses were analysed to identify possible differences in needs and perceptions by users of bicycle sharing services and possible challenges when disaggregated in respect to individual and demographic features. Linear regression (all statistics presented in this paper have been performed by using the software R v.4.0.5, and they have been conducted at the $p < 0.01$ level) was estimated using step-wise analysis in MASS R package on the prediction of satisfaction with bike-sharing services (see Table A5). The key findings of the analysis are presented below:

- The booking and sign-up process is linked to user satisfaction. Easy sign-up process increases user satisfaction, perception of the reliability of the services and in other words the willingness to use the services;
- The proximity of stations, in other words, how far a user must walk to pick up a bike or the distance a user has to walk after returning a bike is found to significantly affect user satisfaction. Increasing the density of docking stations or siting stations close to users makes the service more accessible and increases user satisfaction;
- In general, 68.1% of respondents either disagree or are unsure about the possibility of using bike-sharing services with children. Furthermore, 70.1% of women disagree compared to 65.5% of men. The results further indicate that user satisfaction is linked to the perception about using the services with children. Users who believe trips involving children could be possible are likely to be dissatisfied with the inability to use the service with children. This suggests that supporting trips involving children could increase user level of satisfaction;
- Perception of safety was linked to traffic speed, safety of the infrastructure and neighbourhood cycling environment. Lower traffic, safe infrastructure and safe cycling environment predicted increased perception of safety and consequently, user satisfaction and odds of using bike-sharing services. Similarly, visibility and adequate lighting at the docking stations predicted increased sense of security and user satisfaction;
- The likelihood of cycling or using bike-share was found to depend on user level of understanding of the benefits of cycling, perception about cycling or bike-share and acceptance of cycling or bike-share as an acceptable form of transportation. The results indicate that the acceptance of cycling or bike-share as a legitimate mode of transport and knowledge about the benefits of cycling increases user satisfaction and use of bike-share;
- Unsurprisingly, weather conditions had a significant impact on cycling and bike-sharing; however, supply of cycling raincoats could help mitigate this and increase user satisfaction;
- From the correlation index most questions were not strongly correlated; however, there were higher correlations (>0.45) around the CFC-*Accessibility & Apontaneity* and CFC-*Safety & Security* (see Figure A8).

4.5. Social Media Data

The aim of Social Media Data analysis was to complement the proposed characterisation of the selected docking stations by focusing on the opinion of a larger samples of users about the bike-sharing service managed by VELIB. Social Media Data were collected through the Twitter API from December 2019 to June 2020 by using Kalium [45], a tool that allows one to efficiently and flexibly manage the tracking of social network data in real time. In this way, we collected 44,262 tweets from 8414 users. Geospatial data analysis enabled researchers to focus on the tweets localised within the territory of Paris Region-Petite Couronne (France) and to exclude those with repetitive geographic information due to Twitter business accounts. By retrieving all messages including keyword "Velib", we were able to virtually access all conversations that take place in the social network related to this topic and get a picture of the concerns of the users with regards to it.

Although sociodemographic characteristics of Twitter users are not available, the gender of the users was inferred through the *M3inference* tool [46], that relies on deep learning models, trained over a large sample of users from different countries. This method was proven to achieve high accuracy for all major European countries and languages. Based on the user name, short bio and picture, the tool returns the estimated probability of a user to be man or woman. We assigned a gender to users having a probability above a threshold of 0.9 for one of the two genders. In this way we ensure that we only have reliable estimation and leave gender unassigned for the remaining users. In total, we identified 3729 men users and 916 women users, while 3769 users remained unclassified. This allowed us to focus on the differences between men's and women's discourse. We are aware that this method has the limitations of not dealing with nonbinary gender and of not further characterising women according to other demographic characteristics. Unfortunately, these limitations are embedded in the method, which allows us to study a much larger sample of users but with coarser-grained granularity. Still, we believe that this analysis can add value as it encompasses a large sample of users.

We compared the lexical differences between tweets posted by men and women using a novel method for visualising and explaining pairwise comparisons between texts [47]. In particular, we created a word shift graph based on the difference between the relative frequency of each hashtag in the tweets written by men and women. Results (see Figure 8, Tables A6 and A7) highlight the hashtags exhibiting the largest gender differences, with left bars and right bars indicating hashtags that are more frequent in tweets written by men and women, respectively. We observe a politicised conversation around VELIB for both genders, given the references to Anna Hidalgo, the current mayor of Paris, and the municipal elections that were held in 2020. However, we note a large preference of men for critical hashtags (e.g., #velibgate, #lahonte), while women used the hashtag of the mayor's campaign more often (e.g., #hidalgo2020). In addition, women make more references to the strike (e.g., #greve) and the use of shared bikes to go to the office (e.g., #velotaf).

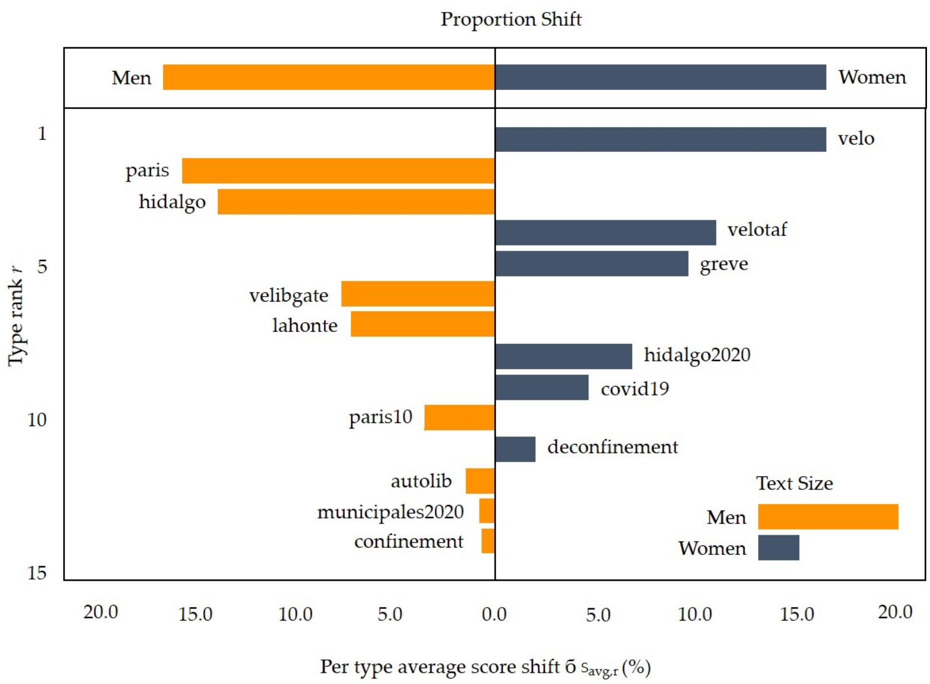

Figure 8. Word shift graph of tweets about VELIB written by men and women.

