

Assessment of EV market diffusion through the analysis of conventional cars in the city of Rome

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Summary

The statistical analysis of conventional cars usage considers experimental data of many vehicles and is funded by the Italian Ministry for Economic Development. The study evaluates how many passenger cars of the Italian fleet in a large city can be replaced by EVs. Starting from a lot of GPS data collected for a month and referred to a fleet of 13,339 vehicles registered in the province of Rome, the daily travelled distances and energy consumption are calculated. The results assess how many vehicles are compatible with current EVs performances and how various charging strategies influence the electrical load demand.

Keywords: charging, fleet, GPS, mobility, BEV

1 Introduction

Electric vehicles (EVs) are one of the most promising alternative to replace conventional vehicles powered by fossil fuels. Despite the good performances in energy consumption a barrier to large diffusion of EVs concern the “range anxiety” involving people when driving an EV. The range anxiety definition, according to the Oxford Dictionary [1], is “the worry of a person driving an electric car that the battery will run out of power before the destination or a suitable charging point is reached”. The fear of not having enough energy to complete planned trip is one of the reasons that slowdown the widespread diffusion of EVs. Based on this worry often the first question that people formulate when are considering the purchase of an EV is “how many kilometers does it?”¹. An interesting study on psychological barrier [2] suggest the possibility to overcome perceived range barrier strengthening psychological and educational actions as driver training or service information. At the same time significant technological improvements in Li-ion electric batteries have increased the EVs range [3] exceeding more than one hundred of kilometers between charges as shown in Figure 1. In some EVs the range was extended even over 300 km increasing the battery capacity with the drawback of an excessive rise of the vehicle purchase cost. Furthermore the more recent Li-ion batteries are ready to accept higher levels of charging current allowing to operate a full charge in a shorter time. These complementary technical improvements give the opportunity to use the EVs: when the daily travelled distance required by drivers are compatible with the vehicle range or when the parking duration is long enough to allow an intermediate battery recharging. The “range anxiety” phenomena was analysed [4] evaluating how many times per years an EV reached very low State of Charge (SOC), not compatible with the expected travelled distance. Possible solutions to partly limit range anxiety consider the increase of

¹ Unlike the diesel/gasoline car where people ask “how many kilometres per liter does it?”

battery size and related energy content, in addition to a larger number of charging stations with faster charging.

From these preliminary conclusions of the mentioned studies, it is possible to argue that the real success of electric mobility greatly depends on the ability to meet the people's mobility requests offering a network of recharging stations or, alternatively, a set of EVs having driving range adapted to real-life driving style. Many studies were carried out to analyse the household daily vehicle usage pattern to assess the daily range. The daily vehicle usage distribution for a sample of 2,286 conventional cars in USA [5] was outlined providing the total travelled distances and the days between each refuelling interval. The 50% of sampled vehicles have shown a maximum daily vehicle travel range lower than 168 km while the 90% of sampled vehicles show a maximum travelled distance less than 289 km.

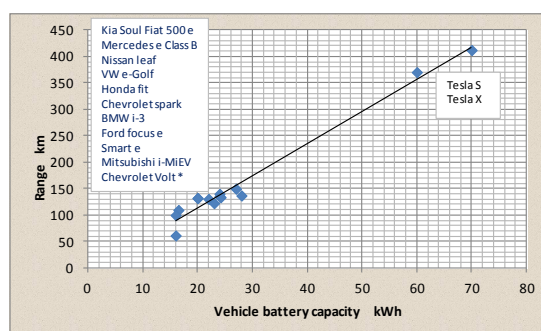


Figure 1: Range of commercial EVs vs. electric battery capacity

To investigate on how much range is required for a day's driving 484 gasoline fuelled cars were equipped with data logger [6] and the data collected were used to analyse daily driving patterns on one year and from which deduce the EVs range requirements. In this research was found that 9% of the vehicles in the sample never exceeded 160 km in one day, and 21% never exceeded 240 km in one day. Accepting some adaptations on 2 days a year (charging during the day or using a gasoline powered cars or shifting the commitments at the next day) EVs with the same range of 160 km would meet the needs of 17% of drivers. Recent advances in space based navigation system technology, as Global Positioning System (GPS), and reductions in equipment cost have suggest to use GPS data for travel surveys. GPS data help to enhance the information collected for transportation analysis purposes and also presents an opportunity for new uses of the data. As example real-world fleet driving data can help to investigate the range of vehicle operation patterns and understanding how much range can be covered by EVs [7].

