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The environmental benefits of carsharing: the case study of Palermo.

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Abstract

The problems related to traffic emissions are becoming increasingly pressing and serious, especially in big cities where the private car plays the main role in the mobility of people, being excessively used, while walking, cycling and the use of public transport are often seen as secondary options and are hampered by a poorly urban environment. Therefore, solutions must be found to reduce the number of cars circulating in the city and to support the most sustainable modes of transport at the same time, in order to reduce emissions of greenhouse gases and harmful substances. A modal alternative which is of undoubted interest could be represented by carsharing, which is a mode complementary to public transport, often involves walking or cycling and causes a reduction in private cars and kilometers travelled. This paper aims to estimate, therefore, the environmental benefits related to carsharing, using the COPERT methodology, developed within the European project CORINAIR for the estimation of road-transport related pollutant emissions. As a case study, the carsharing service in the city of Palermo has been chosen, where pollution and congestion caused by the excessive use of car are fundamental problems that the administration has to solve. The research has shown that there are benefits deriving from the use of carsharing in terms of reducing emissions of pollutants: there is a reduction of 25% for PM10 and of 38% for CO_2. However, these benefits are limited compared to the emissions of the registered fleet circulating in Palermo.

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Keywords: Carsharing; Emissions; Car Ownership; Copert; Urban mobility.

1. Introduction

The problems related to mobility and traffic in urban areas are now to be considered central and priority in any policy of improving the quality of life. The negative effects, due to an inefficient organization of the transport system and a distorted development of mobility, highlight a scenario that assumes ever more critical connotations: congestion,

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atmospheric and acoustic pollution, energy consumption, accidents, excessive occupation of public land by cars, uneven distribution of the increase in costs and benefits, incorrect use of the land, indiscriminate use of private cars are the problems that make our cities unlivable (European Commission, 2017). While forecast estimates confirm the increase of mobility, many of the implemented solutions don't seem to be fully effective. The huge demand for mobility of people and goods by road makes the problem of air pollution particularly relevant: pollutants such as carbon monoxide, carbon dioxide, volatile organic compounds (in particular benzene), nitrogen oxides and particulate matter are particularly burdensome. Although a gradual replacement of old vehicles is in progress in favor of the latest models equipped with the latest technologies to reduce emissions, the growth of the circulating fleet, the relative mileage and fuel consumption, have an emission production that contributes of air pollution in cities.

Unfortunately, Italy is characterized by a rather old circulating park that has a considerable presence of cars with an average age of more than 10 years and in poor state of repair (ISPRA, 2018). Of course, this type of vehicle is characterized by higher emissions and consumption, as well as less security. The Italian situation is further aggravated by the same conformation of urban centers, which is affected by their historical evolution: the streets, usually small, are often blocked by traffic and low speeds and stop-start traffic cause a greater release of pollutants compared to smooth traffic flow conditions. In addition, the problem of vehicle parking is increasingly present in cities and often people have to spend a lot of time looking for a free parking space, causing a significant increase in fuel consumption and emissions that are added to those due to traffic.

In recent years, therefore, an urban environment in which there are too many cars has been created and the cars are not used all the time but remain long parked. Finding solutions that are effective and can lead to environmental benefits is therefore essential: these could be the qualitative and quantitative strengthening of public transport, restrictive measures for motorized private transport (limited traffic zones, pedestrian areas, road pricing, parking pricing), the promotion of walking and cycling or the development of most innovative sharing mobility systems, such as carsharing (Shaheen and Lipman, 2007).

The aim of this article is therefore to estimate the polluting emissions produced by the carsharing fleet to determine the actual benefits in terms of reducing emissions deriving from the split from private cars to shared cars. For this purpose, the specific COPERT software, elaborated within the European project CORINAIR (Coordination Information Air), has been used. This methodology (Ntziachristos et al., 2009; EEA, 2016) is useful to evaluate the emissions produced by a given vehicle fleet, considering all those factors that influence these emissions. Among these factors there are the parameters representative of the constructive characteristics of the vehicles: the type of engine, the type of fuel, the characteristics of the evolving fluid, the type of emission control device, the characteristics of displacement and power. A second category of parameters includes those that influence the state of the mechanics of the vehicle, such as the level of wear and tear, the state of maintenance, the conditions of regulation. Finally, there are parameters that represent the operating conditions of the vehicle in real traffic conditions, such as speed, acceleration and the characteristics of the environment, such as temperature, relative humidity, road surface conditions, the slope, the outflow characteristics and the driving style of the driver. The remarkable correlation between the emissions and the average speed of the vehicles is undoubtedly an important property of the emission phenomenon, which is taken into consideration by the COPERT model.