5. Discussion

The paper is based on an extended GIS-based analysis of Structured Open Data for maximising the diversity of the bike-sharing docking stations managed by VELIB in the territory of Paris Region-Petite Couronne (France), which were subsequently further characterised through Travel Demand Data, Onsite Observations, UESI Questionnaires and Social Media Data from Twitter. This was aimed at ensuring that the observed cases are representative of the different situations/locations of any single docking station.

In particular, GIS-based analysis aimed to assess the level of accessibility for the women users of the bike-sharing service managed by VELIB through the investigation of: (*i*) the level of urbanisation and attractiveness of the areas surrounding each docking station in terms of urban/periurban contexts, available services and facilities; (*ii*) the sociodemographic characteristics of the population living in the areas surrounding each docking station; and (*iii*) the level of connectivity of the bike-sharing service with other public transport services and cycling infrastructure. This enabled to identify and characterise a short list of twenty heterogeneous and nonadjacent docking stations.

The analysis of Travel Demand Data allowed researchers to correlate the overall level of accessibility for women of the selected docking stations with a series of Structured Proprietary Data (e.g., number of started and ended rentals, trip distance and duration, number of unique users, number of female users, etc). Results confirmed that the utilization/capacity ratio of the service is influenced by the level of accessibility of the docking stations. Moreover, the female user ratio related to the docking stations located in the territory outside the City of Paris is slightly lower compared to the one of the overall docking stations.

Then, the selected docking stations were further investigated through Onsite Observations focused on universal design indicators. Results showed that the majority of the docking stations display some negative connotations in relation to spontaneity of accessing the bike service and separate cycling infrastructure. Moreover, half of docking stations had negative features related to safe environment and perceived personal safety.

The analysis of UESI Questionnaires was focused on women's concerns, needs and expectations related to the VELIB's bike-sharing services. Results showed that the overall user satisfaction is strongly influenced by the booking and sign-up process, the proximity of stations, the possibility to use the services with children, the lack of cycling infrastructure and adequate lighting at the docking stations.

The analysis of disaggregated Social Media Data collected from Twitter has been applied to further investigate the opinion of the end users about the bike-sharing service managed by VELIB's. Results showed a politicised conversation around VELIB for both genders, while women where found to make more references to the lack of reliability of the service and on the possibility to use of shared bikes for commuting.

The presented data collection campaign represents a valuable example of the potential of this methodological approach. Indeed, the research work was aimed at investigating the possibility to analyse digitally widespread data sources as a valuable support of the activity of decision-makers by unveiling hidden patterns and specific target-users' needs. The diversity of the data collected and used for this study helps to build a narrative around the diversity of influences on cycling behaviour for women. However, the results of the analysis could be potentially biased by the impact of the lockdown period due to the COVID-19 pandemic. The timing of the data collection was also timely as Paris has seen a large increase in cycling during the COVID-19 pandemic. Therefore, the survey is likely to have captured a diversity of new and established users of VELIB's service.

6. Conclusions and Future Work

The objective of the paper was to identify an appropriate sample of docking stations to be further investigated through travel demand data, onsite observations, survey questionnaires and social-media data collection, focusing on the women users' needs and expectations as users of bike-sharing services. Results showed that women experience and use this transport mode differently than men, since they are more concerned with accessibility, safety and security, social constraints, weather and topography issues.

Future work will focus on the application of data analytics techniques based on Analytic Hierarchy Process (AHP) and Machine Learning techniques (Factor Analysis and Bayesian Networks). This is aimed at defining a hierarchical model for the design of parameters influencing the inclusion of women, by unveiling hidden mobility patterns through a gender-based intersectional analysis. Within the objectives of the H2020 DIAMOND project, the collected disaggregated data will be used to support the definition of guidelines and policies for the inclusion of women's needs in the design of future bike-sharing transport services.

Author Contributions: Conceptualisation, All Authors; methodology, All Authors; software, All Authors; validation, All Authors; formal analysis, All Authors; investigation, All Authors; resources, All Authors; data curation, All Authors; writing—original draft preparation, A.G.; writing—review and editing, A.G.; visualisation, All Authors. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and the General Data Protection Regulation (EU, 2016/679) and approved by the Ethics Committee of the H2020 DIAMOND project.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: All information gathered were treated as anonymous and confidential and can not be reproduced outside the H2020 DIAMOND project and associated scientific reports and publications.

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Abbreviations

The following abbreviations are used in this manuscript:

AHP	Analytic Hierarchy Process
API	Application Programming Interface
CFC	Cluster of Fairness Characteristic
FC	Fairness Characteristic
GIS	Geographic Information Systems
HQ	Highest Quintile
LQ	Lowest Quintile
UESI	Users Satisfaction Index questionnaires
VELIB	Syndicat Mixte Autolib et Velib Métropole

Appendix A. Results of Thematic Literature Review

Table A1. Results of thematic literature review focused on the women's needs and barriers related to the bike-sharing service.