As said the actual mobility behaviour can be investigated using information collected by GPS systems [8]. These data consent to carry out a detailed analysis of driving pattern for a large number of conventional vehicles running inside a limited geographic area for a defined period. To perform the national project on Electromobility carried out in the framework of the National Research Programme on Electricity Grid ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) acquired from a private company specialized in vehicle monitoring for safety and security applications [9], a set of these data collected with GPS/GSM (Global System for Mobile communications) devices that represent many mobility patterns in the Province of Rome. The selected database, which refers to the whole month of May 2011, was employed to identify data related to the geographic distribution of trips, parking times and total daily distance travelled. Subsequently, these data are used in the present work to determine the possible replacement of conventional vehicles with EVs and to evaluate the grid impact when a lot of EVs are charged in daily use. The investigation considers many types of EVs on the basis of their size (weight, power and battery capacity). Additional information about grid impact was carried out considering different option for battery recharging.

2 Database description

Thanks to the application of satellite navigation systems new methodologies for road traffic analysis and management are now available with interesting consequences for the mobility policy. The GPS/GSM

devices are able to collect, during the vehicles operation, a lot of data including: time UTC (Universal Coordinated Time), vehicle position, instantaneous speed, distance travelled. To complete the information parking time and parking location can be also detected and then classified on the basis of parking time duration. The used dataset was composed of 106,985,577 records concerning to vehicles travelling inside a rectangular area of 129x98 km width that includes the whole province of Rome (Figure 2).

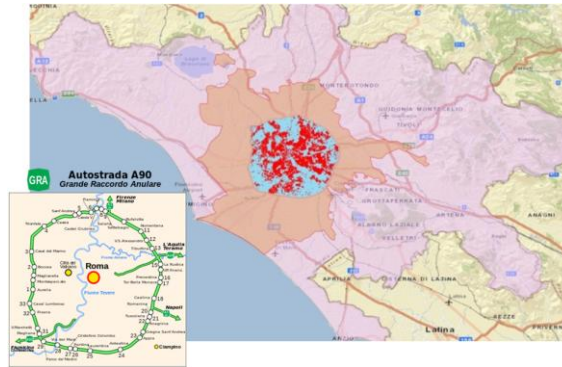


Figure 2: Testing area: highway ring GRA (blue) and drivers home (red dot)

A preliminary cleaning of raw data was carried out to remove spurious data or data concerning vehicles that were not resident inside the testing area but which were only crossing it (i.e. vehicles travelling on A1-highway). After this filtering the remaining vehicles were found to be 80,961 and were identified as vehicles residing in the monitored area. The size of the cleaned sample was equal to the 2.66% of total registered vehicles in Italian Public Register of Vehicles inside the testing area. The analysis was further restricted to 33,193 vehicles which were identified as vehicles resident inside a smaller area delimited by the highway ring of Rome (GRA) (red point in Figure 2). Unfortunately many of them were travelling also outside of the rectangular monitored area with consequently lack of the initial or final position data. To prevent this drawback the dataset was further restricted to 13,339 vehicles characterized by a complete information about the distance travelled (Table 1). The subsample used represent a small portion of total registered vehicles in the monitored area but it is equal to the 40% of the GPS/GSM equipped vehicles resident inside the GRA ring. Data survey is longitudinally oriented (period instead of single days) though only a month of recorded data were used. This is not a long time as required in longitudinal survey but is large enough to catch periodic pattern for daily and weekly trips.

Table 1: Dataset consistency

Surveyed vehicles	GRA restricted sample	Analyzed sample (% of surveyed)	Roma Municipality Area (km ²)	GRA Area (km ²) (% of Municipality Area)
80,961	33,193	13,339 (16.5%)	1,287	346 (27%)

The subsample of 13,339 selected vehicles presents an average monthly mileage of 730 km/vehicle well oriented towards urban trips even if the subsample includes some commuter trips performed within the boundaries of the rectangular monitored area. Therefore the restricted sample is well centered on our investigation concerning the ability to replace conventional cars with EVs in urban context .

2.1 Characteristics of the driving pattern

A weekly shape of the driving pattern is presented below. The share of the fleet in motion, during a week of May 2011, is shown in Figure 3(a) with a double value on ordinate: absolute on the left, and normalized (with respect to the 13,399 vehicles) on the right. In each working day are present two main peaks: in the morning (8:00) and in the evening (18:00). A smaller peak is also present approximately at 12:00. At the weekend the share has a slightly different shape with only two well distanced peak at 12:00 and 18.00. The fleet in motion never exceeds the 9 % of share with a mean value of 4 %. The complement to 100% of the fleet share in motion is equal to the share of vehicles parked: the maximum occurs in the early morning between 3.00 and 5.00 when most of people are at home. The integral of the curve in Figure 3(a) gives the

travel time of all vehicles in motion in a whole day and dividing it by the number of vehicles in motion results in the average daily time spent in travel by each vehicle: it results from 49 to 64 minutes, as reported below the curve. The average speed is shown in Figure 3(b) and the shape depicts a maximum during the night (45 km/h) when few vehicles are running while in daytime, on working days, the traffic congestion decrease the average speed to 18-21 km/h. Whereas during weekend the average speed is less variable and it is included between 24 and 40 km/h. The mileage of whole fleet referred to time is shown in Figure 3(c): the area below the curve represent the travelling distance of all vehicles. The overall daily mileage and the average daily mileage per vehicle are reported in figure 3(c) under the curve. It is noticeable that during the weekend there are less vehicles running but their trips are longer.

