The spatial reconfiguration of parking demand due to car sharing diffusion: a simulated scenario for the cities of Milan and Turin (Italy)

Original
The spatial reconfiguration of parking demand due to car sharing diffusion: a simulated scenario for the cities of Milan and Turin (Italy) / Diana, M., Chicco, A.. - In: JOURNAL OF TRANSPORT GEOGRAPHY. - ISSN 0966-6923. - STAMPA. - 98:(2022), p. 103276. [10.1016/j.jtrangeo.2021.103276]

Availability:
This version is available at: 11583/2963792 since: 2022-05-16T15:17:28Z

Publisher:
Elsevier Ltd

Published
DOI:10.1016/j.jtrangeo.2021.103276

The spatial reconfiguration of parking demand due to car sharing diffusion: a simulated scenario for the cities of Milan and Turin (Italy)

Marco Diana, Andrea Chicco

12th November 2021

Preferred citation: this document may be cited directly referring to the above mentioned final published version:

Diana, M. & Chicco, A. (2022) The spatial reconfiguration of parking demand due to car sharing diffusion: a simulated scenario for the cities of Milan and Turin (Italy). *Journal of Transport Geography*, vol. 98, 103276, doi:10.1016/j.jtrangeo.2021.103276.

The spatial reconfiguration of parking demand due to car sharing diffusion: a simulated scenario for the cities of Milan and Turin (Italy)

Abstract

One of the most expected benefits from the diffusion of car sharing services in urban areas is the decrease of car ownership levels and related impacts in terms of vehicle miles travelled, greenhouse gas emissions, and space consumption. Unlike previous studies in which the effects on public spaces are related to a reduced number of private vehicles, in this paper we present a method to analyse the spatial variation in parking demand in a city with the joint consideration of the kind of parking actually in use. A distinction is made between dedicated parking areas from on-street parking.

A trip-level analysis approach is then followed, where car ownership is an exogenous variable and modelling scenarios on modal diversion patterns for different origin-destination pairs are examined. Travel demand models are calibrated and validated on a stated-preferences travel survey carried out in Turin in 2016 and applied on a revealed-preferences travel survey distributed in the cities of Milan and Turin (Italy) in May 2019. Both surveys were administered to a representative sample of the population living in the cities, therefore results can be generalised.

The ideal scenario resulting from modal diversion patterns show that free-floating car sharing might produce positive and negative impacts on both on-street and on-surface dedicated parking areas. In particular, more positive impacts are expected on daily parking events in central areas, where mobility attractors are concentrated. On the contrary, higher negative impacts on both on-street and dedicated parking events might be encountered in more peripheral areas.

Keywords: *car sharing, parking policy, sustainability, multimodality*

1 Introduction

Cities throughout the world have witnessed a steady increase in both the offer of car sharing services and in the number of car sharing members during the last decade. In Europe, the car sharing market has risen from 10,000 shared vehicles and 330,000 members in 2008 to about 60,000 shared vehicles and 6.7M members in 2018 (Shaheen and Cohen, 2020). Through car sharing services (also known as car clubs in the UK), individuals gain the benefits of private vehicle use without the costs and responsibilities of ownership. Rather than owning one or more cars, car sharing members access to a fleet of shared cars, which are generally owned by the service provider, on an as-needed basis (Shaheen et al., 2019). Members pay an all-inclusive fee for the usage of the vehicles as a function of the rent duration, the travelled distance or both. The fee includes all costs: the vehicle insurance, maintenance, fuel, the use of paid-parking and, in some cases, the access to traffic-restricted areas. The service can be associated to a short term car rental, in which the customer does not necessarily get in direct contact with the service provider.

From the point of view of the general interest, the most important expected benefit from the diffusion of such services in urban areas is the decrease of car ownership levels and of related impacts in terms of environmental footprint and space consumption.

A massive body of research has investigated to which extent and under which conditions car sharing can effectively help in reducing the number of privately owned cars in cities. Results are somewhat controversial and highly dependent on many factors, such as the period in which the analysis is carried out, the operational characteristics of the analysed car sharing service and the study context. Their thorough analysis is outside the scope of the present work, but it can be said that, in general terms, car sharing members report a reduction in household vehicle holdings after joining the service (Becker et al., 2018; Cervero et al., 2007; Jochem et al., 2020; Ko et al., 2017; Martin and Shaheen, 2016). Some differences are encountered by analysing different cross-sectional studies, where the impact is measured in a specific time-point. The longitudinal study developed by Cervero et al. (Cervero et al., 2007, 2002) showed that the impact of car sharing might change over time. Moreover, depending on the service maturity, results might be affected by the presence of early adopters (Firnkorn and Shaheen, 2016).

Concerning car sharing operational characteristics, two main schemes can be found: station-based (roundtrip or one way) and free-floating (Martin and Shaheen, 2016; Schmöller et al., 2015). Members of roundtrip station-based schemes, in which shared car are picked up and returned at the same dedicated location, apparently report stronger impacts on car ownership reduction than free-floating ones, in which cars can be used and parked in any space where the parking is allowed (on-street and dedicated parking areas, both free and paid parking) within an operational area (Becker et al., 2017; Giesel and Nobis, 2016; Namazu and Dowlatabadi, 2018). Furthermore, members living in urban areas report a higher propensity to reduce car ownership than members living in suburban areas (Clewlow, 2016), showing the importance of the built environment features.

Car ownership changes are important to assess because a reduction in the number of privately owned cars in a city would lead to a decrease of the parking pressure in denser areas (Efthymiou et al., 2013; Millard-Ball et al., 2005), and therefore to a potential reduction of parking spaces that could rather be used to increase the quality of the built environment (e.g. using such spaces for green areas or larger sidewalks) or make room for environmental friendly travel modes (e.g. cycle paths). Yet, such variation in parking demand is often quantified by existing research only through the computation of the number of private cars that are substituted by a single shared car.

Considering the state of the art in the research in this sector, such ratio can lie anywhere between 1:1 and 23:1, again depending on local conditions, kind of service, and on the specific methodology that is followed for its computation (6t-bureau de recherche, 2016; Lane, 2005; Martin et al., 2010; Martin and Shaheen, 2016; Shaheen and Cohen, 2007). While these figures have an appealing and intuitive meaning that can be easily communicated to stakeholders and in public debates, e.g. to promote car sharing, they only provide a rough estimation on the average positive impact to relieve the car parking pressure in a city.

As pointed out by (Stasko et al., 2013), not all car ownership reductions have in fact the same impact on parking demand. Indeed, what really matters is in which neighbourhoods the relief in parking pressure is taking place. Less dense residential suburbs might be well equipped with parking lots with little opportunities for a different use of such spaces, whereas shortages might be evident near mobility attractors in denser districts. Additionally, impacts are also affected by the kind of parking that would eventually be substituted, i.e. on-street parking versus parking in dedicated on-surface areas or in private grounds. Clearly, larger benefits for cities are expected in the former case, especially in European cities with large historical districts and narrow streets. Those issues related to where and which kind of parking events can be saved through the implementation of a car sharing service have been little considered in the available literature, to the best of the Authors' knowledge. Only few studies attempted to estimate the potential savings of parking spaces according to the parking type (on-street, dedicated parking area) and in different city areas (Balac et al., 2017; Stasko et al., 2013; Tchervenkov et al., 2018).

Acknowledging such research gaps, the present paper will propose a method to analyse the spatial variation in parking demand in a city by jointly considering the modal diversion patterns towards car sharing at the individual trip level and the kind of parking actually in use. Instead of estimating the impact on parking spaces related to a reduction in car ownership reported by car sharing members, in this study we attempt to quantify the effects on parking demand associated to the adoption of car sharing for a specific trip considering the generic population. This approach therefore is not focusing on the reduction in car ownership level that might be related to the car sharing membership.

To do so, trips data collected within a revealed-preferences travel survey administered to a representative sample of the population is used to define two car sharing scenarios, namely the current and the ideal scenario. Whereas the overall travel demand is kept constant across scenarios, the car sharing demand is changed according to a new service configuration that would maximise the reduction of pollutant emissions, which is detailed in a previous study (Chicco and Diana, 2021). Related changes in parking demand are estimated and geographically matched by considering respondent parking habits together with the reported trip origin and destination. This methodology is then applied to a case study on the two cities in Northern Italy, namely Milan and Turin, which represents two main car sharing markets in Italy. The outcome is useful to understand what kind of parking are interested by a variation in car sharing demand and where they are located within the city landscape.

The remainder of this paper is structured as follows. Section 2 presents a literature review on car sharing impacts on parking demand. Section 3 describes the two study areas and data collection activities. Section 4 details the methods used in this research. Results and discussion are presented in Section 5. Section 6 concludes the paper.

2 Background

2.1 Changes in parking demand as consequence of car sharing impacts on car ownership

As previously introduced, several studies have quantified the variation in parking demand through the computation of the number of private cars that are substituted by a single shared car.

The study carried out in Philadelphia (Pennsylvania) by Lane (Lane, 2005) aimed at evaluating the impacts of the PhillyCarShare on its members after one year into the program. Through member online surveys and detailed usage data, the author found that PhillyCarShare membership was associated with dramatic reductions in car ownership, which directly related to a reduction in local parking demand. In particular, the study showed that each car sharing vehicle has removed an average of 23 private vehicles from the roads, ratio that was obtained by considering members who gave up a car and members who decided not to acquire a vehicle.