Clusters of Fairness Characteristics	Accessibility & Spontaneity							Safety & Security						Social Constraints			Weather & Topography	
Fairness Characteristics	**Public Awareness**	**Sign-Up and Booking Process**	**Membership Cost**	**Spontaneity of Accessing Bike/Dock**	**Proximity of Docking Station**	**Traveling with Children/Carrying Things**	**Insufficient Infrastructure**	**Driver Behaviour**	**Separate Infrastructure**	**Harassment**	**Safe Environment and Personal Safety**	**Confidence/Experience**	**Traffic Safety**	**Subjective Norm (Peer Influence)**	**Socio-Cultural Constraints**	**Family Responsibilities**	**Weather**	**Topography**
[10]					•		•				•							
[26]	•	•	•	•	•		•				•		•					
[23]	•	•		•	•		•	•			•		•				•	•
[33]	•	•			•		•	•			•						•	•
[24]		•	•			•	•			•	•	•	•	•				
[48]	•	•	•	•	•	•	•			•	•	•	•	•	•			
[17]	•		•		•		•				•		•		•			
[49]			•	•	•	•	•			•	•		•	•	•			
[30]	•			•	•		•		•		•		•		•	•		
[42]					•		•						•				•	
[50]							•										•	
[27]	•	•	•		•	•	•								•			
[51]		•					•		•		•		•					
[52]	•		•		•						•							
[40]						•	•		•		•	•	•	•	•	•	•	•
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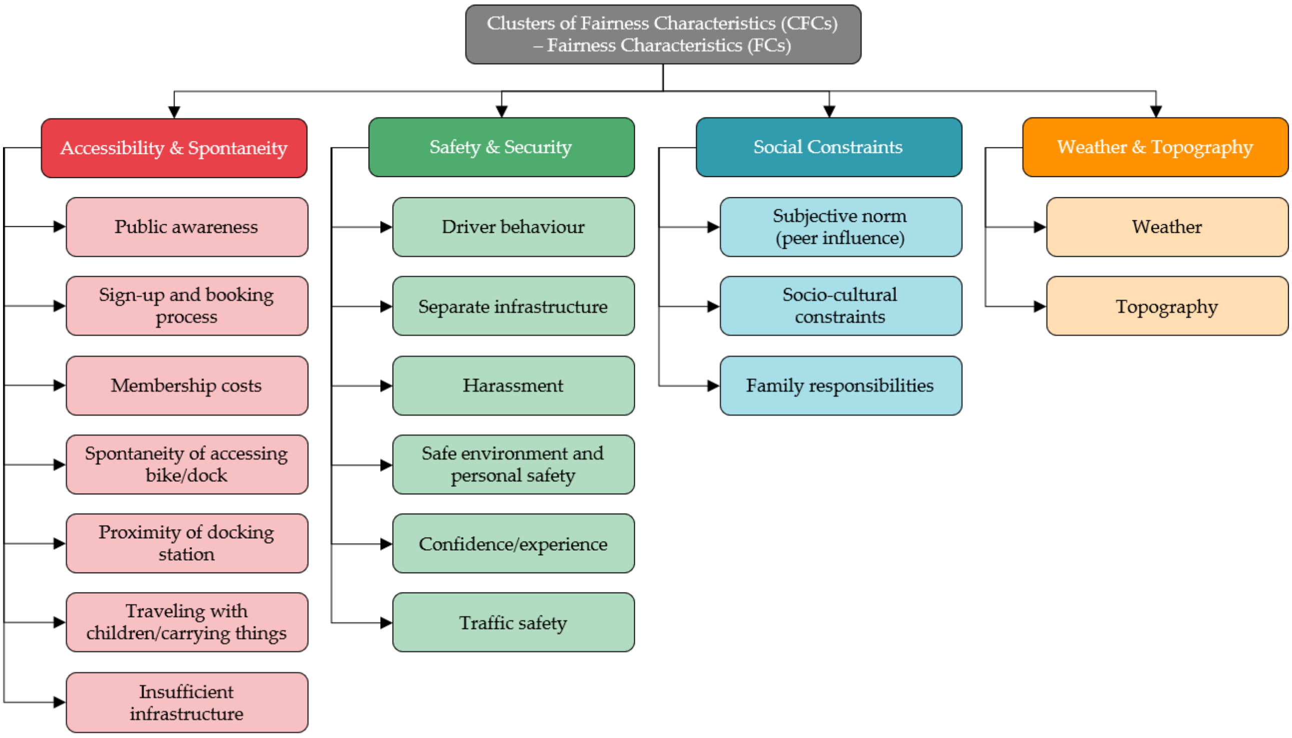

Figure A1. Hierarchy of Fairness Characteristic (FCs) focused on the women's needs and barriers related to the bike-sharing service.

Appendix B. Results of Structured Open Data Analysis

Table A2. Results of Structured Open Data analysis related to the short list of twenty heterogeneous and nonadjacent docking stations, characterised by positively (HQ-Highest Quintile) and negatively (LQ-Lowest Quintile) relevant characteristics.

VELIB's Docking Stations-HQ	UF	PoI	TDI	TP	FeP	EP	FoP	SDDI	PT	RI	MDI
Versailles-Claude Terrasse	0.124	640.314	0.824	4910.506	2730.490	3573.183	609.087	0.972	66.699	9.205	0.931
Square Rene Viviani-Montebello	0.122	1655.296	0.849	3935.356	2177.918	3013.765	627.428	0.950	60.931	12.105	0.952
Godot de Mauroy-Madeleine	0.318	975.057	0.940	3462.193	1815.086	2979.793	540.470	0.906	122.906	4.326	0.872
Charenton-Place du Col Bourgoin	0.132	1207.598	0.956	6405.452	3476.291	5427.468	826.026	0.986	64.234	9.558	0.930
Boyer-Barret-Raymond Losserand	0.064	704.717	0.839	3164.285	1750.472	2658.447	518.904	0.868	50.337	18.373	0.954
Cite Riverin-Chateau d'Eau	0.184	1095.905	0.927	5491.507	2901.320	4429.330	1130.040	0.986	77.358	27.462	0.989
Faubourg Poissonniere-Delta	0.161	1178.711	0.932	6269.308	3098.762	5230.047	1142.367	0.987	101.864	13.024	0.985
Halles-Bourdonnais	0.223	1937.966	0.957	5471.170	2765.326	4410.067	572.353	0.974	156.747	18.667	0.992
Guy Maquet-Saint-Ouen	0.079	669.681	0.859	4360.723	2394.690	3573.505	518.347	0.952	64.808	9.980	0.938
Mathis-Flandre	0.060	904.426	0.926	3331.727	1609.595	2911.729	871.379	0.933	57.424	8.499	0.883
VELIB's Docking Stations-LQ	**UF**	**PoI**	**TDI**	**TP**	**FeP**	**EP**	**FoP**	**SDDI**	**PT**	**RI**	**MDI**
Sorbonne-Ecoles	0.005	129.452	0.039	24.518	6.996	19.345	11.266	0.070	8.091	0.000	0.089
Mahatma Gandhi	0.061	299.327	0.115	959.038	491.381	807.927	163.861	0.167	12.737	0.197	0.110
Serrurier	0.100	77.173	0.115	902.531	465.187	724.253	198.472	0.178	10.290	0.000	0.096
Louis Pasteur-Albert Petit	0.033	21.345	0.028	14.219	2.473	10.436	10.633	0.070	9.852	1.199	0.119
Clichy-Douai	0.077	44.214	0.032	530.196	270.927	460.974	32.074	0.093	12.380	2.349	0.163
Chateau de Vincennes	0.070	47.707	0.034	539.498	285.133	431.631	70.883	0.102	14.032	0.000	0.111
Gare de Lyon-Van Gogh	0.037	207.114	0.062	492.666	261.482	373.657	50.579	0.095	14.794	0.000	0.115
Porte de la Plaine	0.116	34.618	0.151	843.260	417.900	679.971	18.744	0.166	14.836	0.000	0.115
Gare RER les Grasillons	0.061	369.616	0.118	730.718	386.366	606.015	110.422	0.126	5.517	0.000	0.081
Rond-Point Rhin et Danube	0.157	10.099	0.111	986.328	524.400	741.108	88.984	0.140	13.465	0.000	0.109