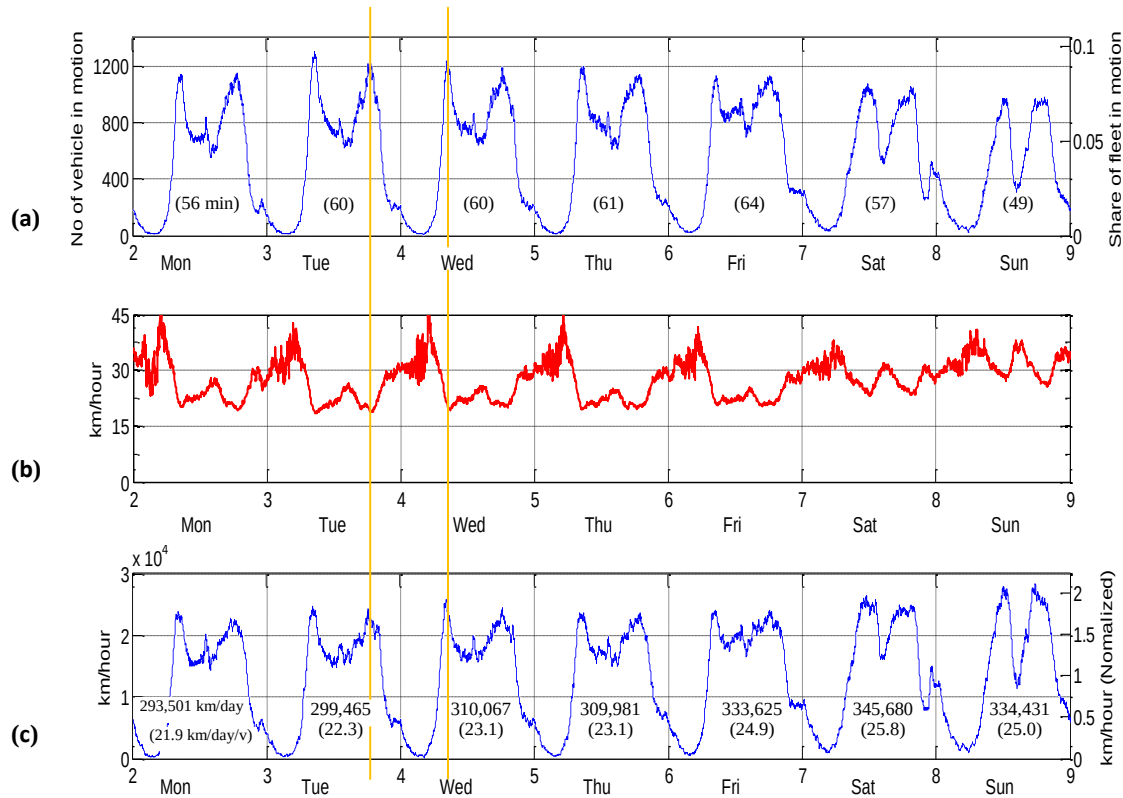


Figure 3: Weekly shape of: share of fleet in motion, average speed and the mileage of the fleet

The relative and cumulative frequency of the distance travelled are illustrated in Figure 4. Figure 4(a) shows the trip length distribution of all trips: 76.6% of them are no longer than 10 km. The average trip length is around 6,45 km. Figure 4(b) depicts the daily distance travelled by vehicle: the 80% of them not exceed 50 km and only 1.2% of travel distances are longer than 150 km. The average daily trip length results 23.2 km while the average weekly mileage results in 166 km. We can observe as many vehicles, on daily or weekly basis, are suitable to remain within the maximum range allowable by a single charge of EVs. Assuming that driving pattern of EVs are the same as for conventional vehicle an early result is the good accordance between domestic charging strategy and the high share of fleet parked overnight. The daily mileage for 98% of vehicles is less than the range of many commercial EVs (120-180 km) available on the market and then one overnight charge is suitable for daily use of EVs.

In Figure 5, the relative frequencies of the travelling time are shown for: single trip (a), in a day (b) and in a week (c). The average single trip time is 14.9 minutes and the 65% of all trips duration result lower than 20 minutes. In Figure 6 the cumulative parking time per day depicts that vehicles are parked for a large part of the day (90%). These first results state that EVs nowadays available on the market can replace a large part of the fleet even if the EVs range is still limited in comparison with conventional vehicles range. A more deep analysis of parking time and of charging mode will be carried out to evaluate the replacement rate of fleet with EVs.