As a case study for the application of the COPERT methodology and the determination of the possible environmental benefits of carsharing it has been chosen the service offered in the territory of the city of Palermo. The variables to be included in the model have been evaluated by analyzing the vehicle fleet circulating in the Sicilian city, by collecting data about the fleet and about the characteristics of the carsharing service and by determining the methods of use of the shared vehicle by interviews.

A review of the existing literature regarding the environmental benefits that carsharing brings to the cities where it is developed is carried out in Section 2. In Section 3 are described the carsharing service of the city of Palermo and how the average Palermo carsharing user, whose profile has been obtained from a customer satisfaction survey, uses it. In Section 4, the dramatic situation of mobility in Palermo, which is characterized by an excessive use of private cars and the crisis of public transport, is analyzed. In Section 5, the COPERT methodology applied for the estimation of pollutant emissions is described. Finally, Section 6 and Section 7 describe the results of the research and how much the benefits are relevant.

2. The environmental benefits of carsharing

Carsharing is one of the most prominent examples of sharing economy and many studies have attributed carsharing as a product service system, a use-oriented PSS resulted by a process of "servitization" in particular (Liu et al., 2014; Mahut et al., 2015). In fact, according Boehm and Thomas (2013) a product service system is "an integrated bundle of products and services which aims at creating customer utility and generating value". Servitization in transportation contributes to create a sustainable urban mobility, in order to develop a comprehensive mobility service offer that responds to citizens' needs for flexibility and convenience, removing the need for vehicle ownership (Pinto et al., 2019). Therefore, the main value proposition of the carsharing service is that the users can still receive the benefits of a private car but without concerning the cost and responsibility associated with actually owning a car.

Carsharing allows first of all to make variable the fixed costs of owning a car and it makes the costs of each trip more evident to the user. This contributes to reduce the excessive use of the private car, useful only to try to amortize the annual invariable costs. The shared car is available only when necessary and the choice of the mode of transport to be used by carsharing members is not a decision to be taken rarely but is instead made trip by trip. Considering the hierarchy of transport modes, short trips should, in fact, be carried out on foot or by bicycle, long trips by public transport, such as buses and trains. The car upsets this hierarchy, effectively becoming a mean of transport for all the types of trips: the user, due to its availability, flexibility and comfort, tends to use his own car on every occasion. Moreover, the decision to walk or cycle is not always possible because cycling or walking could be dangerous when adequate infrastructures for cyclists and pedestrians aren't available.

This dependence on the private car leads to having on the road some cars sized for a small number of atypical trips, and therefore oversized with respect to the needs that the user manifests for most of the movements. This means that in general there are cars on the road that consume more fuel, that emit more pollutants and that, due to the larger footprint, amplify the congestion and need more space for parking. Moreover, the purchase of a new car is often delayed and the cars in circulation are old or in a poor state of maintenance.

Carsharing, on the other hand, allows in most cases to choose between several car models depending on the needs arising for each trip and uses fleets that are better maintained. They are also newer vehicles, which have fewer emissions, and in many cases electric vehicles are available.

The need to book every time, having to go on foot or with another mode until the nearest carsharing station and having always clear the travel costs are three characteristics of carsharing that act as deterrent to a systematic use of this service. Therefore, it is understandable that carsharing is in fact a mode of transport that is complementary to local public transport (buses and trams) and to pedestrian and cycling mobility. According to Kopp et al. (2015), carsharing subscribers, especially those using a free-flowing model, are more intermodal and multimodal in their behavior. Cycling trips are much more numerous for carsharing members than non-members, while the shares of private car trips are lower.

Joining carsharing changes the user's habits. It has been observed that every shared car that makes 20,000 km a year replaces at least 8 private cars (ICS Studies Office, 2005). Moreover, according to several studies about station based carsharing, there are reductions in vehicular kilometers traveled by carsharing users compared to previous travel habits, and these are of a different entity in relation to the analyzed city. In fact, Cervero (2003) finds a reduction of about 2% for users of the San Francisco service, Ryden et al. (2005) a bigger reduction (45%) for the city of Bremen.

The reduction in vehicle kilometers traveled, in favor of trips made by public transport or by walking and cycling (Martin and Shaheen, 2011), means that emissions of polluting gases are reduced. This can be more or less significant and must be evaluated city by city, since every urban context has its own demand for mobility and a different transport offer, that is characterized by specific performances.