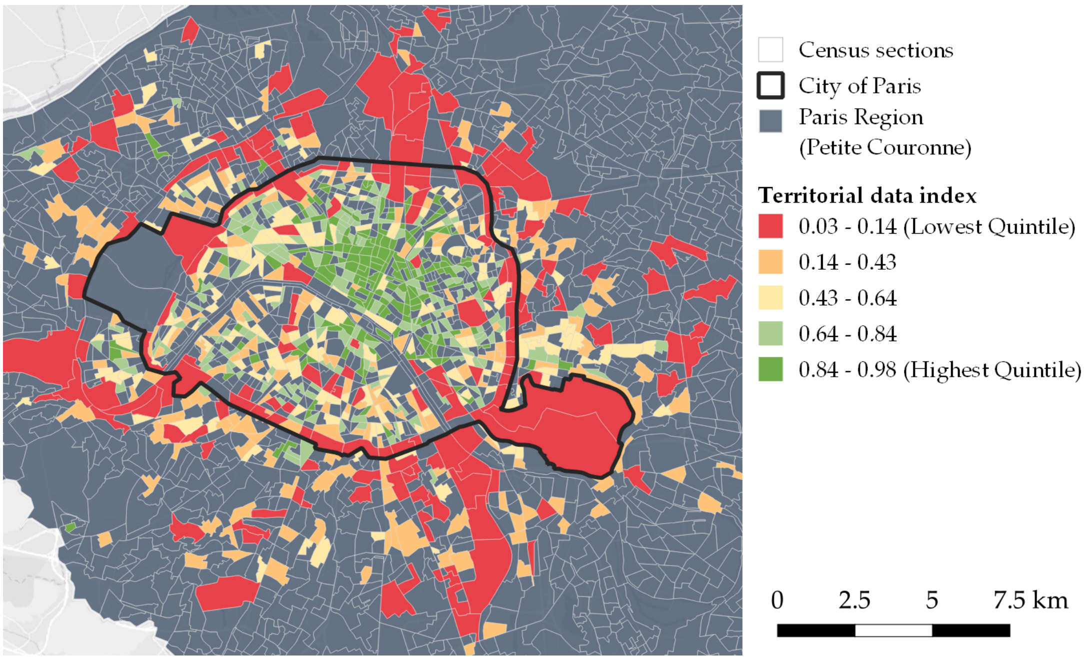

Figure A2. Quintile frequency distribution of Territorial Data Index (TDI) related to the census sections of Paris Region-Petite Couronne (France) containing at least one VELIB's bike-sharing docking station.

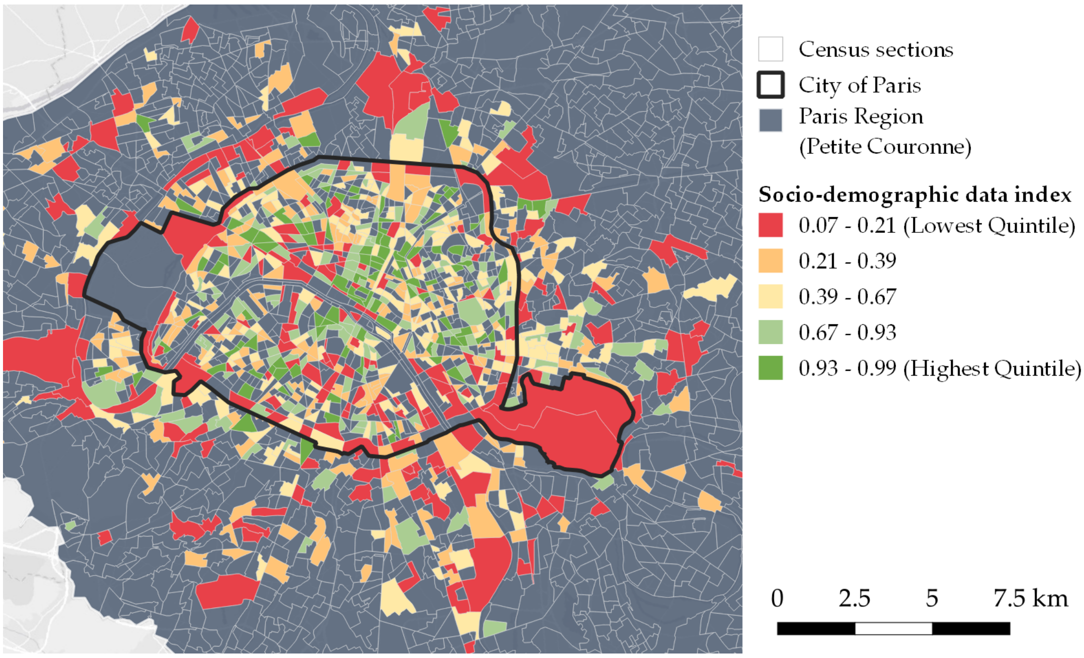

Figure A3. Quintile frequency distribution of Socio-demographic Data Index (SDDI) related to the census sections of Paris Region-Petite Couronne (France) containing at least one VELIB's bike-sharing docking station.

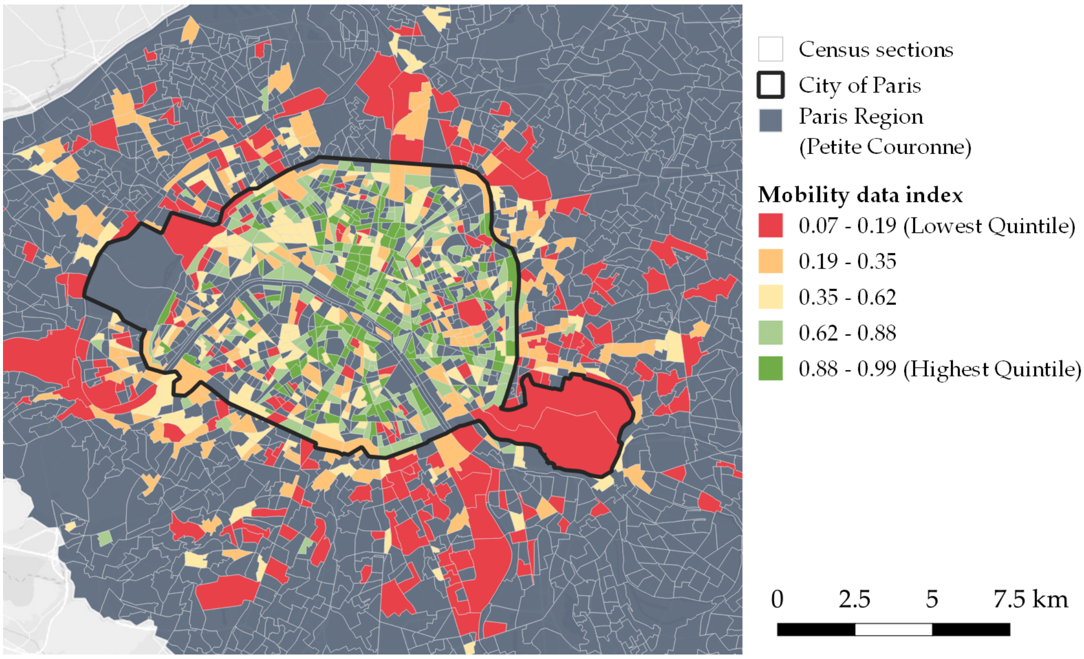

Figure A4. Quintile frequency distribution of Mobility Data Index (MDI) related to the census sections of Paris Region-Petite Couronne (France) containing at least one VELIB's bike-sharing docking station.