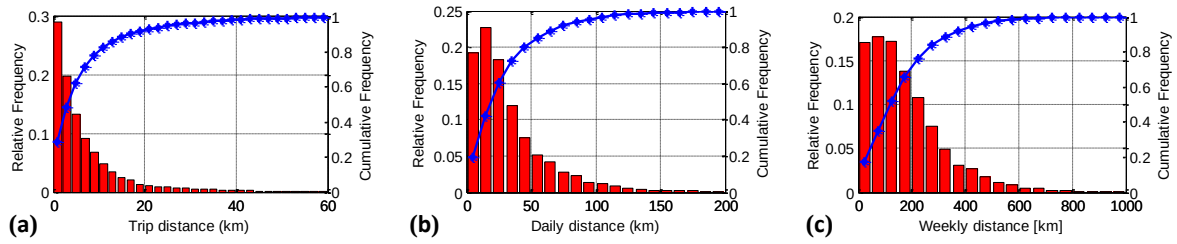


Figure 4: Relative and cumulative frequencies of the travelling distances.

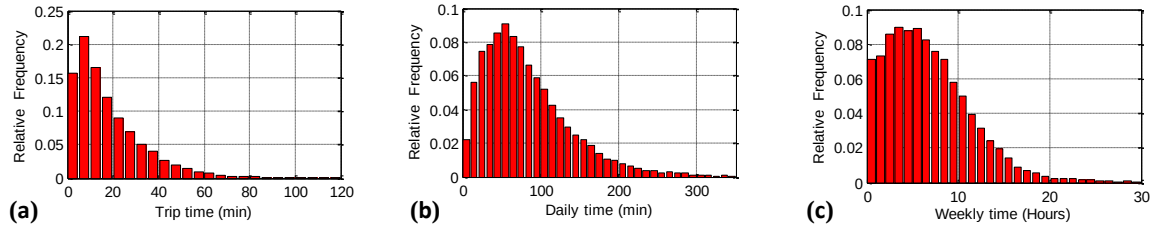


Figure 5: Relative frequencies of the travelling times

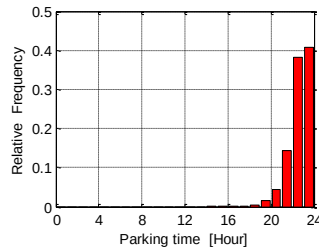


Figure 6: Cumulative parking time per day

2.2 Parking time analysis

The time required to fully charge a battery of an EV is strictly depending both on the battery capacity and by the charging mode (slow or fast) related to the available power by battery charger. Since, in urban areas, almost all vehicles are traveling no more than 4 hours by day, the remaining time is suitable to perform the charging operation of EVs. Therefore knowledge of parking time duration and daily distribution are useful to choice the charging strategy that join the driver requirements with EVs range performances.

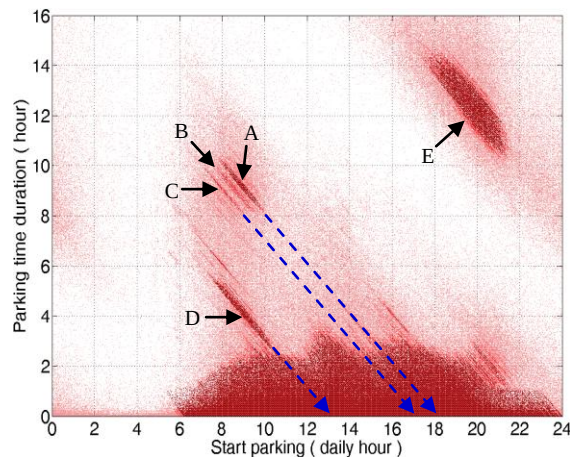


Figure 7: Daily parking start time and parking time duration

The map of a typical daily distribution of parking time for the analyzed sample is shown in Figure 7 where abscissa reports the starting time of parking and ordinate reports the parking time duration in a workday.

Many points are grouped in clouds having a slope at -45° respect to abscissa. The intersection of this straight line with the abscissa gives the hour of parking end. The A cloud shows the vehicles that begin to park in the morning between 8:00 to 10:00 and going away at 18:00. B and C in the same way represent the parking starting in the same time frame but finished between 17:00 and 17:30. A,B and C correspond to the parking related to a complete working day (8 hours). The D cloud shows the parking time related to the half workday (in the morning). In the upper right of Figure 7 the E cloud depicts the parking events that started in the evening and finished in the morning of next day at 7:00 to 9:00 (overnight home parking). In the lower side the large cloud of points are the stops having a time duration lower than 4 hours that started between 06:00 and 24:00. Taking into account only the stops lasting more than 1 hour, the relative frequencies of stops durations are reported in Figure 8 (1 hour bin size). The upper side histograms show the relative frequency of parking time duration that began in the morning respectively during a Parking Start Time (P.S.T.): 7-8, 8-9 and 9-10, while the selected P.S.T. in the evening between 18 and 21, are shown in the lower side. The last bar reports also the parking events that were longer than a day.