For example, Vasconcelos et al. (2017), analyzing the Lisbon carsharing system, underline that environmental benefits actually derive only from the use of electric carsharing vehicles, while petrol and diesel vehicles fail to make improvements even though they have better performance compared to Portugal's representative car park. This is due to the fact that the existence of the carsharing system in the city of Lisbon leads to a greater use of the motorized mode, succeeding in attracting some trips that would otherwise be done with non-motorized modes (bicycle and pedestrian mobility) or with public transport, which has a lower environmental impact. In addition, the relocation of vehicles by the operator to rebalance the distribution of the fleet vehicles in the territory involves additional kilometers that reduce environmental benefits.

Martin and Shaheen (2010), on the other hand, analyzing the impact of the carsharing system in North America, find that 46% of carsharing users who own a private car, which drove on average 21,250 km a year before joining the service, reduce to 800 km per year and have sold their car. Moreover, although users who were part of households that did not own a car traveled with a motorized vehicle such as carsharing, emitting pollutants into the environment, they actually gave up buying a car: these families would have, therefore, reported highest emissions in the absence of carsharing.

Carsharing can also have significant effects on reducing the number of vehicles owned by users. In fact, users can decide to sell their car making the decision to use the shared mobility service in association with public transport, or they can renounce or delay the purchase of a second family car, or they can still decide to recover the car in the garage, which means reducing the demand for parking and consequently the time and the kilometers traveled by the citizens to search for parking. These actions once again have positive repercussions in terms of reducing emissions.

Firnkorn and Muller (2015) investigate the propensity of the car2go subscribers in Ulm, Germany, to purchase a new car through online interviews. Researchers reaches the conclusion that driving an electric carsharing vehicle increases the user's willingness to give up buying a new private car or replacing a car among those available in the family. Considering different scenarios, Rabbitt and Gosh (2016) argue that the introduction of the carsharing service in Ireland and in Dublin would imply a big saving in terms of CO_2 emitted thanks to the renunciation of the car ownership by carsharing users.

The survey carried out on the Car2go service (Martin and Shaheen, 2016) records a maximum reduction of 10% of the number of cars owned after joining carsharing; while the reductions observed by the various studies that analyze station based services are of the order of 30-40% (Le Vine and Polak, 2017; Myers, 2009; Zipcar, 2005; Cervero and Tsai, 2004; Cervero et al., 2007; Ryden and Morin, 2005).

Giesel and Nobis (2016) underline how station based and free-floating carsharing lead to reductions of private cars in Germany that are of different entities (DriveNow 7%, Flinkster 15%).

The survey conducted by Martin and Shaheen (2011) on the impact of carsharing in North America shows that the shared vehicles used by the respondents are more efficient than the vehicles normally used in the urban contexts. This differential, referring to the entire fleet and to the minor mileage carried out, determines an annual reduction of 34.5% of greenhouse gas emissions. The analysis of the Car2go free-floating carsharing service (Martin and Shaheen, 2016) translates the reduction in mileage in an estimate of the fuel not consumed and of the reduction of emissions. Overall, there is an average reduction of 10.6% of greenhouse gases for each member of Car2go.

Baptista et al. (2014) estimate that CO2 emissions would be reduced by 35 or 65%, if the shift to hybrid or electric vehicles is promoted in Lisbon respectively.

Chen and Kockelman (2016) analyze the carsharing life-cycle, determining the impacts on ownership, traveled distances, fuel consumption, parking demand and the use of modal alternatives. Scholars estimate an individual reduction in greenhouse gas emissions by 51% after joining the carsharing service. This translates into a 5% reduction in the US, due primarily to the modal split and avoided journeys, and secondarily to the reduction in demand for parking and fuel consumption.

Nijland and van Meerkerk (2017), on the other hand, argue that Dutch car-sharing members emit between 240 and 390 kilograms less per person per year due to the reduction of owned vehicles and the use of cars.

Musso et al. (2012) compare the carsharing fleet and the private car fleet circulating in Rome to determine the environmental benefits in terms of reducing emissions that arise from the adoption of carsharing. The researchers used the Copert methodology to arrive at the result that the most significant reductions were in the emissions of carbon monoxide (-64%) and non-metallic volatile hydrocarbons (-81%).

Finally, Kent (2014) highlight how carsharing has not only beneficial effects on the environment and the economy, but also positive effects on health. Carsharing, in fact, in addition to reducing cars on the road and kilometers traveled on private vehicles, that are the main cause of air pollution, creates a sense of belonging to a community that shares an active and environmentally friendly lifestyle, and it is a testing ground for innovative energy sources and low-pollution vehicles. Therefore, the sharing mobility service would counteract the profound negative health effects caused by the excessive use of the cars, which in recent years has led not only to high mortality due to numerous accidents, but also to climate change, to the dispersion of communities, to the wider spread of diseases related to physical inactivity, such as obesity, or related to traffic, such as stress and anxiety, and to noise pollution, such as insomnia and depression. The excessive dependence on cars of the modern lifestyle does not, therefore, only cause the problem of air pollution, which turns out to be only the issue most affected by public opinion: road traffic emissions, increasing concentrations in the air of ozone, particulate matter, nitrogen dioxide and carbon monoxide, affect both the respiratory system (lungs and airways) and the cardiovascular system (heart function and blood circulation).