Appendix C. Results of Travel Demand Data Analysis

Table A3. Results of Travel Demand Data analysis related to the short list of twenty heterogeneous and nonadjacent docking stations, characterised by positively (HQ) and negatively (LQ) relevant characteristics.

VELIB's Docking Stations-HQ	**No. Bikes**	**Started Rentals**	**Started Rentals (% e-Bikes)**	**Ended Rentals**	**Ended Rentals (% E-Bikes)**	**Distance [m]**	**Duration [min]**	**Utilization/Capacity ratio**	**Unique Users-Total**	**Unique Users-Ratio Female Users**	**Unique user ratio**
Versailles-Claude Terrasse	46	1628.583	38%	1429.500	38%	3304.741	25.381	66.480	762.083	27%	47%
Square Rene Viviani-Montebello	34	3244.545	30%	2716.818	31%	2759.284	24.769	175.334	1901.000	31%	59%
Godot de Mauroy-Madeleine	22	2859.917	33%	2452.667	34%	2636.323	22.464	241.481	1726.167	29%	60%
Charenton-Place du Col Bourgoin	35	4374.417	29%	3428.000	30%	2329.506	20.773	222.926	1870.583	32%	43%
Boyer-Barret-Raymond Losserand	23	1161.583	38%	1065.333	38%	2879.409	22.477	96.822	519.417	32%	45%
Cite Riverin-Chateau d'Eau	18	2428.250	31%	2111.083	31%	2128.001	20.017	252.185	1241.917	31%	51%
Faubourg Poissonniere-Delta	36	1349.900	49%	1228.700	47%	2550.902	19.467	71.628	870.200	31%	64%
Halles-Bourdonnais	20	3038.750	41%	2586.500	41%	2765.714	24.122	281.263	1893.875	27%	62%
Guy Maquet-Saint-Ouen	53	2716.083	38%	2308.167	38%	2574.237	21.142	94.797	1306.167	29%	48%
Mathis-Flandre	55	3388.917	42%	2757.583	40%	2731.655	24.463	111.755	1503.917	29%	44%
VELIB's docking stations-LQ	"	"	"	"	"	"	"	"	"	"	"
Sorbonne-Ecoles	50	2888.750	32%	2485.500	33%	2618.003	21.121	107.485	1681.833	30%	58%
Mahatma Gandhi	26	627.571	44%	578.857	45%	4263.677	61.438	46.401	438.571	33%	70%
Serrurier	18	584.250	65%	530.667	63%	3288.454	35.791	61.940	235.833	25%	40%
Louis Pasteur-Albert Petit	31	341.250	60%	290.667	60%	3978.669	54.266	20.384	119.917	23%	35%
Clichy-Douai	32	4630.000	54%	3386.818	48%	2455.970	18.762	250.526	2664.182	29%	58%
Chateau de Vincennes	52	3272.750	36%	2221.000	38%	3103.751	25.178	105.649	1678.417	30%	51%
Gare de Lyon-Van Gogh	51	3163.417	27%	2641.917	28%	2596.127	21.381	113.830	1406.917	26%	44%
Porte de la Plaine	35	594.750	35%	547.500	35%	2505.084	23.013	32.636	263.167	27%	44%
Gare RER les Grasillons	22	656.667	55%	558.000	54%	3697.466	57.710	55.212	197.833	24%	30%
Rond-Point Rhin et Danube	53	1192.083	40%	1021.417	40%	3605.020	25.380	41.764	502.667	27%	42%

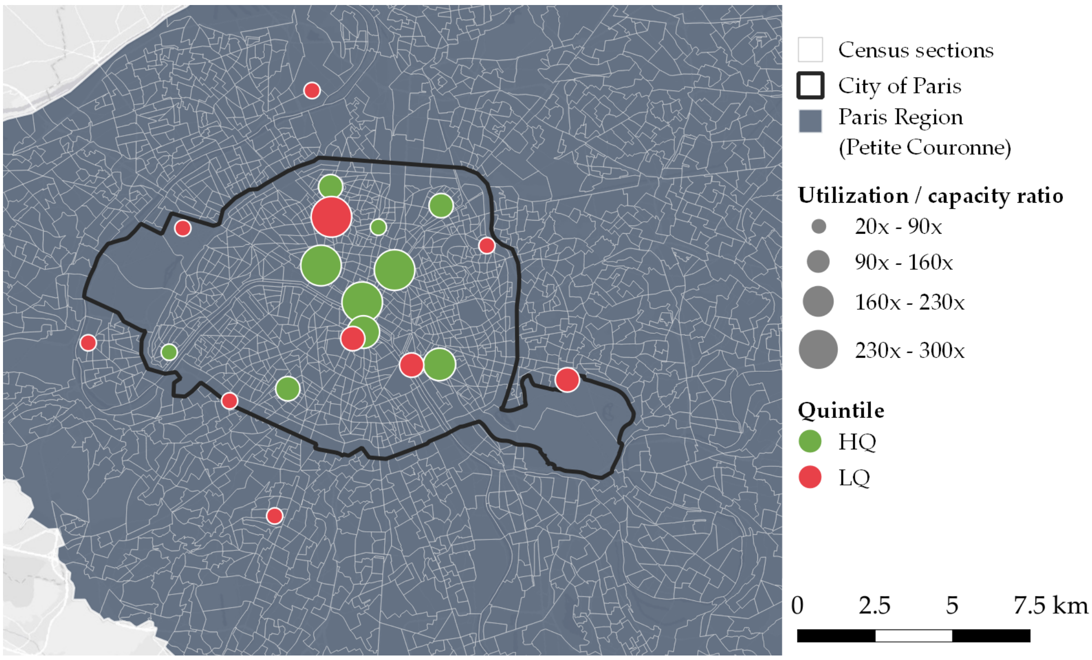

Figure A5. The ratio between the sum of started and ended rentals, over the capacity of the selected docking stations.