Reported benefits in terms of vehicle ownership for Europe and North America are summarized from a range of studies in (Shaheen and Cohen, 2007). The authors found that each car sharing vehicle reduced the need for 4 to 10 privately owned cars in Europe, 6 to 23 cars in North America, and 7 to 10 vehicles in Australia. However, parking effects were not directly examined.

Another survey-based study aimed at estimating the car sharing's effects on household vehicle holdings and on the aggregate vehicle population was carried out in North America, by involving a sample of about 6,300 car sharing members (Martin et al., 2010). The authors found that the average number of vehicles per household of the sample dropped from 0.47 to 0.24. According to their aggregated analysis, car sharing might have taken between 90,000 and 130,000 vehicles off the streets, which can be translated in a ratio from 9 to 13 private vehicles per shared car (including shed cars and postponed car purchases) (Martin et al., 2010).

The same authors analysed the impacts of car2go (a free-floating car sharing) through an online users' survey administered in five US and Canadian cities (Calgary, San Diego, Seattle, Vancouver, and Washington DC) between September 2014 and September 2015, which collected about 9,500 completed responses. They found that each free-floating car sharing vehicle, on average, removed from 7 to 11 vehicles from the road, including vehicles sold and foregone vehicle purchases (Martin and Shaheen, 2016).

Similar results were found in the French study carried out by the 6-t research office (6t-bureau de recherche, 2016). A national car sharing survey aimed at investigating changes in users and their behaviour was distributed in France in 2016, collecting 2,061 completed questionnaires. The authors estimated that each car sharing vehicle replaced from 5 to 10 passenger cars. Additionally, crossing the car ownership reduction results with the place in which these replaced cars were parked, the research group evaluated the distribution of the parking spaces released by type of parking. They estimated that a car sharing vehicle parked on the street freed up 1.6 to 4.2 spaces on the street, 0.3 to 0.6 places in public parking, and 2.1 to 4.2 spaces in private parking (6t-bureau de recherche, 2016).

As mentioned in the introduction, these studies focusing on private car substitution rates only provide a rough estimation on the average positive impact to relieve the car parking pressure in a city, since they do not consider where the affected parking demand is located within a city, and which kind of parking spaces are involved. Those papers that have partially overcome such research gap and that are therefore nearer the present contribution are reported in the following.

2.2 The spatial dimension of parking demand affected by car sharing adoption

The study of Stasko et al. (Stasko et al., 2013) evaluated the impact on parking spaces due to the introduction of a car sharing service in Ithaca (NY), by analysing where and when changes in parking demand occurred. They estimate the change in the number of personal vehicles through a survey administered to car sharing members. Participants were asked how many vehicles they would have had if Ithaca Carshare did not exist, and how sure they were of their answer.

The authors found that if Ithaca Carshare did not exist, the number of personal vehicles would be expected to increase of roughly 0.19 vehicles per driver, which corresponded to about 15 personal vehicles per car sharing vehicle. Additionally, in order to evaluate both the location and type of parking reduction, car sharing members who indicated they would have a different number of vehicles without carsharing were asked where those vehicles would be parked most of the time in different time period (on-street, personal garage/driveway, or other off- street parking).

Results suggested that the majority of vehicles given up because of car sharing would be parked near the residences of the members, either on the street or in other off-street parking, where the parking demand reductions are likely to yield greater benefits.

Using an agent-based simulation approach, Balac et al. explored the impacts of different parking prices on the demand for free-floating car sharing and on the parking occupancy (i.e. the average number of hours the parking space is occupied by a vehicle in a day) in the city of Zurich, Switzerland (Balac et al., 2017). Three levels of free-floating fleet-size in the city coupled with three levels of parking prices were simulated, showing that as the parking prices increased the number of car sharing trips increased and the parking pressure from privately owned vehicles decreased. This produced an increased parking availability for free-floating cars that could be parked closer to the destination. The authors found that the highest car sharing demand and the lowest average parking occupancy occurred in the central area of Zurich in all scenarios, where the main train station, main shopping and business districts are located. Indeed, the higher usage of free-floating car sharing compared to private cars led to a reduction of parking time but also increased the spatial and temporal utilization and turnover of parking slots (Balac et al., 2017). On the contrary, the highest average parking time was observed in the outer areas of the city, meaning that in those areas the parked vehicles were not used for prolonged periods of time (Balac et al., 2017).

Considering the same study area and using a simulation approach, Tchervenkov et al. investigated the maximum number of parking spaces that could be removed from the city due to the availability of a free-floating car sharing and by considering different service adoption rates (Tchervenkov et al., 2018). Thus, travel behaviour patterns in different scenarios were analysed with a multi-agent transport simulation tool. Each scenario corresponded to a different adoption rate, where all adopters give up their private vehicle to become customers of the car sharing service. Comparing the baseline scenario and the best-case scenario, in which all agents switched to free-floating car sharing, the authors estimated a reduction in parking requirements of 22%, which corresponded approximately to 2.35 parking spaces per car sharing vehicle. However, no distinction were made between the different types of parking facilities (Tchervenkov et al., 2018).

3 Study area and data collection

3.1 Mobility alternatives and car sharing market

The study area comprises the cities of Milan and Turin, both located in the North-Western part of Italy. Milan is the largest city in northern of Italy and the most important economic hub of the nation, with about 1.4M inhabitants[1] living on about 182 square kilometres. In terms of mobility offer, the city is characterised by a motorisation rate of 49.5 private cars per 100 inhabitants in 2019 (ISFORT, 2020), while the public transport system is composed by four metro lines, 19 tram lines

[1] http://dati.istat.it/Index.aspx?DataSetCode=DCIS_POPRES1 – Accessed: 01/06/2021

and 133 bus lines (ATM, 2020), covering Milan and other municipalities within the metropolitan area.

According to the estimation provided by the Environment and Territory Mobility Agency, in 2013 the average daily travel demand inside the city was about 2.9M trips, whereas exchange travel demand between the city and surrounding municipalities accounted for additional 2.3M (Comune di Milano and AMAT, 2015). The share of private vehicle trips inside the city (mainly cars and mopeds) is around 37% and the use of public transport is 56%. However, the share of car trips rises to 58% when the exchange trips between the city and the external areas are considered, with negative consequences in terms of congestion, air pollution and parking spaces (Berrini, 2021).

The city of Turin is the second largest city in northern Italy, with about 900,000 inhabitants living on about 130 square kilometres (AMM, 2015).

Concerning mobility options, the city is characterised by a higher motorisation rate compared to Milan, with 63.7 private cars per 100 inhabitants in 2019 (ISFORT, 2020). The public transport offer is made up of one metro line, eight tram lines, and 83 bus lines (GTT, 2016). According to the data provided by the Regional and Metropolitan Mobility Agency, in 2013 the average daily travel demand within the metropolitan area of Turin was about 2.9M trips of which 1.9M were performed with motorized transport means (AMM, 2015). Motorized trips within the city of Turin were about 1.1M. Although 39% of the Turin's travel demand is satisfied by public transport (AMM, 2015), the highest share of trips starting and ending in Turin is performed with private cars. The relevant presence of private cars and their usage within the city is negatively influencing traffic conditions, air quality and the use of public spaces, therefore the same issues identified in Milan. To address such problems, several mobility strategies have been identified and implemented within the Sustainable Urban Mobility Plan (SUMP) of both cities (Città di Torino - Divisione Infrastrutture e Mobilità, 2010; Comune di Milano and AMAT, 2015). Among other actions, a shared mobility governance with coordinated strategies and tools has been put in place, allowing the development and integration of several shared mobility services, such as bike sharing, car sharing, and more recently, e-scooter sharing.

The cities were selected because they represent two of the main car sharing market in Italy. Milan is the Italian city with the largest car sharing offer, in terms of operational schemes that coexist (free-floating and roundtrip station-based), fleet dimensions, and number of customers (Ciuffini et al., 2020, 2019). Turin, despite the lower number of operators, is one of the main car sharing markets in Italy. Concerning car sharing offer, there were four services operating in the city of Milan in 2019, accounting for 3,080 vehicles. Three services provided a free-floating scheme (ShareNow, Enjoy, and Sharen'go) whereas one operator implemented a roundtrip station-based service (Ubeeqo). In the same year, the car sharing offer in Turin was made of two services (ShareNow and Enjoy) providing 788 gasoline vehicles in free-floating and one operator (Bluetorino) accounting for about 330 electric cars distributed in 94 charging stations and following a one-way station based scheme (Ciuffini et al., 2020).

Car sharing membership in both cities has steadily grown in past years, whereas the demand reached a plateau immediately before the Covid era, as showed in Table 1 and Table 2. Comparing such figures with the usage of car and public transport, car sharing can be defined as a niche market.

Table 1: Free-floating car sharing members and trips in Milan (Ciuffini et al., 2020)

	2016	**2017**	**2018**	**2019**
Members	516,578	653,307	815,868	1,040,693
Annual trips (rents)	3,966,415	5,013,394	6,239,417	6,156,385
Average daily trips	10,867	13,735	17,094	16,867

Table 2: Free-floating car sharing members and trips in Turin (Ciuffini et al., 2020)

	2016	**2017**	**2018**	**2019**
Members	88,000	152,250	181,215	209,125
Annual trips (rents)	1,146,511	1,400,947	1,642,360	1,720,224
Average daily trips	3,141	3,838	4,500	4,713

Lastly, since a roundtrip service is only available in Milan and its usage represents a small fraction of the total number of car sharing trips in the city, in the following we focus on the trips that are covered by free-floating services.