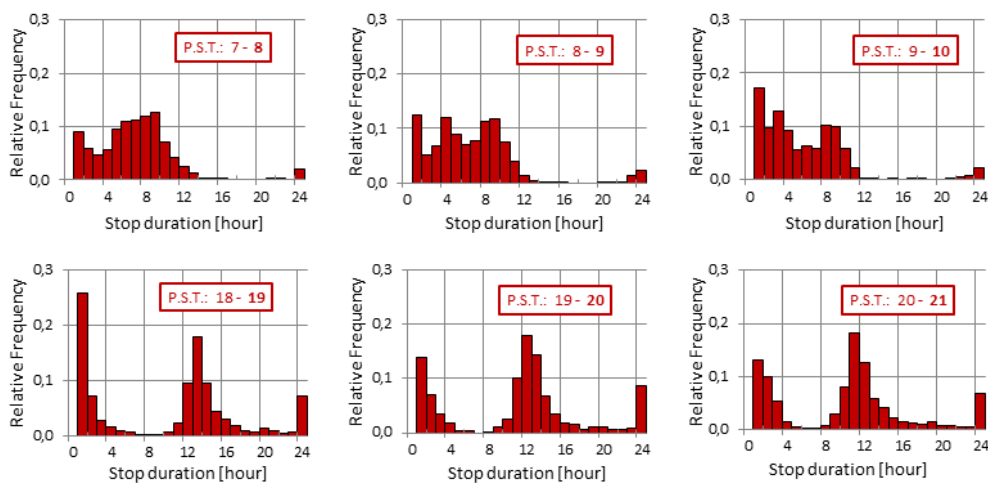


Figure 8: Typical distribution of the stops in the morning, between 7-10, and in the evening, between 18-21.

Referring only to the travelling vehicles in a day, the mean value of parking events longer than eight hours is 1,18 so that all vehicles have at least one long parking event and someone two. Taking into account that all vehicles have the opportunity to charge at least one time during a long parking event, a slow charging was selected as charging mode.

3 Electric mobility feature

To investigate in which measure the urban mobility can be fulfilled by EVs we need to evaluate the mobility supply-demand relationship. The behavioral model of drivers, understood as intensity of use and not as driving style, is described by the statistical analysis of driving pattern (trip length, number of trips, parking duration) and it depicts the demand of mobility. In order to meet the mobility demand the EVs performances are to be taken into account. Specifically the EVs range affects the drivers behavior and the charging strategy which can make more or less attractive the use of the EVs. Charging strategies implemented in the charging model, as explained later, have variable time duration at fixed power. The electric power demand emerging from EVs charging model is added at the electric grid load as passive load without any vehicle to grid (V2G) implementation or auxiliary storage support systems. To have a more complete description five EVs have been considered, each one representing a different market segment, as reported in [10]:

- a light quadri-cycle
- a small size vehicle (typical city-car, four passengers)
- two medium size vehicles (a typical family car and a high-performance family car)

- a large size vehicle

In Table 2, a summary of the performances of used vehicle are reported. Energy consumption were detected by driving test [11] and include the auxiliary consumption to have a complete figure of the energy consumption. The batteries usually used in EVs are characterized by two State of Charge (SOC) limits that define the operative SOC range. Below the minimum or above the maximum SOC batteries might be subject to irreversible damage. To meet these battery safety requirements the model of charge/discharge is achieved by setting the SOC limits to 20% and 95% of nominal capacity. The battery self-discharging is considered assuming a discharging rate of 10% in 30 days when the EV is stopped for long time [12] and then it is sized proportionally to the parking time. At the first time the batteries are assumed fully charged at the 100% of maximum available capacity.

3.1 Charging strategy

The charging strategy implemented is referred to a soft recharge responding to a relaxed drivers behavior. This reflect a charging strategy that can be operated when a parking event is rather long. According with this criterion four parking classes were considered to estimate the sensitivity of EVs conversion as function of the available charging time. The four charging mode are discriminate among them only by the parking time duration: more than one, two, four and eight hours respectively. The charging operation is enabled when the parking time is longer than the defined time threshold, regardless of the actual battery energy level unless the SOC is out of maximum SOC limit. So more than one charging can be performed when daily EV mileage is characterized by more stops each one long enough to exceed the selected time threshold. This multiple daily charging lead to increase the daily mileage which can be performed by EVs. The battery is always charged with a 3 kW AC single phase charging power infrastructure (2.7 kW DC). A charge/discharge efficiency equal to 90% was considered. The charging power is set constant during charging until the occurrence of one of two events: end of stopover or reaching the maximum SOC. The SOC level after a trip is determined on the average specific consumption, as shown in Table 2, and the kilometers traveled by the vehicle. Test is considered passed by the vehicles that completed all monthly trips with a SOC > 20% and therefore considered eligible to travel in electric mode in each time.