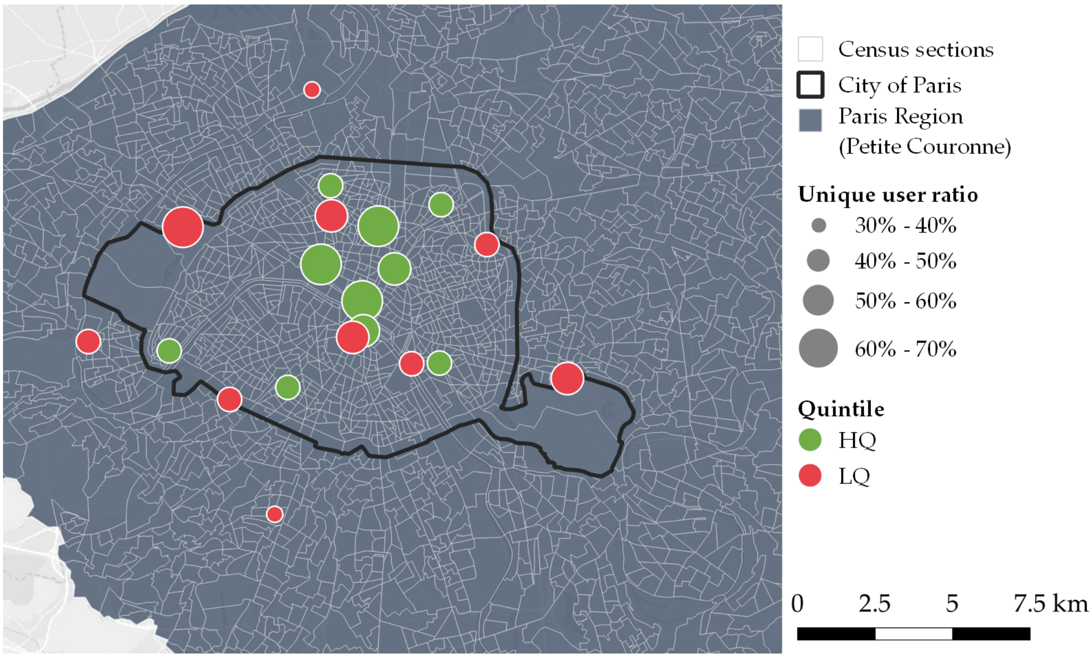

Figure A6. The ratio of unique users over the number of started rentals of the selected docking stations. Lower values show a higher usage from the same users, indicating non occasional patterns.

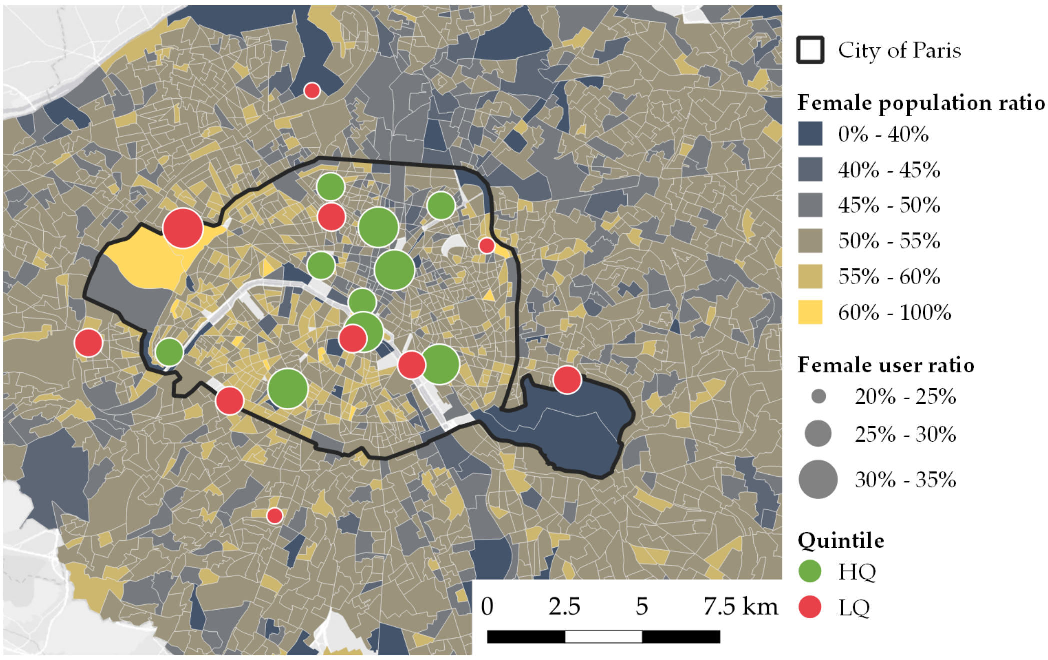

Figure A7. The ratio of female users over the overall users number of the selected docking stations. The background of the map shows the female population ratio of each census sections of the Paris Region-Petite Couronne (France).

Appendix D. Onsite Observation Checklist

Table A4. The CFCs, FCs and items included in the onsite observations checklist focused on the evaluation of infrastructure design and surrounding context characteristics related to the selected bike-sharing docking stations.

CFs	FCs	Checklist Items	Record
Accessibility & Spontaneity	Spontaneity of accessing bike/dock	Percentage of bikes recorded during the observation	%
	Insufficient infrastructure	Accessibility of the docking station for women with children and disability	Yes/No
		Presence of shelter, toilets, female only toilets, changing facility	Yes/No
	Travelling with children and carrying things	Presence of bikes with a child seat, child trailer or carriages for children	Yes/No
		Presence of bikes with cargo trailers for carting goods or luggage	Yes/No
	Public awareness	Percentage of female users	%
Security & Safety	Separate infrastructure	Presence of a cycle lane nearby the docking station	Yes/No
		Presence of a separate cycle infrastructure	Yes/No
	Safe environment and personal safety	Adequate lighting condition	Yes/No
		Presence of CCTV devices at the docking station	Yes/No
		Presence and visibility of CCTV cameras on the cycle network	Yes/No
		Adequate lighting condition of the cycle lanes	Yes/No
		Safety of the cycle paths and lanes for cycling at night	1-5
		Percentage of users wearing hi-visibility cycling gear	%
		Percentage of worthy bikes among the fleet	%
Weather & Topography	Weather	Weather friendly cycle network nearby the docking station	Yes/No
		Availability of cycling raincoats for users	Yes/No
	Topography	Percentage of e-bikes recorded during the observation	%

Appendix E. Results of UESI Questionnaires Analysis

Table A5. Results of the regression analysis focused on the Users' Satisfaction Index Questionnaires (code '*': regression is significant at the 0.01 level; R^2: 0.306, Adjusted R^2: 0.2865, *p*-value: <0.000).

Variable	Estimate	Std Error	*t*-Test	*p*-Value
Intercept	−0.08	0.777	−0.103	0.918
Subscription_type: Please, could you indicate the type of subscription pass you have?	0.10	0.041	2.446	0.014
Signing_up: Signing-up for bike share membership is very easy and flexible.	0.19	0.050	3.874	0.000 *
Booking_a_bike: I find it easy to book a bike for a bike-sharing trip	0.10	0.039	2.533	0.011
Docking_stns_near: There are always docking stations near	0.18	0.047	3.864	0.000 *
Network_safety: The existing cycle network is safe enough to cycle with children.	0.12	0.038	3.258	0.001 *
Neighb_cycling: I feel very safe cycling in my neighbourhood	0.10	0.042	2.412	0.016
Lowering_speeds: Lowering traffic speeds on roads with cycle lanes will make me feel safer to cycle/use bike share	0.10	0.030	3.223	0.001 *
Legitimate_transport: Cycling or bike sharing are socially acceptable as legitimate forms transport	0.15	0.047	3.158	0.001 *
Cycling_with_kids: Trips involving children are (will be) possible to make with bike sharing services	−0.15	0.038	−4.010	0.000 *
Cycling_benefit: Are you familiar with the benefit of cycling?	1.02	0.564	1.809	0.071
Friendly_infrastructure: Are the existing cycling infrastructure (network and facilities) cycle friendly and encourage cycling?	−0.22	0.108	−2.017	0.044