3. Carsharing in Palermo

Carsharing was launched in Palermo in March 2009 by AMAT , which still manages the service today. AMAT is the municipal company that engages in public transport in Palermo (bus, tram) and this certainly brings some benefits. First of all, the local government can develop mobility policies promoting the use of carsharing and discouraging the use of private cars, such as the introduction of restricted traffic areas or parking fees. Moreover, the carsharing system should always be developed complementary with public transport and with the infrastructures for pedestrians and cyclists, since only an integrated transport system can meet the mobility needs of citizens, which is necessary in order to achieve a large-scale reduction in the use of private cars. Therefore, a deep cooperation between carsharing and public transport is desirable in order to improve intermodality in terms of pricing and infrastructures: this could happen more easily in Palermo than in cities where private companies are involved in carsharing services.

The local government has joined the national Car Sharing Initiative network (ICS), which coordinates carsharing services in various Italian cities, and the service has been registered under the national IOGuido brand. The service has been characterized by a constant growth both in economic terms and in terms of consents since its birth, in line with the carsharing services in the other Italian cities belonging to ICS network. There has been a steady increase in the number of subscribers, the number of trips, hours of use and kilometers traveled. The growing trend from 2014 to 2017 is shown in table 1.

Table 1. – Statistics of the car sharing service in Palermo.

Year	Subscribers	Reservations	Trips	Kilometers	Hours
2014	1,535	12,053	10,956	458,094	107,044.94
2015	2,884	23,399	20,984	894,051	187,209.12
2016	4,235	34,042	30,009	959,888	206,461.86
2017	5,256	31,913	28,647	848,498	210,264.66

AMAT manages a station-based carsharing system, providing parking spaces reserved for carsharing distributed in the city and often close to places of interest and intermodal nodes. There are two ways to use carsharing: in round trip carsharing the user, once has picked up the car and make his trip, must drop off it in the same pick-up location; in one way carsharing, the user can return the car in a different place from where he picked up the car. In fact, the service consists of 85 reserved car parks, with over 300 available parking slots, distributed in a vast area of the city. Booking can be done via website, via call center or via app.

In 2018, AMAT also developed the "free-floating" service: within a delimited rental area, the user is able to identify the nearest car using the app, pick up it and return it freely on any road within the perimeter, in compliance with the parking regulations. The free-floating service is, therefore, designed for short journeys in time and space and last mile trips, and the fare is based on the minutes spent in the car for this reason. The rental area is 4.88 sq km wide and is located in one of the most central and populated areas of the city (Libertà, Politeama, Resuttana-San Lorenzo districts). In fact, analyzing the data about the carsharing subscribers, it was found that 43.3% of the service members reside in the identified area. For the free-floating service AMAT provides electric vehicles, which contribute with zero emissions to the mobility of an area of the city that is currently very congested and polluted.

Thanks to a customer satisfaction survey (Migliore et al., 2018) developed by AMAT in 2017, it is possible to establish the average carsharing user profile in Palermo and to understand how the carsharing members use the service. The survey consists of an online questionnaire answered anonymously by filling out an appropriate format sent by e-mail to the customers of the carsharing service. The interview consists of 25 questions useful for understanding the degree of user satisfaction and possible areas for improvement. The survey shows, for example, that 29.9% of subscribers have a family of 2 people, but the percentage of those with a family of 3 (22.4%) or 4 people is also high (27 , 3%). These data, together with the fact that the majority of users in the survey claim to own one car in the family (51.7%) and that will not give up it (61.3%), lead to claim that the use of carsharing in Palermo is very often linked to the unavailability of a car, since it is mainly used by the other members of the family, and actually replaces the purchase of a second car.

As regards the fleet, it is important to underline that it consists of 159 vehicles in December 2017. The user can choose between different types of vehicle based on the travel needs (presence of luggage or bulky loads, presence of several passengers): city cars, medium cars, station wagons and van. In table 2, the available cars and their main characteristics are shown for the years 2016 and 2017. The rate, which is hourly and mileage-based, related to the use of the service, varies according to the type of car. For a city car, the rate is 2.40 euros per hour and 0.54 euros per kilometer.

Table 2. – Characteristics of the carsharing fleet in 2016 and 2017.