3.2 Land use patterns and zoning for this study

In order to identify and localize the impacts of car sharing on parking demand, the characteristics of parking locations of diverted trip are aggregated on a zone basis. As in any zonal aggregation problem, the level of aggregation needs to be carefully considered on the basis of the spatial density of the available experimental data. Too small zones might lead to unreliable results if there is an insufficient number of observations in each zone; on the other hand, the number of zones should be enough to show how impacts are differentiated across the urban area under consideration.

In our case, the main objective is to make a distinction between (mainly) outer residential areas and areas where mobility attractors are concentrated (business districts, shopping areas). Therefore, we consider data about population and economic activities to characterize different parts of the city and to provide a preliminary interpretation about the parking demand location of each zone.

The latest complete census that was carried out in 2011 provided information on population and economic activities at the census tract level[2]. In particular, the population density and the employment density are considered as the two key indicators to characterize an area of the city as mainly residential or attractive in mobility terms. After some trials, it turned out that the best compromise considering our sample size was to adopt for the city of Milan its nine neighbourhoods (Municipi, named "Mun." in the following) as zoning scheme, whereas for the city of Turin its eight areas (Circoscrizioni, named "Circ." in the following), thus ensuring a comparable level of detail between the two cities. Moreover, both zoning schemes correspond to the aggregation of several census tracts, which eases the computation of population and employment densities.

[2] https://www.istat.it/it/archivio/104317 – accessed 07/06/2021

Population and employment density maps defined on the basis of the zoning scheme of Milan and Turin are reported in Fig. 1 and Fig. 2 respectively.

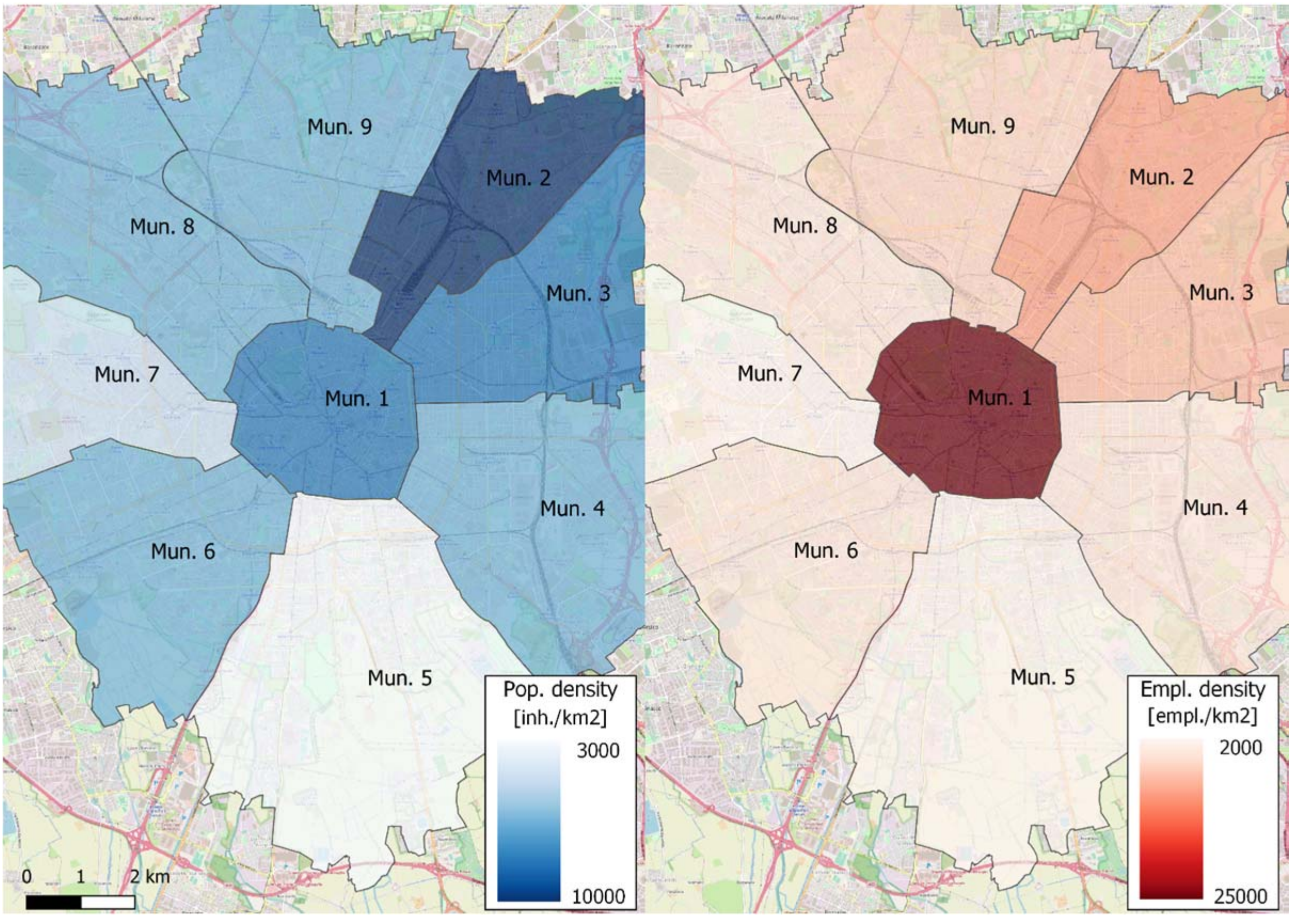


Fig. 1. Population density (left) and employment density (right) within the considered zoning scheme in Milan

In Milan, peripheral North-East areas are more densely populated according to adopted zoning (Mun. 2, Mun. 3, Mun. 8 and Mun. 9). In Turin instead, residential areas characterized by a high population density are located in the Western part of the city (Circ. 3, Circ. 4 and Circ. 5).
Both the central areas of Milan (Mun. 1) and Turin (Circ. 1) are characterised by a relatively high population density and a high number of commercial and business activities to which correspond the highest density of employment. For this reason, these areas can be considered the most important mobility attractor. Other important areas in terms of employment density are located in

the North-East part of Milan (Mun. 2 and Mun. 3) and in the West area of Turin (Circ. 3 and Circ. 4).

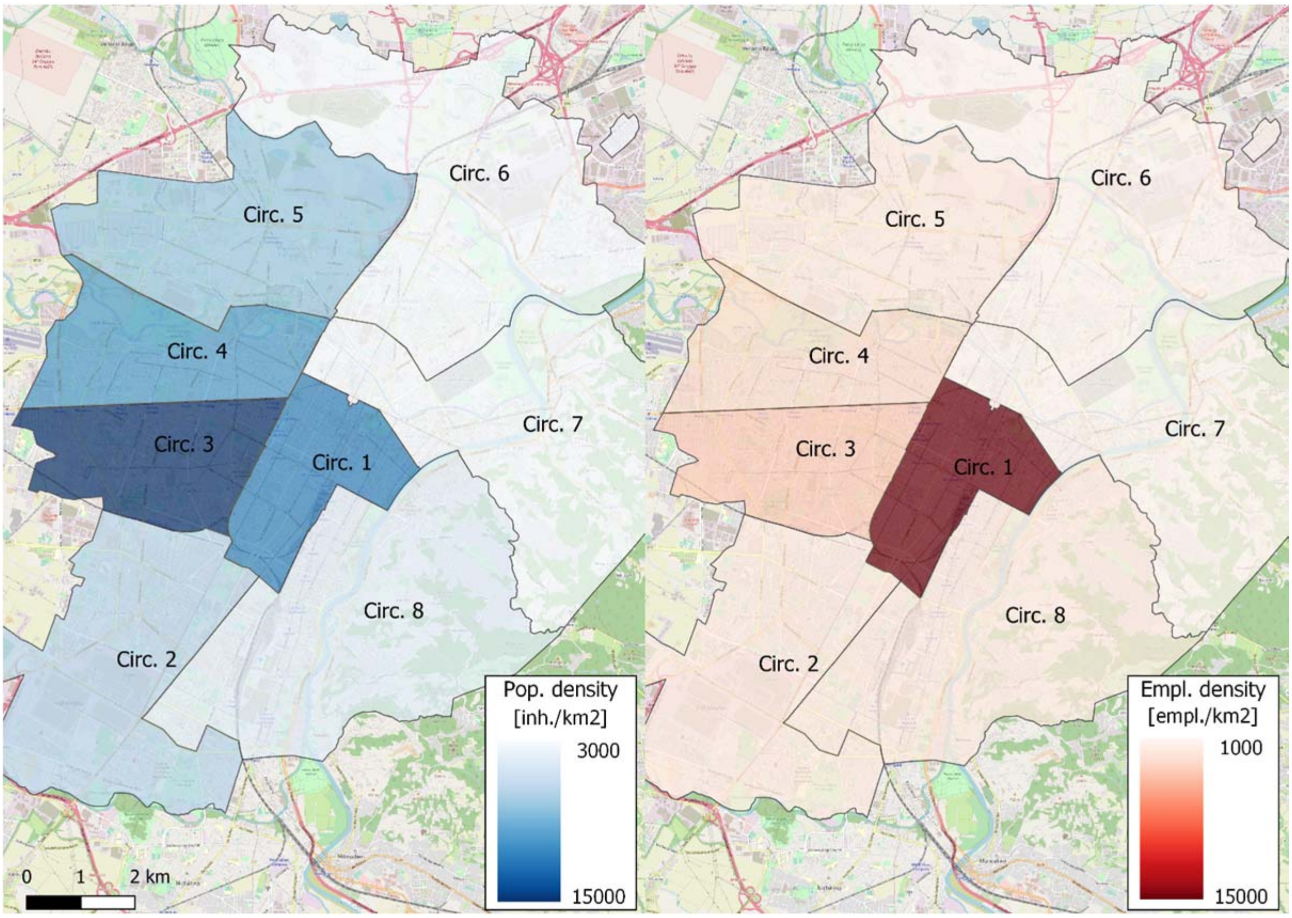


Fig. 2. Population density (left) and employment density (right) within the considered zoning scheme in Turin

3.3 Data used for the definition of car sharing scenarios

In order to define the car sharing scenarios mentioned in the introduction section, and which will be described in the following, we exploited the data coming from a revealed-preferences travel survey administered to a statistically representative sample of individuals living in Milan and Turin (Chicco et al., 2020b). The survey aimed to understand differences between car sharing members and non-members in terms of mobility behaviours, travel habits, car ownership and sociodemographic characteristics.