4 Electric mobility with overnight charging only

Before proceeding with the analysis on electromobility according to the charging strategy above mentioned, a first result is carried out evaluating the number of conventional vehicles (CVs) that can be replaced by EVs when no intermediate charging is actued. For this aim the largest daily cumulative trip (LDCT) in the month by each monitored vehicle is selected. The cumulative distribution of the LDCT in a month for the whole sample is shown in Figure 9 (green line). The cumulative distribution shows that 29.4% of CVs have a mileage below the small size EV range (86 km) while the 78.3% remain below the distance of 186 km (light quadricycle). The replacement rate increases if the longest daily cumulative trip in the month by each vehicle that exceed the EV range is discarded imagining that it can be made with a different transport mode. In this occurrence the 2nd maximum daily distance in the month is supposed as critical.

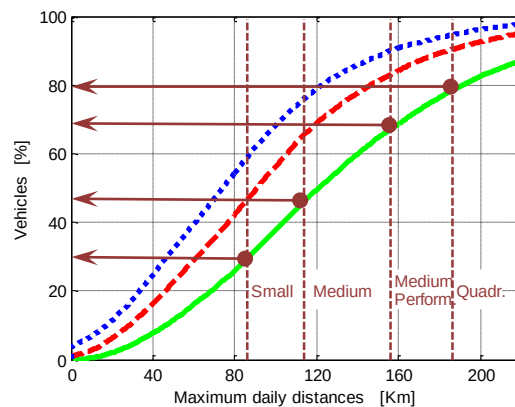


Figure 9: Cumulative distribution of daily distance of sampled CVs

Table 2: Summary of EVs performances

Vehicle type	Weight (kg)	Power (kW)	Battery size (kWh)	Energy consumption		Specific energy (kWh/tons)	Range (km)
				(Wh/km)	(km/kWh)		
Light Quadricycle	450	13	13	70	14.3	28.9	186
Small size	1,080	47	16	186	5.4	14.8	86
Medium size	1,521	80	24	210	4.8	15.8	114
Medium size (high performance)	1,815	125	32	205	4.9	17.63	156
Large size car	2,108	310	85	236	4.2	40.3	360

Then the EV range (Table 2) is compared with the cumulative distribution of LDCT to find the percentage of EVs that can travel in the month starting with the full charged batteries and charging batteries only overnight. In Figure 9 dashed line and dotted line show the cumulative distribution for 2nd and 3th maximum daily distance in the month as critical. The percentage of CVs able to travel for 86 km increase from 29.4% to 46.5% and 58.8% respectively whereas the percentage of CVs able to cover 186 km increase from 78.3% to 90.3% and 94.6% respectively. This first results state that an high replacement rate of CVs with EVs is possible in urban context adopting the overnight charging as earlier depicted by the parking time analysis. The replacement rate is higher when EVs have an higher energy/weight rate (kWh/tons) because despite the larger weight of vehicle there is a larger battery capacity on board.

5 Electric mobility with intermediate recharging

The opportunity to recharge the batteries during the daily parking events is now considered as strategy to increase the CVs replacement. In order to assess the consequence of the intermediate charging strategy on the EVs actual range, various charging operations are simulated on the basis of the parking time. Thus multiple daily charging should lead to increase the EVs daily mileage. The main assumption is to allow a charging session anywhere, even more than once a day, according to the parking time duration and the battery SOC level. Only parking events less than one hour long are not utilized for charging operations. So frequent daily charging can be performed when EVs trips are characterized by more stops long enough to exceed a selected threshold. Analysis highlighted that the replacement of CVs with low range EVs (small size) is largely depending by the charging time available while it is not true for large range EVs, as shown in Figure 10 (a).