Year	Car model	Number	Type of fuel	Displacement	Standard
	Fiat 500 L	9	Diesel	1,3 L	Euro 5
	Opel Combo	3	CNG Bifuel	1,4 L	Euro 5
	Volkswagen Golf	6	CNG Bifuel	1,4 L	Euro 6
	Volkswagen Golf Plus	1	CNG Bifuel	1,6 L	Euro 5
	Fiat Panda	10	CNG Bifuel	0,9 L	Euro 6
2016	Valkswagen Polo	20	CNG Bifuel	1,2 L	Euro 5
	Renault Zoe	24	Electric		
	Skoda Fabia	8	CNG Bifuel	1,2 L	Euro 5
	Volkswagen Touran	4	CNG Bifuel	1,4 L	Euro 5
	Volkswagen Up!	33	CNG Bifuel	1 L	Euro 5
	Opel Zafira	3	CNG Bifuel	1,6 L	Euro 6
	Fiat Punto	45	Petrol	1,2 L	Euro 6
	Opel Combo	3	CNG Bifuel	1,4 L	Euro 5
	Valkswagen Golf	6	CNG Bifuel	1,4 L	Euro 6
	Valkswagen Golf Plus	1	CNG Bifuel	1,6 L	Euro 5
	Fiat Panda	10	CNG Bifuel	0,9 L	Euro 6
	Valkswagen Polo	20	CNG Bifuel	1,2 L	Euro 5
2017	Renault Zoe	24	Electric		
	Fiat Doblò	5	CNG Bifuel	1,4 L	Euro 6
	Valkswagen Touran	4	CNG Bifuel	1,4 L	Euro 5
	Valkswagen Up!	33	CNG Bifuel	1 L	Euro 5
	Opel Zafira	3	CNG Bifuel	1,6 L	Euro 6
	Fiat Tipo	5	Diesel	1,3 L	Euro 6

The presence of 24 electric cars and the fact that the cars meet the most stringent European emission standards are one thing in favor of carsharing in the fight against air pollution. The renewal of vehicle fleet is extremely slow in Palermo compared to other Italian cities, with obvious repercussions on air quality. Therefore the circulating car fleet still remains today for a good percentage made up of old and highly polluting vehicles: only 52% of the cars circulating in Palermo belong to the Euro 4, 5 and 6 categories. In table 3 the composition of the circulating fleet in Palermo in 2016 is shown; cars are grouped by type of supply and emission standard.

Table 3. – Composition of the circulating fleet in Palermo in 2016.

Circulating cars	385103
Euro 0	13,54 %
Euro 1	3,74 %
Euro 2	13,40 %
Euro 3	17,31 %
Euro 4	31,61 %
Euro 5	14,68 %
Euro 6	5,72 %
Petrol	55,20 %
Diesel	39,57 %
LPG	4,59 %
CNG	0,51 %
Hybrid/electric	0,13 %

4. Urban mobility issues in Palermo

Carsharing, if widespread and used on a large scale, can contribute significantly to reducing emissions of polluting gases, and this especially because there is a reduction in the use of private cars, which in Italy is a serious problem.

In Italy there are about 625 cars per 1000 inhabitants and only one out of two Italians owns a bicycle. Italy is, therefore, very far from other European countries, such as Netherlands, which has 481 cars per 1000 inhabitants and 1.2 bikes per inhabitant. A comparison between the modal share in Italy (ISFORT, 2016) and in Netherlands (Statistic Netherlands CBS, 2016) is presented in Tab.4.

Table 4. – Comparison between the modal share in Italy and in Netherlands (%).

Transport mode	Italy (2016)	Netherlands (2016)
Pedestrian	17.1	18
Bicycle	3.3	27
Car	64.5	47
Bus/tram/metro	4.4	3
Train	0.9	2
Other	8.9	3

The excessive use of the private car is a problem in Palermo more than in other Italian cities. The motorization rate of Palermo, i.e. the number of cars circulating per 100 inhabitants, is in fact quite high: in 2017 the circulating cars amounted to 388,986, which means that 58.2 cars per 100 inhabitants circulate. The data collected in the Strategic Plan of Sustainable Mobility (PSMS), drawn up in 2007, and in the Urban Traffic Plan (PUT), drawn up in 2010, confirm that the most used mode of transport is the private car (as driver), used in about 35% of cases, while the percentage of those who move systematically by car as a passenger (15% of the total) is particularly significant. In fact, practically half of the cars travel with 1 to 2 people on board (the car occupancy rate is equal to 1.3). The public transport use (which does not exceed 15% overall) is low, but it is positively observed that cycling and walking are a quarter of the total commuter mobility (Figure 1). Urban buses and trams are little used in Palermo because the citizen associates to them a sense of distrust and insecurity, caused by a poor service regularity, by a transport supply not able to meet the mobility needs of the transport demand.