The survey structure followed the cross-sectional travel survey standard practice (Cornick et al., 2019; Ortúzar and Willumsen, 2011) and was enriched with specific car sharing questions retrieved from some existing studies (Ceccato and Diana, 2021; Schreier et al., 2018). More specifically, the questionnaire consisted of 56 questions divided into four sections:

1. Travel behaviour and mobility habits: respondents were asked to report the use frequency of different travel modes, public transport season ticket ownership, car sharing, and bike sharing membership. Individuals with a car sharing membership were also asked to report the changes of travel habits after the registration to the service.
2. Compact travel diary: in this section, information about the last trip performed by car sharing (for members) and by any other travel mode (non-members) was collected. The used means of transport, the trip duration, and the trip purpose were collected, along with the geographic coordinates of trip origin and destination through a clickable map. Only information about the last trip was collected to achieve the highest possible response rate (minimising the non-response bias).
3. Changes in car ownership: respondents were asked to report the number of cars owned at different time point according to their status (members or non-members). In this section, additionally, interviewees were asked to select where each car available within the household is usually parked during weekdays (from 9:00AM to 17:00PM) and in other time periods (night and weekend) among eight parking options. The available parking options have been later grouped in three main categories (namely on-street parking, parking in dedicated on-surface area, and parking in garage). This information is used in the present study to estimate where private cars were parked during the last trip and how the potential switch to car sharing would impact the parking demand at both the trip origin and destination.
4. Socioeconomic characterisation: in this section, both individual and household socioeconomic characteristics of the respondent were asked.

Filters were applied in accordance with respondents' former answers in order to present only those questions that were relevant under given circumstances. The full logic of the questionnaire along with the complete list of questions is published in (Chicco et al., 2020b), whereas the complete dataset is openly available through Zenodo (Chicco et al., 2020a).

It is worth noting that last trip and socioeconomic questions were accurately designed to obtain information that is comparable with a previous study (Ceccato and Diana, 2021), whose data are used to calibrate modal switching models which will be later presented.

In order to obtain a representative sample of the population living in the two cities, the survey was distributed by an external poll firm to a sample stratified by gender and age. Both Computer-Assisted Web Interviews (CAWI) and Computer-Assisted Telephone Interviews (CATI) were used to reach all different social groups.

The data collection activity took place between the 13th and the 28th of May 2019. During this period, 1474 completed questionnaires were collected within the two cities. However, since the aim of this paper is to estimate the impact on parking demand related to the trip level modal diversion from different travel means towards car sharing, only non-members answers are retained. As a result, 808 questionnaires (553 from Milan and 255 from Turin) are considered.

4 Methods

The above discussion has pointed out that car sharing can have an indirect impact on parking demand, which is mediated by a decrease in car ownership levels and by an increase of use of alternative travel means. However, wishing to study how parking demand is affected in different zones within an urban area induced us to use a different approach, namely studying the maximum extent to which car sharing can affect everyday modal choices. A trip-level analysis approach is then followed, where car ownership is an exogenous variable and modelling scenarios on modal diversion patterns for different origin-destination pairs are examined.

As a consequence of the above framework, it must be noted that the effects on public spaces related to a reduced number of private vehicles are not considered in this work. Here we are rather concerned with trip-level impacts on parking spaces, that might happen even if car ownership levels were not affected by car sharing, due to a different spatial configuration of the demand for parking spaces. A discussion on the two approaches for the study of car sharing demand, namely person-level versus trip-level analyses, is reported in Ceccato and Diana (Ceccato and Diana, 2021).

4.1 Definition of the ideal scenario for car sharing

As previously observed, car sharing services still represent a niche market in Turin and Milan compared to traditional modes such as private cars, public transport, walking, and even bikes. Therefore, rather than attempting to measure the impacts of the actual services that is also likely to quickly change in the (near) future, this paper will present an analysis that considers a service offer and travel demand assuming a future ideal scenario, where car sharing will be fully deployed in the two cities. Such car sharing scenario was already introduced for the city of Turin in a previous study (Chicco and Diana, 2021) and it is extended here to the city of Milan. While defining such car sharing scenarios, current transport policy priorities in the two cities that are emphasising the need to reduce pollutant emissions from road transport were considered, since the flatland in northern Italy where both Milan and Turin are located is one of the areas with the worst air quality in Europe (European Environmental Agency, 2019; Legambiente, 2019).

The above definition of the ideal scenario assumes that car sharing services in both cities would have the following characteristics:

- The operational area of the service is extended over the whole territory of both municipalities, whereas it is only covering inner areas (about 55% and 40% of the Milan and Turin municipalities, respectively) (Moschini, 2017).

- The service coverage and accessibility are improved until the average walking time from the trip origin to the nearest available vehicle is comparable with the average walking time to the location of the private vehicle that is used to complete a car trip.
- Travel times of car sharing services are comparable with those by private cars.
- Travel costs by car sharing (i.e. fares for individual trips) and parking costs of private cars on public street are initially set as in the actual condition and then jointly changed, up to twice the current values, considering the combination that maximises the switches from private cars to car sharing while minimising the switches from public transport, bike, and walk trips, consistently with the goal of minimising transport-related emissions.
- The performances of the other means (public transport, bike, walking) are the same as in the current situation in both cities.
- Alternative travel options not available or not permitted within the study areas at the time of the study are also considered not available in the ideal scenario.

Clearly this ideal scenario could be deemed economically not viable, since it might imply the operation of a disproportionately large fleet, even distributed in areas with a low population density. These areas are usually not included in free-floating services' operations due to exiguous fleet utilisation rates and the marginal revenues' increase compared to the initial investment for the asset, which often makes free-floating car sharing not really profitable (Kortum et al., 2016; Stolle et al., 2019). However, this aspect will not be considered in the present exercise.

Modal shares of both the ideal scenario and the current scenario will be considered to quantify the changes in parking demand related to the modal diversion patterns. Concerning the current scenario, modal shares for car sharing were available from published statistics on car sharing usage (Ciuffini et al., 2020), while those for the other modes were directly derived from the presented travel survey, also considering that survey results were consistent with those from the latest regional travel survey (AMM, 2015) that was made in 2013 and that is therefore quite outdated by now.

4.2 Travel demand modelling

Consistently with this research perspective, binomial logit models were first estimated in order to predict switching intentions of non-users from the currently used mode to car sharing on a representative set of trips observed in the Turin metropolitan area, assuming the above-defined ideal scenario concerning the offer of shared services. Both socioeconomic characteristics of the respondent, of her household, and trip characteristics (distance, duration, generalised cost, purpose) were considered as explanatory variables. The calibration dataset came from a previous modal diversion study based on a stated-preferences travel survey carried out in the Turin metropolitan area in 2016 (Ceccato and Diana, 2021), in which 4,466 complete questionnaires were collected. In the present study however, only 2,293 (51.3%) observations were retained, since respondents living outside the urban area of Turin, those who did not travel the day before the interview or had only trips longer than 50km were not considered. The calibration is not detailed in this paper since it is ancillary and related to this specific task, while the following section will focus on the activities that are directly related to the research that is presented here. The reader interested in the modelling details is referred to (Chicco and Diana, 2021).

Four distinct binomial switching models were developed by considering four main travel means, namely walk, bike, car, and public transport. Indeed, a switch from either public transport or active means to car sharing is not desirable, whereas the opposite is true if car sharing is substituting private car trips due to the worse environmental performances of the latter (Diana and Ceccato, 2019). The trip-level switching probabilities from each of these four modes to car sharing were then applied to the universe of trips observed through the later introduced sample surveys in Turin and Milan to estimate the number of trips that could be diverted from each traditional means to car sharing in the ideal scenario.