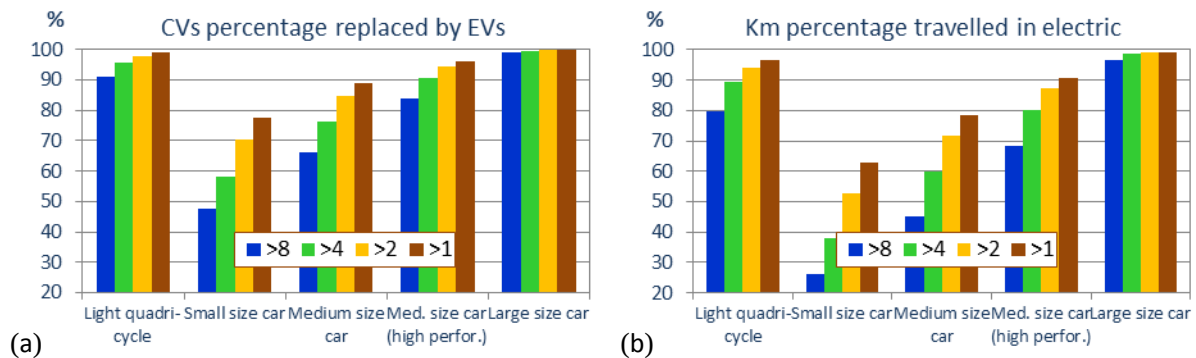


Figure 10: CVs replacement with EVs (a), and respective share of monthly mileage for each EVs type and parking time threshold

In Table 3 are summarized, for each vehicle model, the percentage of CVs replaceable by EVs. For light quadricycle the percentage grows up the 99% for vehicles that recharge batteries frequently (selected threshold of 1 hour). For small size car and medium size car the percentage of CVs replaceable is

increasing respectively to 78% and 89%. Instead light quadricycle and high performance medium size car are less sensitive to the intermediate charging operation. For the light quadricycle model this is attributable to the low energy consumption that discharge the battery slightly between stops. For high performance medium car the high battery capacity smooth the differences. On the whole the intermediate recharge has a positive impact on the number of EVs that can complete their trips in the month. As shown in table 3, the percentage of CVs replaceable, increases for all EVs model when the minimum parking time duration useable to recharge decreases and more frequent are the charging session.

Table 3: Percentage of CVs replaced by EVs for different selected threshold

Vehicle type	Threshold to recharge (hours)			
	8	4	2	1
Light quadri-cycle	91.0	95.6	97.9	99.0
Small size	47.5	58.3	70.5	77.7
Medium size	66.0	76.5	84.6	88.8
Med. Size high perform.	83.9	90.5	94.3	96.1
Large size	99.1	99.7	99.8	99.9

Intermediate charging has effect also on the monthly mileage by vehicles as reported in Figure 10 (b). The percentage of the monthly mileage of EVs are always less than the percentage of replaced vehicles. This happen because the EVs replace a share of CVs characterized by a minor mileage.

6 Power impact on electric grid

The charging strategies also affect the power demand from the grid. The diagrams of the daily power demand for a fleet of EVs fully composed by small size EVs or large size EVs are depicted for each of the four time charging strategies (figure 10). Each charging operation is characterized by a constant charging power and by a time duration variable in relation to the SOC level and/or parking duration. Power demand for the EVs fleet is showed on the left ordinate while the normalized power demand (respect the whole sample of 13,339) is reported on the right ordinate.

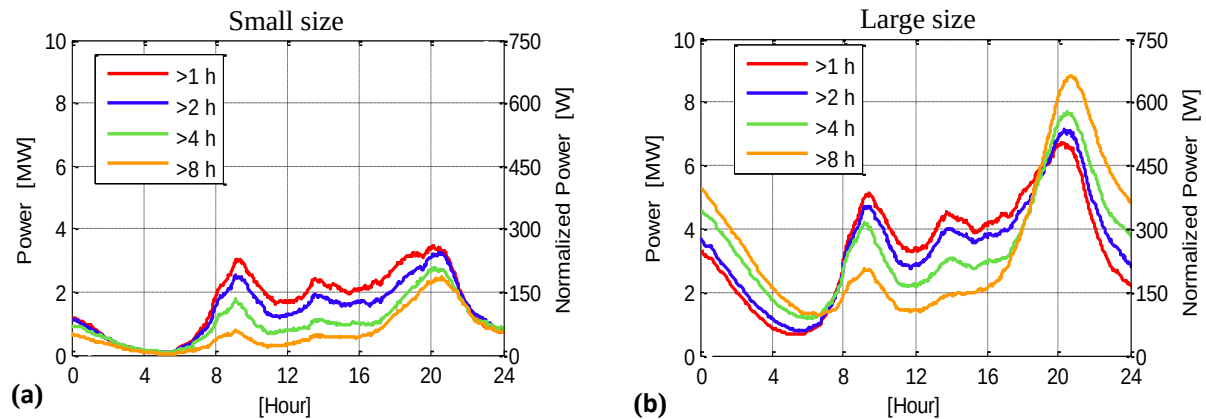


Figure 11: Electric power demand for EVs: “small size” (a) and “large size” (b)

The “small-size” fleet requires lower power than “large size” fleet for two reasons: first one is that the replacement rate of “small size” vehicles is lower than “large-size” vehicles and second one is their minor energy consumption. The shape of daily power demand shows two main peaks: in the morning around the 9.00 and in the evening at 20.00. Furthermore the large vehicles fleet cause an higher power demands in the evening (home recharging). At 20:00, the required power is about 3.5 and 8.8 MW respectively for “small” and “large” size EVs fleet. The charging power demand of small size fleet with the minimum

parking time threshold (red curve) requires more power (many charging) and is flatter because a greater number of stops can be used during the day. For large size fleet the limited charging time available in daytime produces an higher peak in the evening when drivers are at home. The power peak demand is highest for charging strategy of 8h because EVs don't have enough parking time to fully charge the batteries in daytime.