Furthermore, about trip purpose, the survey found that it divides more or less equally between education and work; the peak time is between 7.15 and 8.15 and the travel time doesn't exceed 15 minutes for almost half of the cases. The data show that the trips are short both in time and space and are often made by car, preferring to use the private vehicle, always at their disposal, rather than other modes of transport more suited to these types of movement and more sustainable, such as cycling, pedestrian mobility, bike sharing or even carsharing.

Table 5 shows how most of the trips lasting up to 10 minutes are made by private car, as a driver or as a passenger.

Fig. 1. – Modal shares in Palermo (Source: OD trip matrix for work or study detected by ISTAT)

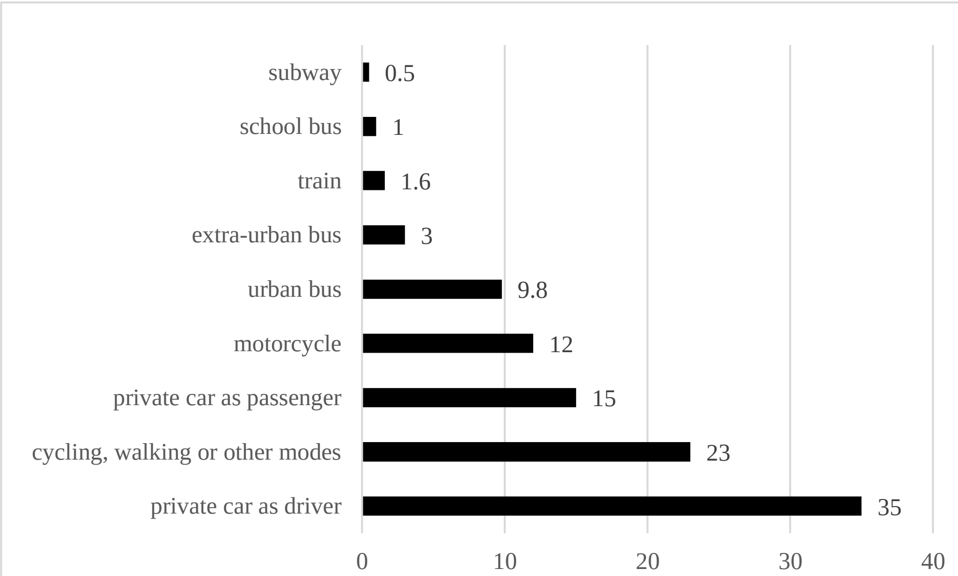

Table. 5. – Passenger trips with Palermo as origin and/or destination by travel time and mode of transport.

Mode/Travel time	10’	25’	45’	70’	TOTAL
Train	92	674	1,347	725	2,838
Urban bus and tram	2,172	6,976	4,625	665	14,438
Extra-urban bus	48	517	1,647	1,518	3,730
School bus	371	564	416	130	1,481
Private car as driver	15,074	23,616	8,798	1,521	49,009
Private car as passenger	12,178	7,808	1,989	197	22,172
Motorcycle	8,540	7,352	1,007	31	16,930
Cycling, walking or other modes	28,450	4,015	408	64	32,937
TOTAL	66,925	51,522	20,237	4,851	143,535

This leads to frequent congestion in the main axes of the city, especially during peak hours, and to the overcoming of the legal limits of the concentrations of air pollutants. Particularly PM10 exceed the limits several times a year (50 µg / m3 is the legal maximum daily value and the maximum number of exceedances allowed in a year is equal to 35), as can be seen from the air quality data collected by control units installed by RAP S.p.A, a municipal company that deals with the environment in the territory of Palermo, reported in Tab. 6.

The greatest responsibility for exceeding the limits of particulates is certainly borne by cars. The strong weight of the car category is given by the high number of this type in the vehicle fleet, compared to light and heavy commercial vehicles and public transport. In fact, commercial vehicles (especially heavy vehicles) have emission factors for PM10 to 3 times greater than those of motor vehicles, but their presence in the vehicle fleet is very low compared to cars.