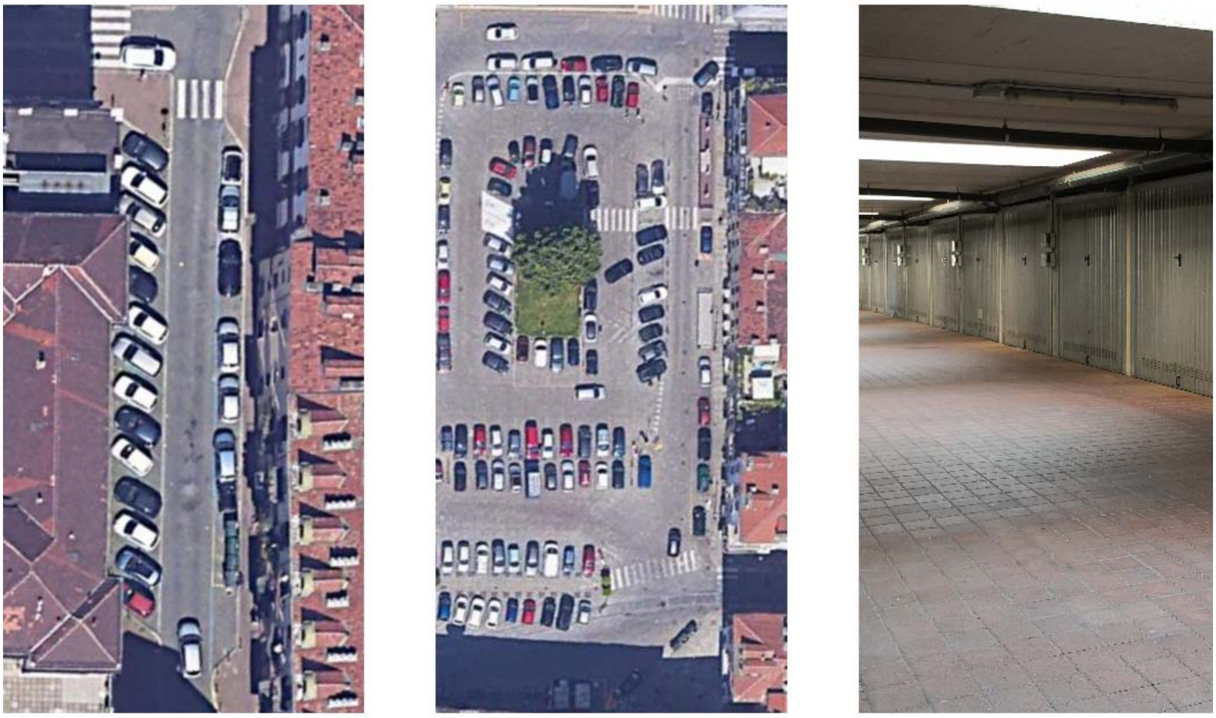
4.3 *Quantification and evaluation of the impacts on the use of public space due to modal diversion*

Impacts on the spatial configuration of the parking demand were measured in terms of number of saved parking events in a given area (both on-street parking and on-surface dedicated parking). A "saved parking event" is defined as a parking space that is not any more occupied by a vehicle, since the related trip was switched to car sharing. Therefore, the number of parking events is a conceptual measurement unit that is not equivalent to the number of parking spaces (one parking space can host several events since the latter are defined on a temporal basis), but this quantification is a useful input to a GIS-based analysis to make decision-makers aware of the reduced parking pressure in a city, especially near mobility attractors. In addition, this kind of unit measure can be evaluated only by comparing two different scenarios, because the consideration of just one scenario would only lead to a positive number of consumed parking events.

In order to estimate the impact of modal diversion induced by car sharing on public spaces, the results of the above-introduced switch models were interpreted by considering additional information coming from the travel survey presented in section 3.3. Namely, the reported parking habits and trip characteristics of a representative sample of individuals living in the two study areas were used to quantify how many "parking events" can be saved after the modal switch of a trip in the sample from private car towards car sharing. Switch from other modes, namely walk, bike and public transport, to car sharing were not considered in this analysis, since the parking demand for those specific trips would have not been affected anyway.

It is worth mentioning that, according to this framework, car sharing impacts on parking demand could be not only either positive or neutral in any area and under any circumstance. Indeed, the trip diversion from car to car sharing could also imply an increase of the private car parking time in the area where the trip is originated, therefore an increase of the parking demand in that area. Thus, the parking location at both origin and destination of the trip is an important aspect that needs to be considered. The second driving element to positively, neutrally or negatively evaluate the trip modal switch is the kind of parking space associated to the parking event variation. As mentioned in section 2.3, three different spaces are considered in the present work, namely street parking, parking in a dedicated on-surface area, or parking in a garage.

The three parking configurations are illustrated in Fig. 3.



a b c

Fig. 3. Parking configurations considered in this study: a) on-street parking, b) parking in dedicated on-surface area, c) garage – Sources: a) and b) satellite images from Google Maps; c) author.

It is worth noting that on-street parking and parking in dedicated on-surface area categories include both free and paid parking. Additionally, dedicated on-surface parking classification is done without considering their size, namely the number of parking lots composing the parking area.

The joint consideration of the above two elements allowed us to identify several different situations that are enumerated in rows of Table 3. In particular, the car sharing impact is considered positive at destination when the origin parking is a garage (private or owned by the work company) and the destination is a roadside or a dedicated parking area. Indeed in these cases, if the shift occurs, the private car would remain parked in a garage at the origin (neutral impact on public space) while the shared car would be parked for less time at destination (Balac et al., 2017; Millard-Ball et al., 2005). For the same reason, car sharing impact is considered neutral when the destination is a private garage independently from the origin car parking location, even if car sharing vehicle would not be parked in a private garage but on public space. On the contrary, the impact of the diverted trip is considered negative, if the car is parked on the roadside at the origin, because it would keep on occupying public space.

Table 3: Evaluation of the impacts on parking events according to parking areas characteristics

Parking at the trip origin	**Parking at the trip destination**	**Impact on parking at the origin**	**Impact on parking at destination**
Garage	Garage	Neutral	Neutral
Garage	Dedicated on-surface parking area	Neutral	Positive
Garage	Street	Neutral	Positive
Dedicated on-surface parking area	Garage	Negative	Neutral
Dedicated on-surface parking area	Dedicated on-surface parking area	Negative	Positive
Dedicated on-surface parking area	Street	Negative	Positive
Street	Garage	Negative	Neutral
Street	Dedicated on-surface parking area	Negative	Positive
Street	Street	Negative	Positive

Clearly the above evaluation criteria are an approximation since the complete trip chain should be considered rather than focusing on a trip-level analysis as done here. However trip-level rather than trip chain-level analyses are the state of the practice in transport modelling, despite well-known limitations for example concerning the study of modal choices.

Once determined the effects of car sharing on public spaces at the origin and destination of each trip in the sample, the results were expanded to the universe, therefore assuming that the parking habits of the considered sample are representative of those of the universe. Indeed we have no reason to reject such assumption, also recalling that the sample was stratified by gender and age. Then positive, negative, and neutral impacts were aggregated in each of the two cities according to the zoning scheme previously introduced but keeping a distinction among the three above introduced kinds of parking places where the parking events happened.

Finally, the open-source software QGIS (QGIS Development Team, 2019) was used to generate maps with spatial representations of aggregate impacts.

5 Results and discussion

As mentioned in the previous section, details on the estimation results of the four modal switch models are reported in (Chicco and Diana, 2021), while the following Table 4 and Table 5 report both the resulting modal shares estimates in the current scenario, and the models forecasts for the ideal scenario, respectively in the city of Milan and Turin. Results are already expanded to the universe of all trips in both tables.

According to the models' results, the potential car sharing demand might increase from about 1% of the daily travel demand currently served in Milan and Turin, up to about 10% estimated in the ideal scenario.

Table 4: Modal split in the current scenario, potential trips switching to car sharing and modal split in the ideal scenario in Milan

Travel mode	Current daily trips		Diverted trips to car sharing	Daily trips in the "Ideal scenario"	
	N	%	N	N	%
Walk	245,941	11.5	8,321	237,620	11.1
Bike	109,179	5.1	7,735	101,444	4.7
Car	974,248	45.6	97,474	876,774	41.0
Car sharing	16,867	0.8	-	201,923	9.5
Public transport	790,935	37.0	71,526	719,409	33.7
Total	2,137,170	100	185,056	2,137,170	100

Table 5: Modal split in the current scenario, potential trips switching to car sharing and modal split in the ideal scenario in Turin

Travel mode	**Current daily trips**		**Diverted trips to car sharing**	**Daily trips in the "Ideal scenario"**	
	N	**%**	**N**	**N**	**%**
Walk	192,856	15.1	11,266	181,590	14.3
Bike	27,735	2.2	2,157	25,578	2.0
Car	684,452	53.7	71,048	613,404	48.1
Car sharing	4,713	0.4	-	122,743	9.6
Public transport	364,532	28.6	33,559	330,973	26.0
Total	1,274,288	100	118,030	1,274,288	100

Table 6 and Table 7 report positive and negative impacts on both on-street and on-surface dedicated parking areas that are derived from these modal diversion patterns, along with the neutral impacts related to garages. The last two columns in those tables report the net impact on daily parking events by type of parking, which is obtained as the difference between positive and negative impacts. The quantification and distribution of the estimated effects depend on both land use (distribution of residential areas and attractors) and infrastructural factors (number of roadside parking slots, dedicated parking and garages). It can be noted that also impacts outside the two city areas have been estimated (rows labelled with EXT), due to those reported trips connecting the city and the surrounding municipalities.