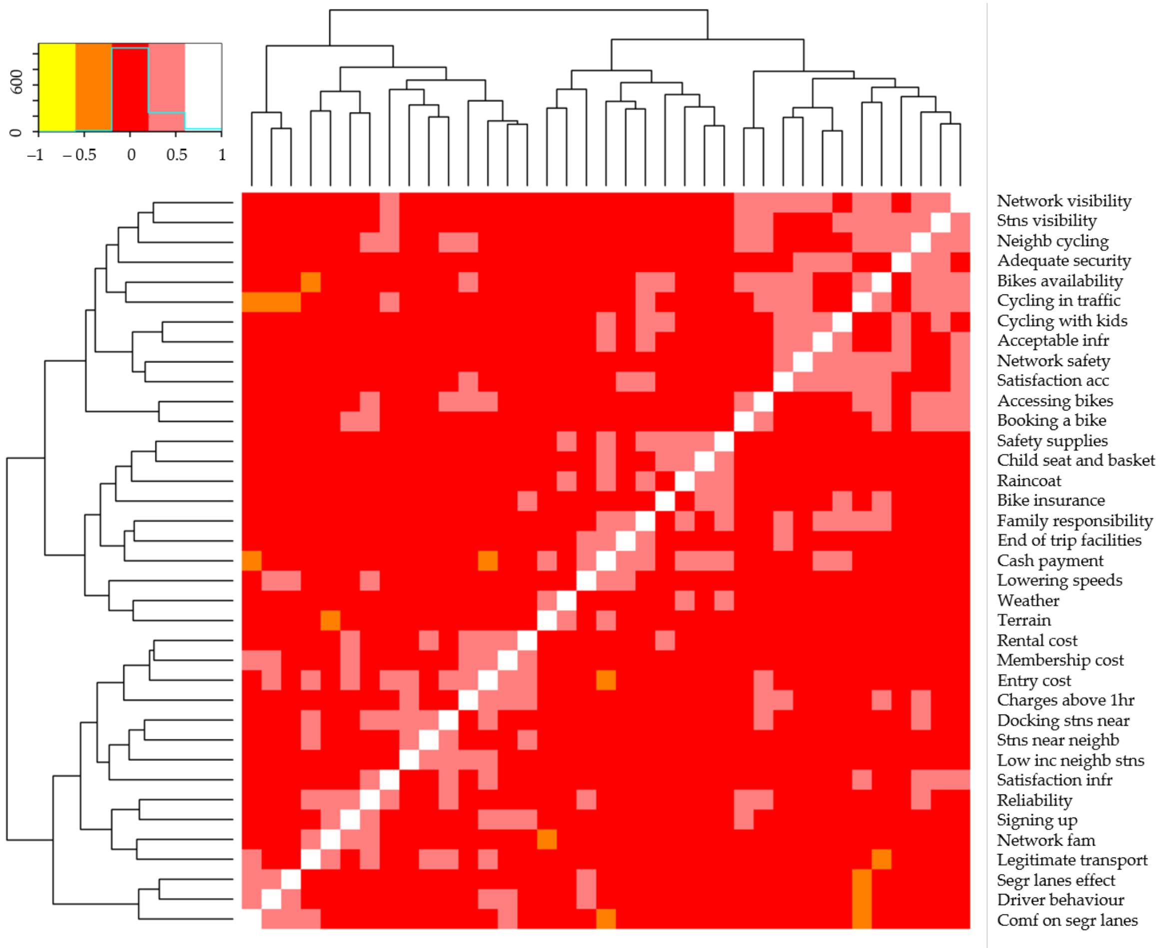

Figure A8. Correlation matrix for the variables considered in the Users' Satisfaction Index Questionnaires.

Appendix F. Results of Social Media Data Analysis from Twitter

Table A6. Top-3 tweets ordered by number of likes and retweets for each hashtag, produced by male users.

Hashtag	Text	Likes	Retweets
#paris	le premier adjoint de la maire de #paris vient surveiller lui-même les pistes cyclables rue saint-antoine à #velib…	82	19.0
	#paris la dernière idée de bidonville, mare à moustiques, égout à ciel ouvert, vallée du crack, cimetière à velib'…	63	36.0
	en velib avec mon masque de la ville de @paris mais ils sont bien ces masques #covid19 #paris17…	35	11.0
#hidalgo	le velib' #hidalgofiasco par excellence ! ou comment détruire un service plébiscité par les parisiens, qui faisai…	32	15.0
	drôle d'approche du point. la dynamique du vélo à paris a été lancée par delanoë puis #hidalgo a failli planter l'i…	26	10.0
	encore merci à anne #hidalgo qui par haine personnelle envers jcdecaux a infligé* aux parisiens le pollution visuel…	22	11.0
#velibgate	quel symbole les deux stations @velib autour de l'hôtel de ville buguées ... #velibgate	2	2.0
	station 10036 7 velib, 6hs #velibgate	1	1.0
	#velib #velibgate #onsefoutdenous #scandale @parisjecoute @anne_hidalgo merci velib pour cette nouvelle journée qu…	1	1.0
#lahonte	#velib #lahonte. au 16ème jour d'utilisation, pas eu un seul velib qui fonctionne correctement. ce matin, après ceu…	4	2.0
	#velib#lahonte. ce matin, station marignan françois 1er pleine. aucun vélo retirable, icône du sablier....	3	3.0
	#velib#lahonte. ce soir. a radio france kennedy, 8 vélos en station, aucun utilisable, ou en pause. j'ai pu prendre…	1	1.0
#autolib	les 2 plus beaux services rendus aux parisiens : autolib' et velib' cassés par @anne_hidalgo. pourtant 2 services d…	66	42.0
	@anne_hidalgo : "six ans, en fait, c'est court"...mais bien suffisant pour : ✔ faire disparaître autolib ✔ lai…	50	20.0
	hallucinant ! après autolib, velib, les panneaux publicitaires, la dette abyssale, l'insécurité, la saleté inégalée…	46	24.0
#paris10	ce qui est extraordinaire, c'est qu'il y a cinq stations @velib place de la république #paris10 et que le seul vélo…	1	1.0
	station pleine de @velib inutilisables rue des petites écuries #paris10, quartier rempli de bagnoles depuis la grèv…	1	1.0
	ce qui est extraordinaire, c'est qu'il y a cinq stations @velib place de la république #paris10 et que le seul vélo…	0	0.0
#municipales2020	dernier dimanche avant les #municipales2020 si tout n'est pas à jeter de la mairie sortante, l'explosion de la dett…	23	11.0
	#aimerparis aime le peuple de paris. #municipales2020	17	12.0
	a partir de ce lundi, la cellule #municipales2020 du @le_parisien publiera chaque jour un fact-checking sur une d…	9	5.0
#confinement	a compter d'aujourd'hui et pour toute la période de confinement, les trajets à @velib deviennent gratuits pendant 1…	108	46.0
	toutes les courses #vélib de moins d'une heure gratuites pendant le confinement via @le_parisien	37	23.0
	je trouve ça top qu'on développe le vélo en alternative au métro à paris au #deconfinement . mais rassurez-moi,…	14	3.0

Table A7. Top-3 tweets ordered by number of likes and retweets for each hashtag, produced by female users.