This is a big problem because the situation of mobility in Palermo is critical. The city of Palermo is characterized by a high demand for mobility due to the presence of attractors poles such as schools, universities, public offices, cultural, recreational and sports facilities, hospitals and commercial poles. In particular, there is a strong component of mobility within the urban area, which constitutes the majority (80%) of the total number of journeys affecting the entire urban transport system; but also the phenomenon of commuting has progressively increased due to the increase in population that resides in the neighboring municipalities. The role as the main city of Sicily also generate a further rate of mobility demand due to the presence in the city of offices of provincial and regional interest, whose presence is strongly centralized with respect to the regional territorial context, but at the same time it is extremely dispersed in the urban area. These realities, together with the strong attractiveness that the city offers in terms of services, commercial and tertiary activities which have a quantitative and qualitative level certainly higher than those in near municipalities, contribute to raising the levels of commuting determined by employees who do not live in the city. Moreover, there is a system of industrial activities, located in three industrial areas (Carini, Brancaccio and Termini Imerese), a situation that determines a further increase in the levels of mobility, generated by home-work journeys and by freight transport, which, in a rather disorganized and pulverized manner, causes non-negligible increase in congestion of the main road network.

Table 6. – Number of annual exceedances of the limit of the maximum daily value of PM10.

Year	Boccadifalco	Indipendenza	Giulio Cesare	Castelnuovo	Unità d'Italia	Belgio	Di Blasi	CEP
2015	5	7	16	12	13	11	69	0
2016	7	16	20	14	20	15	45	13
2017	7	16	16	11	14	7	26	0
June 2018	7	21	15	23	12	n.d	23	6

5. COPERT methodology for the estimation of traffic emissions

The COPERT methodology for the estimation of road traffic emissions is based on the calculation of the emission factors of the main pollutants, starting from the knowledge of the following variables:

- type of vehicle (type of fuel, year of production, displacement for light vehicles or motorcycles and weight for goods transport vehicles);
- average speed;
- kilometers traveled;
- presence or absence of the preheating cycle (given the existence of the three emission contributions: cold, hot and evaporative);
- type of road traveled (urban, extra-urban, highway);
- climatic environment.

Ten pollutants are considered: nitrogen oxides NO_x, biazoto oxide N_2O, sulfur oxides SO_x, methane CH_4, non-metallic volatile hydrocarbons, carbon monoxide CO, carbon dioxide CO_2, ammonia NH3, particulate matter and lead compounds. Generally, for substances such as CO, VOC, NOx and PM (for diesel vehicles only) and for fuel consumption (in g/km), a fairly accurate estimation of emission factors is obtained. For CO_2, SO_2, N_2O, CH_4, NH_3, heavy metals and benzene, the estimates are rather inaccurate, based, in particular, on the amount of fuel consumed.

COPERT V applies the methodology to passenger cars, light commercial vehicles, heavy commercial vehicles, buses, motorcycles and mopeds, classified by displacement classes, type of supply, and anti-pollution standards.

In addition to the emission factors, present in the calculation code of the program, other data must be introduced during the creation of the input database. The COPERT V model associates to each vehicle class and for each pollutant the mathematical functions for estimating emissions and fuel consumption depending on speed. These functions represent average emission and fuel consumption curves; they are derived from emissions measurements for different vehicle types and brands and refer to tests carried out in many European countries, on a variety of urban and extra-urban driving cycles, including those provided for by European regulations. The total quantities of substances emitted into the atmosphere by road transport depend both on the specific emissions of the individual vehicles (emission factors) and on the number of different fleets (petrol, diesel, LPG, vehicles with or without catalytic converter, etc.) and their relative journeys.

The road emissions are evaluated by COPERT as the sum of three types of contributions:

E_{hot} = "hot emissions", produced during engine operation at operating temperature (about 90° C), i.e. when the engine is thermally stabilized;

E_{cold} = "cold start emissions", produced during the warming-up phase. They include those generated during departure at ambient temperature and the effects of preheating. Conventionally, it is the emissions that occur when the temperature of the cooling water is below 70° C;

E_{evap} = evaporative emissions consisting only of non-methane volatile organic compounds, due to the evaporation of the fuel.

Hot emissions are estimated for all types of vehicles, cold emissions for light vehicles, and evaporative emissions are only relevant for petrol vehicles.

6. Results and discussions

It has been decided to estimate the emissions for the carsharing fleet, using the 2016 data. The fleet consisted mainly of methane-powered vehicles Euro 5 and Euro 6, small and medium-sized, and some diesel and electric vehicles. The vehicles of the carsharing fleet are therefore more new than vehicles circulating on average in Palermo, most of which have a pre-Euro 5 standard. For each type of car belonging to the carsharing fleet, classified by displacement, power and emission standard, the kilometers actually traveled in 2016 have been obtained from the data provided by the company.