Table 6: Car sharing impacts on parking events resulting from the difference between ideal and current scenario in Milan

Zone	**Origin**			**Destination**			**Net impact**	
	Street (negative)	Parking* (negative)	Garage (neutral)	Street (positive)	Parking* (positive)	Garage (neutral)	Street	Parking*
Mun. 1	7,044	1,611	1,933	12,231	122	3,162	5,187	-1,489
Mun. 2	1,158	5,200	492	1,458	410	216	300	-4,790
Mun. 3	8,670	566	4932	3,476	0	0	-5,194	-566
Mun. 4	947	0	5,172	1,537	3,396	666	590	3,396
Mun. 5	41	0	81	97	42	0	56	42
Mun. 6	2,999	419	2,774	5,684	373	206	2,685	-46
Mun. 7	995	0	6,185	3,957	1,372	469	2,962	1,372
Mun. 8	4,546	8	189	1,772	0	121	-2,774	-8
Mun. 9	4,060	296	1,622	8,350	39	860	4,290	-257
INT – City of Milan	30,460	8,100	23,380	38,562	5,754	5,700	8,102	-2,346
EXT-Municipalities surrounding Milan	19,591	1,319	14,624	36,954	7,178	3,326	17,305	5,859
Total	50,051	9,419	38,004	75,516	12,932	9,026	25,465	3,513

* Dedicated parking areas

The total number of diverted trips that is considered in each table can be computed by summing the three corresponding values in the last row (either columns 2 to 4 or 5 to 8) and it is consistent with the figures that are reported roughly the middle of Table 4 and Table 5 (namely, 97,474 diverted trips for the city of Milan and 71,048 for the city of Turin).

Table 7: Car sharing impacts on parking events resulting from the difference between ideal and current scenario in Turin

Zone	Origin			Destination			Net impact	
	Street (negative)	Parking* (negative)	Garage (neutral)	Street (positive)	Parking* (positive)	Garage (neutral)	Street	Parking*
Circ. 1	3,356	974	418	5,414	0	769	2,058	-974
Circ. 2	7,322	52	1,766	4,693	0	0	-2,629	-52
Circ. 3	4,961	273	5,649	2,973	0	0	-1,988	-273
Circ. 4	1,823	719	2,124	4,375	436	1,056	2,552	-283
Circ. 5	1,968	403	2,204	2,392	0	0	424	-403
Circ. 6	638	302	1,030	1,121	260	0	483	-42
Circ. 7	0	0	1,135	1,888	52	264	1,888	52
Circ. 8	1,096	243	835	5,554	539	1,505	4,458	296
INT – City of Turin	21,164	2,966	15,161	28,410	1,287	3,594	7,246	-1,679
EXT-Municipalities surrounding Turin	6,150	3,424	22,183	29,448	5,778	2,531	23,298	2,354
Total	27,314	6,390	37,344	57,858	7,065	6,125	30,544	675

* Dedicated parking areas

A selection of information from both tables is also more effectively presented through maps reported in Fig. 4 and Fig. 5, respectively for the city of Milan and of Turin. Impacts on surrounding municipalities is not shown there. In addition, neutral impacts are not reported since they always occur when private cars have been parked in garages, thus not producing a tangible impact on public spaces. Therefore, only positive and negative impacts were considered for each zone, by distinguishing on-street parking events and parking events on dedicated parking slots. In each zone, red bars represent the negative impact on street while green ones the positive impact on street; orange and light green bars represent negative and positive impacts on dedicated parking areas, respectively.

Negative and positive impacts for both kinds of public space are separately considered first, since they might have a different meaning. On the one hand, a positive impact given by one less parking event represents one less vehicle that is actively looking for a parking spot in the area. On the other, a negative impact could represent longer occupancy times of already occupied parking spots. It is therefore clear that the two are not always compensating each other on a practical viewpoint.

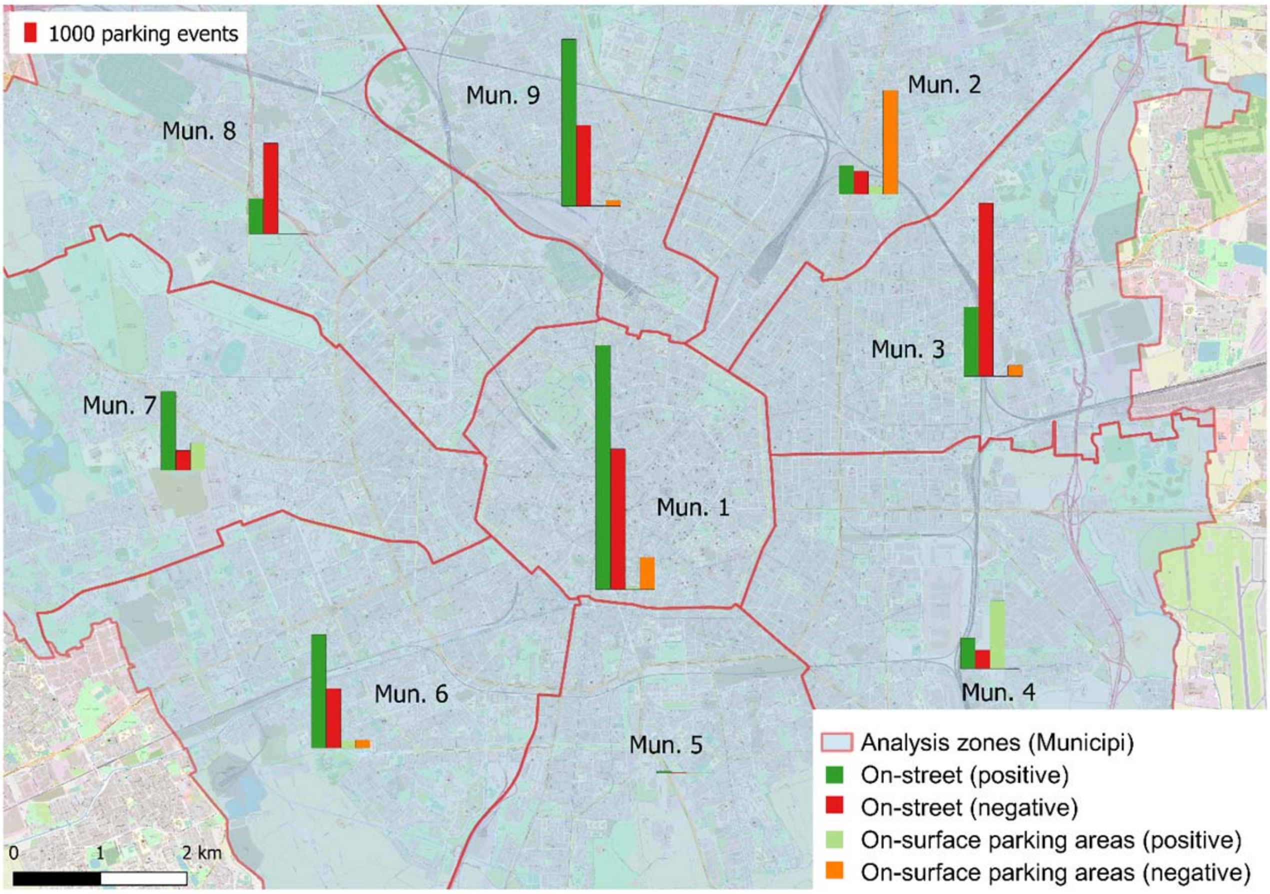


Fig. 4. Daily parking events variation in the city of Milan between current and ideal scenario

By observing the central area of Fig. 4, which coincides with the Milan city centre (Mun. 1), it can be noted that there are positive and negative impacts of parking events on street, however the green bar is higher than the red one (so a higher absolute value). Concerning parking events in dedicated parking, only negative impacts were estimated. Therefore, when considering their algebraic sum, car sharing might produce a positive impact on daily central areas parking events in the ideal scenario. On the contrary, higher negative impacts on both street and dedicated parking events might be encountered in more peripheral areas, for example in zones closer to the north-eastern and north-western quadrant (Mun. 2, 3 and 8). Indeed our results are not univocal, since for example Mun. 9 presents a different pattern. The coarseness of our zoning, which is a limitation that is essentially due to sample size, makes it hard to fully explain this latter finding.

Net impact columns in Table 6 show that some zones have a positive balance in terms of daily parking events in both street and parking areas (e.g. Mun. 4 and Mun. 7), while in others the balance is negative (e.g. Mun. 3) or mixed (e.g. Mun. 1). When looking at the overall balance at the whole city level (row "INT – City of Milan" of Table 6) car sharing might produce a positive effect on street spaces, quantifiable in 8,160 daily parking events. On the other hand, car sharing might produce negative effects on dedicated parking spaces, quantifiable in 2,346 daily parking events. The total balance of public surfaces is still positive (8,160 - 2,346).

Similarly, the graphic representation of the zoning and of the daily parking events impacts of car sharing in Turin is reported in Fig. 5, with the same graphical layout. It is interesting to observe that car sharing might produce a positive effect on-street parking events in the city centre area (Circ. 1), where one of the two major railway stations of the city is located. This is related to the fact that in many of the private car trips diverted to car sharing in the ideal scenarios are related to cars that are parked on streets of that area. In line with results obtained for the city of Milan, larger on-street negative impacts were encountered in peripheral areas, especially in the south-west area of the city (Circ. 2 and 3) where more residential neighbourhoods can be found.

Finally, information reported in the last two columns of Table 7 shows that car sharing might overall produce a positive effect on street spaces of the city of Turin, quantifiable in 7,246 daily parking events. On the other hand, car sharing might produce negative effects on dedicated parking spaces, quantifiable in 1,679 daily parking events. The total balance of public surfaces is however still positive (7,246 – 1,679) also for the city of Turin.