Hashtag	Text	Likes	Retweets
#velo	hello @anne_hidalgo, ça faisait longtemps continue à dire que c'est chouette de développer le vélo mais: 1/o...	51	22.0
	bravo @parisenselle @mdbidf: 1ère victoire des municipales: le soutien massif au #velopolitain. poursuivons l...	22	8.0
	les convictions c'est bien mais ça ne suffit pas. après 6 ans de mandat, on attendait des résultats! #velib, #velo,...	13	6.0
#velotaf	50 km de pistes cyclables supplémentaires à #paris d'ici à l'été! #velotaf #velib #velo	4	3.0
	#velotaf #veloinparis #velo #velib	2	2.0
	station 16026 ranelagh 100% des vélos présents dégonflés déraillés ..... l @velib #velotaff	2	1.0
#greve	mon seul et unique moyen de me déplacer en cette période de #greve, le @velib ! 1/ après 8 tentatives pour diverses...	13	4.0
	pourquoi la grève nous transforme-t-elle en sauvages dans les transports ? #greve #ratp-via @20minutes	9	4.0
	#velib à la rescousse! #greve	6	4.0
#hidalgo2020	il n'est plus possible de refaire confiance à l'équipe menée par #hidalgo2020	1	3.0
	c est pas grave les bobos parisiens laisseront la dete aux générations a venir #hidalgo #hidalgo2020 #cavous...	0	4.0
	à aucun moment on n'a pensé aux parisiennes et parisiens lors de ce carnage. #hidalgo2020	0	0.0
#covid19	#covid19 #lemondedapres	2	3.0
	@anne_hidalgo le #covid19 est l'opportunité de développer l'usage du vélo. il faut que les @velib soient gratuits e...	0	0.0
#deconfinement	ça va être quelque chose.. comme une impression d'assister au tour de france. #deconfinement #tourdefrance #velo...	0	0.0
	les velib sont prêts!! le post #covid-19 made in #paris19 #paris #hidalgo #deconfinement	0	0.0
	#deconfinementjour28 le retour au bureau qui fait trop de bien, trajet en @velib, réunion d'équipe dans la plus gra...	0	0.0

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Short Biography of Authors

Dr. Andrea Gorrini is an environmental psychologist with experience in human behaviour in transport systems, pedestrian crowd dynamics and walkability. Since 2019, he collaborates with Systematica as Transport Research Consultant. He oversees research and development activities related to the identification, collection and exploitation of different mobility data sources through GIS, data analytics, behaviour tracking tools and questionnaires. He is author of several scientific papers and he has experience of international research projects.

Rawad Choubassi currently acts as a Director and Board member of Systematica where he leads planning and research projects on mobility in urban environments and complex buildings. Choubassi has gained previous experience, prior to joining Systematica in 2008, through intensive work on largescale projects during his work with Arata Isozaki (Tokyo), Kliment-Halsband Architects (New York) and others. He leads a team of multidisciplinary consultants for expanding the limits of the science behind mobility engineering dynamics on every scale, Regional, National, Urban, etc.

Federico Messa joined Systematica in 2016. He is an Architect since 2021 and he has been active as a transport consultant on a diverse set of projects, ranging from territorial studies to masterplans and complex buildings mobility strategies. He is also involved in architecture and mobility research studies, mainly related to urban dynamics, mobility data analysis and visualization, project performance analysis and spatial analysis.

Professor Wafaa Saleh is the Chair of the international committee of the Travel Demand Management (TDM) Symposium, a member of the scientific committee of international symposium of transportation reliability (INSTR) and the author and coauthor of over 100 publications in national, international journals and conferences. Wafaa is a Chartered Engineer with over 30 years' experience in teaching, research and practice. The main focus of her research interests includes travel demand management, modelling travel behaviour, accident analysis and investigations, transport and the environment and traffic engineering.

Dr. Augustus Ababio-Donkor is a Researcher at the Transport Research Institute, Edinburgh Napier University. Augustus had his degree in Geodetic Engineering and his Master and PhD degrees are in Transportation Planning and Modelling. Augustus was a Senior Engineer at the Department of Urban Roads (DUR), Ghana until 2016. His research interests include travel demand modelling, behavioural economics and behavioural based travel modelling.

Dr. Maria Chiara Leva is the cochair of the technical committee on Human Reliability for the European Safety and Reliability Association, former chair of the Irish Ergonomics Society and cochair of the scientific steering group for the first Symposium on Human Mental Workload (H-Workload). Dr. Leva has more than 60 publications on Human Factors, Operational Risk Assessment and Safety Management in Science and Engineering Journals, she is a member of the editorial board for two of those journals. She is a Lecturer in Dublin Institute of Technology in the College of Environmental Health, she is also a visiting research fellow in the Centre for Innovative Human systems both in Trinity College Dublin.

Dr. Lorraine D'Arcy is a Senior Lecturer in the School of Transport Engineering, Environment and Planning at TU Dublin. A Civil Engineer with a PhD in exercise and environmental psychology, her research explores neighbourhood features that deter people from walking, cycling or using public transport which result in higher car dependency, social isolation and a more sedentary population, all which impact on population health and carbon emissions. In TU Dublin she has been instrumental in setting up a new part-time MSc in Sustainable Transport and Mobility aimed at upskilling practitioners and those interested in a career in sustainable mobility.

Francesco Fabbri is a third year PhD student at Pompeu Fabra University, Barcelona, in the Web Science and Social Computing Group (WSSC). He is supported by the Vicente López scholarship, awarded by Eurecat, Research Center in Catalunya. His work focuses on analyzing and mitigating unintended and potentially harmful effects embedded in online social platforms (e.g., social networks, music streaming platforms or rental marketplaces). He obtained a master's degree in Data Science and a bachelor's degree in Statistics from Sapienza University, Rome.

Dr. David Laniado is Senior research scientist in Computational Social Science, in the Data Science and Big Data Analytics unit at Eurecat. His main research interest is the study of patterns of online conversation and discussion, controversies, collective dynamics and deliberation processes in peer production communities, gender differences and sociotechnical aspects of online interactions.

Dr. Pablo Aragón is a research scientist and adjunct professor at Universitat Pompeu Fabra. He is interested in computational social science and social computing through interdisciplinary and participatory approaches to characterize and facilitate participation, deliberation, and collaboration in online platforms, primarily civic technologies and social media. These interests have led him to participate in EU-funded research projects like DECODE, focused on free open-source infrastructures to increase data sovereignty of European citizens; or D-CENT, committed to transforming democratic decision-making through free open source digital technologies.