The data obtained from the customer satisfaction survey are useful for determining some model input parameters. The fact that the carsharing vehicle replaces the purchase of a second car has led to the choice to compare the emissions of the carsharing fleet with the emissions of new cars (Euro 6) fueled by petrol, which carry out a total of kilometers just over the kilometers of the carsharing fleet, i.e. 2,500 km/year for each car. In fact, 53% of respondents claim to have traveled the same number of kilometers by car after joining carsharing, while 41.6% have traveled less kilometers by car. It has been decided to compare the 121 cars in the car sharing fleet with 484 petrol cars, because considering the data about the distances and the number of subscribers it is possible to estimate that in Palermo a shared car will replace 4 private cars. Moreover, the time slot 7-15 is the one in which the service is mostly used, although in the 15-20 time slot and at night time the carsharing remains equally widely used (respectively by 32.8% and 26.5% of the users). This has led to consider the kilometers covered at 70% in peak hours and 30% in off-peak hours.

Emissions of CH_4, CO, CO_2, NMVOC, NO_x and PM10 have been calculated and the comparison between the carsharing fleet and the purchase of new gasoline cars have been made. The results are shown in Tab. 7.

Table 7. – Air pollutant emissions.

Pollutant	Private fleet emissions [t]	Carsharing emissions [t]	Difference [%]
CH_4	0.0258	0.0688	+ 167
CO	0.7309	0.4502	- 38
CO_2	334.5237	208.9314	- 38
NMVOC	0.1751	0.0291	- 83
NO_x	0.077	0.0892	+ 16
PM10	0.028	0.021	- 25

The NMVOC have the maximum reduction (83%), while the carsharing fleet increase the CH_4 and NO_x emissions, because there are diesel and CNG vehicles. CO_2 and PM10, that are problematic for Palermo, have significant reduction with the use of carsharing instead of the private car.

The analysis of the results shows that, although in absolute terms the use of the carsharing fleet has positive effects in terms of reducing emissions of polluting substances, considering the 385,103 cars circulating in Palermo these effects are limited. This is true also taking into account that the modal share of carsharing according to the application of a modal choice model is about 3.5%, therefore it has a fairly limited impact on Palermo's mobility (Catalano et al., 2008; Migliore et al., 2018).

Furthermore, road transport is not the only and most serious source of pollution. For example, about 43% of the PM10 emissions in Palermo is due to heating systems, 42% is caused by road transport and the remaining part is due to industry, agriculture and other types of transport. With regard to NMVOCs, 60% of emissions are produced by waste, while 33% by road transport.

In order to increase the environmental benefits of carsharing in Palermo, AMAT should then increase the number of users, expanding the fleet with electric or hybrid vehicles. Tough the conversion to all-electric is not feasible, the company should allocate all electric cars to the more polluted and congested areas of the city. Furthermore, it is also necessary to reduce vehicle relocation operations, which involve additional kilometers traveled by each shared car, applying optimization criteria.

7. Conclusions

Sustainable mobility, a fundamental principle of the green economy, represents a new way to move and transport people and goods, especially in urban areas, that does not generate negative environmental and health externalities. Carsharing is one of the most important services related to sustainable mobility and could be a contribution to resolving the problem of air pollution in modern cities. Therefore the aim of the paper has been to evaluate the environmental benefits of carsharing and to establish if the impact on the reduction of emissions is considerable or not. To achieve this goal, the internationally recognised COPERT methodology has been applied.

COPERT is a user friendly software tool which can be used for the estimation of road-transport related pollutant emissions. The methodology and speed-dependent emission factors applied have been drawn from previous versions of COPERT, from European research projects and contributions from various European scientific sources, including official national inventories, and this make the model reliable. These are the main reasons for the choice of COPERT rather than other models for evaluating the environmental benefits of carsharing.

The application of the COPERT model to Palermo mobility shows that carsharing brings environmental benefits but in this case the positive effects in terms of emissions’ reduction are limited. Carsharing, however, plays an important role because it is an alternative mode of transport to private car and is complementary to public transport. Public authorities can also reinforce this complementarity by providing the necessary infrastructure of carsharing in the neighbourhood of important public transport hubs and areas that are currently poorly served by transport services. Carsharing could be a valuable aid to sensitize the population towards the pollution problem and orientate the choice towards cleaner modes of transport. Moreover, the presence of electric cars in the fleet could be a useful incitement to the diffusion of this type of vehicles and to the strengthening of the necessary infrastructures. A further and significant contribution that carsharing could give is, instead, linked to the improvement of the air quality within the central areas of the city and the limited traffic area, aimed at the protection of monumental assets and the creation of tourist itineraries less polluted and more enjoyable. Future works will investigate the possible increase in environmental benefits due to the expansion of the fleet, the increase of the users, the increase of the number of electric cars in the fleet and the vehicle-relocation optimization.

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