From these figures it could be concluded that net impact on parking usage of a switch from the current situation to the ideal situation is sizable in absolute terms. However, when compared with the estimates on the total number of trips diverted to car sharing in the ideal scenario (see Tables 4 and 5) such impact becomes negligible. The main impact is instead a redistribution of parked cars from street/dedicated parking within the two cities to the municipalities surrounding them.

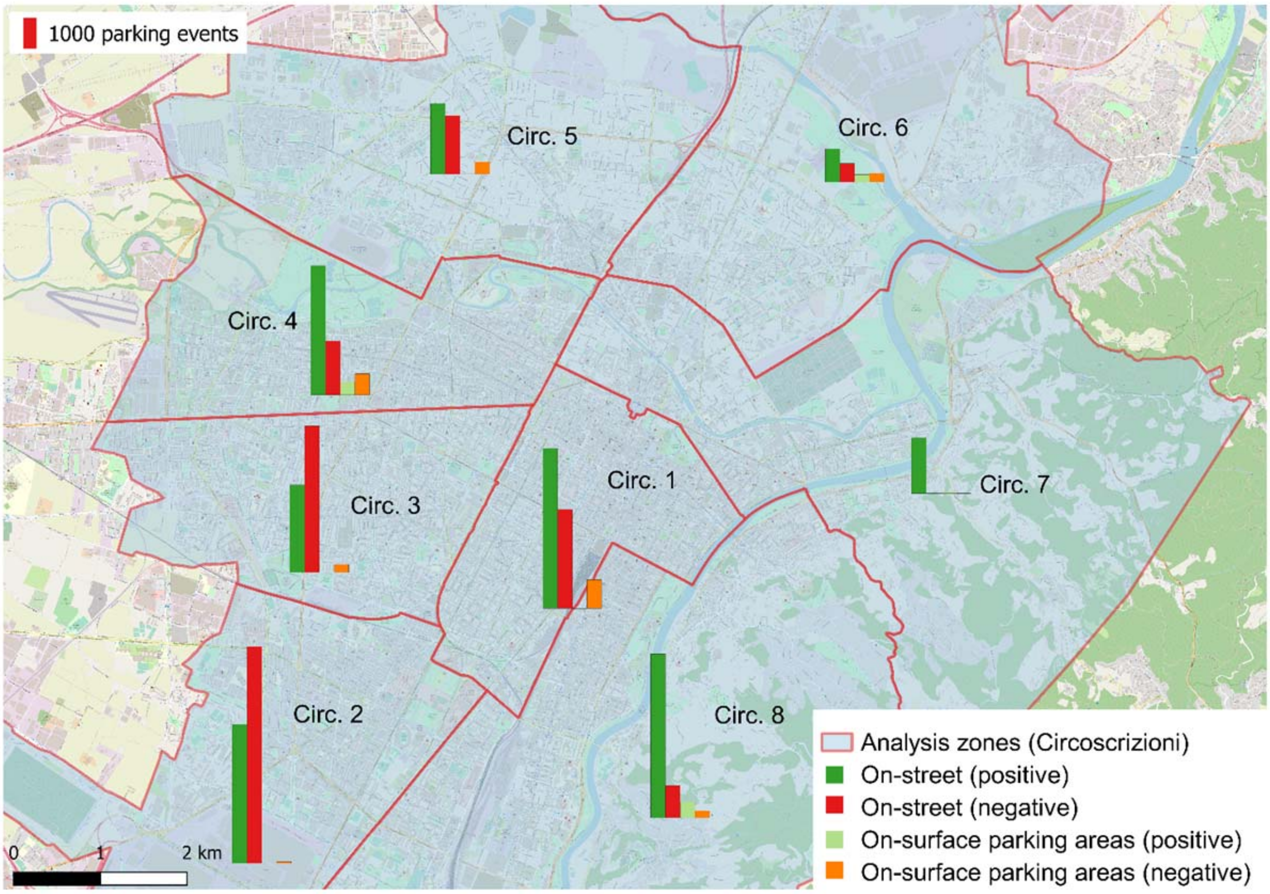


Fig. 5. Daily parking events variation in the city of Turin between current and ideal scenario

To sum up, in both cities analysed in this study, the number of productors (residential areas) produces a negative effect on parking events, whereas the presence of attractors generates a positive impact. As a final remark, it is worth stressing that these results are based only on the last trip performed by respondents at the interview time, so areas with no impact might be due to the fact that there are few reported trips starting or ending there, and additionally a low switching probability towards car sharing of those trips was estimated in the ideal scenario. Aggregation problems might therefore affect results for such areas, whereas both the more aggregated figures at the city level and the policy indication on the kind of areas where car sharing can effectively relieve parking demand can represent a useful indication for decision makers that are involved in policies and planning of the city.

6 Conclusions

This study has given a preliminary evaluation of the impacts on parking demand due to the diffusion of car sharing services in urban areas. The focus of the research was solely on the impacts in the short run due to modal diversion patterns and everyday mobility behaviours with special reference to modal choice, thus complementing existing studies that rather focus on how car sharing affects long-term and strategic decisions such as car ownership. Clearly the latter has also an indirect but arguably strong impact on travel demand, whose analysis is however not within the scope of the present paper.

Based on travel survey data and stated switching intentions towards car sharing services, two ideal scenarios were defined for the Italian cities of Turin and Milan to quantify the potential of such services in serving the actual travel demand. A distinction was made between dedicated parking areas from on-street parking, given the different policy relevance and implications of saving parking space in the two cases. Impacts are quantified in terms of parking events rather than saved parking lots, therefore they are represented by parking units in time.

Positive impacts were found, both in the overall urban areas and, more specifically, in central areas of both cities, probably because many car trips were substituted by car sharing rentals ending there. In more peripheral and residential areas, negative impacts were found, since private cars might remain parked for more time due to the car sharing usage. However, parking pressure in those areas is typically lower, so that the overall effect of car sharing is still positive.

It is worth remarking that the ideal scenario defined in this study, which could produce the mentioned positive effects on parking demand, has to be economically assessed. While some assumptions can be met in reality by the city administration, for example through more restrictive parking policies for private cars, others need to be planned together with car sharing providers.

Therefore, our findings represent an upper bound of the impacts that can be realistically achieved, thus providing an initial guidance to policy makers on the maximum extent to which the parking demand in a city can be affected by the potentially maximum development of car sharing services, while the lower bound can realistically be represented by the current scenario.

Future studies will be aimed at assessing the number of parking spaces that can indeed be saved in different zones on the basis of the results here presented, by looking at the patterns of use of different parking areas. This could be a key input for policy makers interested in redesigning public spaces. More disaggregated analyses based on a larger dataset of trips would be needed to consider smaller and therefore to provide a better characterisation of different areas. This would allow better insights on how the provision of shared mobility services can impact parking demand in relation with different land use patterns.

References

6t-bureau de recherche, 2016. Enquête Nationale Autopartage – Mise à jour 2016 – Analyse des enquêtes [in French]. ADEME, Angers. https://www.ademe.fr/sites/default/files/assets/documents/enquete-nationale-autopartage-ena1bis-2017-enquetes.pdf.

AMM, 2015. IMQ 2013 Indagine sulla Mobilità delle Persone e sulla Qualità dei Trasporti [in Italian]. Agenzia per la Mobilità Metropolitana e Regionale, Torino. https://mtm.torino.it/it/dati-statistiche/indagine-imq-2013/pdf-1/IMQ2013_RapportoSintesi.pdf/view.

ATM, 2020. Carta della mobilità ATM 2020, [in Italian]. Azienda Trasporti Milanese, Milano. https://www.atm.it/it/IlGruppo/Governance/Documents/Carta%20della%20Mobilit%C3%A0%202020.pdf.

Balac, M., Ciari, F., Axhausen, K.W., 2017. Modeling the impact of parking price policy on free-floating carsharing: Case study for Zurich, Switzerland. Transp. Res. Part C Emerg. Technol. 77, 207–225. https://doi.org/10.1016/j.trc.2017.01.022

Becker, H., Ciari, F., Axhausen, K.W., 2018. Measuring the car ownership impact of free-floating car-sharing – A case study in Basel, Switzerland. Transp. Res. Part D Transp. Environ. 65, 51–62. https://doi.org/10.1016/j.trd.2018.08.003

Becker, H., Ciari, F., Axhausen, K.W., 2017. Comparing car-sharing schemes in Switzerland: User groups and usage patterns. Transp. Res. Part A Policy Pract. 97, 17–29. https://doi.org/10.1016/j.tra.2017.01.004

Berrini, M., 2021. The challenge: tranform the Urban Mobility model to make Milano a more Livable city Milan – Mobility main data. Agency for Mobility,Environment,Territory, Milan. https://na.eventscloud.com/file_uploads/d23dc9cc58635262e5d20a4e48f4d087_MILANO_LONG.pdf.

Ceccato, R., Diana, M., 2021. Substitution and complementarity patterns between traditional transport means and car sharing: a person and trip level analysis. Transportation (Amst). 48, 1523–1540. https://doi.org/10.1007/s11116-018-9901-8

Cervero, R., Creedman, N., Pohan, M., Pai, M., 2002. City CarShare : Assessment of Short-Term Travel-Behavior Impacts (No. 2002– 01), IURD Working Paper Series.

Cervero, R., Golub, A., Nee, B., 2007. City CarShare longer-term travel demand and car ownership impacts. Transp. Res. Rec. 70–80. https://doi.org/10.3141/1992-09

Chicco, A., Diana, M., 2021. Air emissions impacts of modal diversion patterns induced by one-way car sharing : A case study from the city of Turin. Transp. Res. Part D 91, 102685. https://doi.org/10.1016/j.trd.2020.102685

Chicco, A., Diana, M., Nehrke, G., Ziesak, M., Rodenbach, J., Matthijs, J., 2020a. Shared mobility opporTunities And challenges foR European citieS (STARS) - Work Package 5, Task 5.1 (Version 1) [Dataset]. https://doi.org/http://doi.org/10.5281/zenodo.3731284

Chicco, A., Diana, M., Rodenbach, J., Mathijs, J., Nehrke, G., Ziesak, M., Horvat, M., 2020b.

STARS Deliverable 5.1 - Mobility scenarios of car sharing: gap analysis and impacts in the cities of tomorrow. https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5cc8f22af&appId=PPGMS.

Città di Torino - Divisione Infrastrutture e Mobilità, 2010. PUMS - Sintesi non tecnica, [in Italian]. Città di Torino, Torino. http://geoportale.comune.torino.it/web/sezioni-tematiche/piano-urbano-della-mobilita-sostenibile-introduzione. Accessed: 05/07/2021.

Ciuffini, M., Asperti, S., Gentili, V., Orsini, R., Refrigeri, L., 2020. 4 ° Rapporto Nazionale sulla Sharing Mobility 2019, [in Italian]. Osservatorio Nazionale Sharing Mobility, Roma. http://osservatoriosharingmobility.it/wp-content/uploads/2020/12/IV-RAPPORTO-SHARING-MOBILITY.pdf.

Ciuffini, M., Orsini, R., Asperti, S., Gentili, V., Grossi, D., Milioni, D., Refrigeri, L., Romano, G., Rossi, G., Soprano, L., Specchia, L., 2019. 3° Rapporto Nazionale sulla Sharing Mobility 2018, [in Italian]. Osservatorio Nazionale Sharing Mobility, Roma. http://osservatoriosharingmobility.it/wp-content/uploads/2020/12/come-sta-la-sharing-mobility_III-Rapporto-SM_13-e-FRONT.pdf.

Clewlow, R.R., 2016. Carsharing and sustainable travel behavior: Results from the San Francisco Bay Area. Transp. Policy 51, 158–164. https://doi.org/10.1016/j.tranpol.2016.01.013

Comune di Milano, AMAT, 2015. PUMS Piano Urbano Mobilità Sostenibile Milano - Documento di piano. Comune di Milano. http://download.comune.milano.it/24_03_2015/Documento%20di%20Piano%20febbraio%202015%20(1427206289866).pdf.

Cornick, P., Cant, J., Byron, C., Templeton, I., Hurn, J., 2019. National travel survey. https://doi.org/10.1016/0160-7383(78)90383-3

Diana, M., Ceccato, R., 2019. A multimodal perspective in the study of car sharing switching intentions. Transp. Lett. 00, 1–7. https://doi.org/10.1080/19427867.2019.1707351

Efthymiou, D., Antoniou, C., Waddell, P., 2013. Factors affecting the adoption of vehicle sharing systems by young drivers. Transp. Policy 29, 64–73. https://doi.org/10.1016/j.tranpol.2013.04.009

European Environmental Agency, 2019. Air quality in Europe - 2019 report. Publications Office of the European Union, Luxembourg. https://op.europa.eu/en/publication-detail/-/publication/7d42ac97-faca-11e9-8c1f-01aa75ed71a1/language-en, Copenhagen. https://doi.org/10.2800/822355

Firnkorn, J., Shaheen, S., 2016. Generic time- and method-interdependencies of empirical impact-measurements: A generalizable model of adaptation-processes of carsharing-users' mobility-behavior over time. J. Clean. Prod. 113, 897–909. https://doi.org/10.1016/j.jclepro.2015.09.115

Giesel, F., Nobis, C., 2016. The Impact of Carsharing on Car Ownership in German Cities. Transp. Res. Procedia 19, 215–224. https://doi.org/10.1016/j.trpro.2016.12.082

GTT, 2016. Carta della mobilità 2016 [in Italian]. Gruppo Torinese Trasporti, Torino. http://gtt.to.it/cms/risorse/impegni/carta_della_mobilita_2016.pdf.

ISFORT, 2020. 17° Rapporto sulla mobilità degli italiani [in Italian]. Istituto Superiore di Formazione e Ricerca per i Trasporti, Roma. https://www.isfort.it/wp-content/uploads/2020/12/RapportoMobilita2020.pdf.

Jochem, P., Frankenhauser, D., Ewald, L., Ensslen, A., Fromm, H., 2020. Does free-floating carsharing reduce private vehicle ownership? The case of SHARE NOW in European cities. Transp. Res. Part A Policy Pract. 141, 373–395. https://doi.org/10.1016/j.tra.2020.09.016

Ko, J., Ki, H., Lee, S., 2017. Factors affecting carsharing program participants' car ownership changes. Transp. Lett. 11, 208–218. https://doi.org/10.1080/19427867.2017.1329891

Kortum, K., Schönduwe, R., Stolte, B., Bock, B., 2016. Free-Floating Carsharing: City-Specific Growth Rates and Success Factors. Transp. Res. Procedia 19, 328–340. https://doi.org/10.1016/j.trpro.2016.12.092

Lane, C., 2005. PhillyCarShare: First-year social and mobility impacts of carsharing in Philadelphia, Pennsylvania. Transp. Res. Rec. 158–166. https://doi.org/10.3141/1927-18

Legambiente, 2019. Mal'aria di città 2019. Legambiente, Roma. https://www.legambiente.it/wp-content/uploads/Malaria2019_dossier.pdf.

Martin, E., Shaheen, S., 2016. Impacts of car2go on Vehicle Ownership, Modal Shift, Vehicle Miles Traveled, and Greenhouse Gas Emissions: An Analysis of Five North American Cities, Working Paper from the University of California, Berkeley. Berkeley, California 94720.

Martin, E., Shaheen, S.A., Lidicker, J., 2010. Carsharing's impact on household vehicle holdings: Results from a north American shared-use vehicle survey. Transp. Res. Board 2143, 150–158. https://doi.org/https://doi.org/10.3141/2143-19

Millard-Ball, A., Gail, M., Ter Schure, J., Fox, C., Burkhardt, J., 2005. Car-Sharing: Where and How It Succeeds, TCRP Report 108. Transportation Research Board, Washington D.C. http://www.ccdcboise.com/wp-content/uploads/2016/02/Document-D1-TCRP-Car-sharing-Where-and-How-It-Succeeds.pdf.

Moschini, E., 2017. Car sharing in tasca [in Italian], PC Professionale. http://www.utesandonatosangiuliano.org/InforMatica/Documentazione/Tecnologie-Car sharing.pdf. Accessed: 05/07/2021.

Namazu, M., Dowlatabadi, H., 2018. Vehicle ownership reduction: A comparison of one-way and two-way carsharing systems. Transp. Policy 64, 38–50. https://doi.org/10.1016/J.TRANPOL.2017.11.001

Ortúzar, J. de D., Willumsen, L.G., 2011. Modelling Transport, Fourth Edi. ed. John Wiley & Sons, Ltd.

QGIS Development Team, 2019. QGIS 3.4.13.

Schmöller, S., Weikl, S., Müller, J., Bogenberger, K., 2015. Empirical analysis of free-floating carsharing usage: The Munich and Berlin case. Transp. Res. Part C Emerg. Technol. 56, 34–51. https://doi.org/10.1016/j.trc.2015.03.008

Schreier, H., Grimm, C., Kurz, U., Schwieger, D.. B., Keßler, S., Möser, D.. G., 2018. Analysis of the impacts of car-sharing in Bremen, Germany (Final report). team red, Berlin. https://northsearegion.eu/media/5724/analysis-of-the-impact-of-car-sharing-in-bremen-2018_team-red_final-report_english_compressed.pdf.

Shaheen, S., Cohen, A., 2020. Innovative Mobility: Carsharing Outlook; Carsharing Market Overview, Analysis, and Trends. UC Berkeley: Transportation Sustainability Research Center, Berkeley. https://doi.org/10.7922/G2125QWJ

Shaheen, S., Cohen, A., Chan, N., Bansal, A., 2019. Sharing strategies: Carsharing, shared micromobility (bikesharing and scooter sharing), transportation network companies, microtransit, and other innovative mobility modes, Transportation, Land Use, and Environmental Planning. Elsevier Inc. https://doi.org/10.1016/B978-0-12-815167-9.00013-X

Shaheen, S.A., Cohen, A.P., 2007. Growth in Worldwide Carsharing. Transp. Res. Rec. 3483, 81–89. https://doi.org/10.3141/1992-10

Stasko, T.H., Buck, A.B., Oliver Gao, H., 2013. Carsharing in a University setting: Impacts on vehicle ownership, parking demand, and mobility in Ithaca, NY. Transp. Policy 30, 262–268. https://doi.org/10.1016/j.tranpol.2013.09.018

Stolle, W.O., Rodewyk, V., Peine, A., Steinmann, W., Gil, A.R., 2019. The Demystification of Car Sharing. A.T. Kearney. https://www.kearney.com/documents/20152/4956327/The+Demystification+of+Car+Sharing+LOCKED.pdf.

Tchervenkov, C., Balać, M., Hörl, S., Becker, H., Axhausen, K.W., 2018. How much parking space can carsharing save?, ETH Zurich Research Collection. Zurich, Switzerland. https://doi.org/10.3929/ethz-b-000283791