It is possible to extend the results obtained at a generalized scenario simply multiplying the number of vehicles, provided by the scenario, for the normalized values of power demand. Additional power demand at national level is evaluated using the normalized power demand and scaling to the whole Italian CVs fleet adopting replacement rate for the different recharging strategies. The calculated power demand is then added to the national grid load, as shown by the orange curve in Figure 12, in a workday of May 2011. The national grid power demand is characterized from a maximum load of 48 GW [14] around the midday and an average daily energy requirement of 957 GWh. Taking into account that the private vehicles registered in Italy in the year 2011 amount to 37,113,300 [13], a scenario with the replacement of 20% of CVs is considered to estimate the additional power demand. To evaluate the greatest impact possible is assumed a replacement with large size EVs. The expected changes in the electrical grid load, including the actual daily national grid load are shown in Figure 12 (a). Furthermore, in Figure 12 (b) is showed the result of a challenging scenario with a replacement rate of 50%. The maximum power demand is 50 GW for the green curve and 49 GW for the red one while the energy required for both curves is 965GWh. In the second scenario the maximum load demand is 53 GW for the green curve while for the red curve rises to 55 GW. The daily energy requirements rise for both curves at 1,034 GWh.

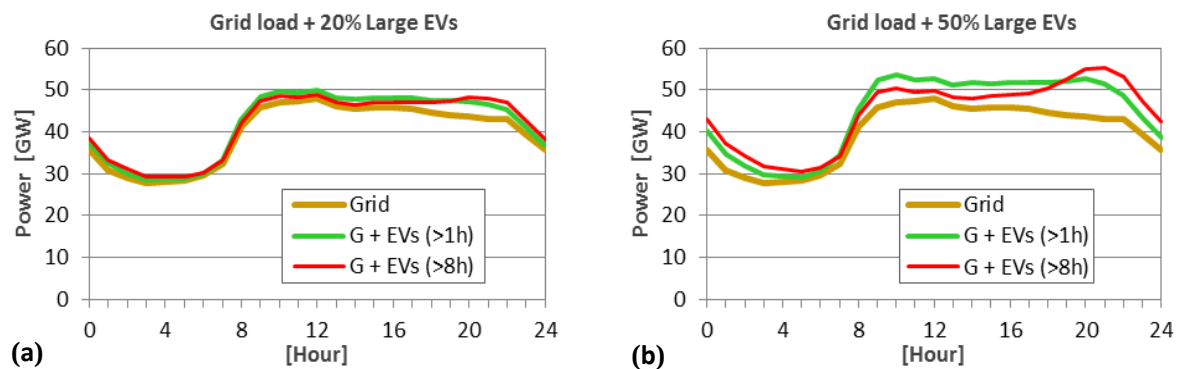


Figure 12: Electric power demand from national grid including the EVs recharging. Share of EVs: 20% (a) and 50% (b) with Grid+EVs and without EVs

In the Table 4, the increments of the power and energy on the grid are shown, in detail. Data refer to the charging strategy with one hour threshold.

Table 4: Power and energy increments on the grid

EVs Percentage	Increased Power		Increased Energy	
	(GW)	%	(GWh)	%
20	1.8	3.9%	46	4.8%
50	5,6	11,7 %	115	12 %

7 Conclusion

In this paper is presented the analysis of urban driving patterns of 13,339 vehicles detected by GPS in May 2011 in Rome. The travelling vehicles have a number of average daily stops longer than 8h equal to 1,18 and the daily mileage for urban mobility, in 95% of cases, is less than 100 km. Four recharging strategy with a threshold related to the parking time duration are considered and two of them selected (8h and 1h). The analysis carried out allowed to obtain the electric consumption of the replaced CVs fleet with four different sized EVs and under four charging strategies. The performed analysis consent to verify that the impact on the grid is acceptable. In fact, the replacement of half national fleet with only large size EVs,

leads to an increase of 10% of both energy and power. Maximum electric power demand for EVs fleet in Rome is forecast to be between 3.5 and 8.8 MW depending on charging strategy and vehicles size. Results showed as GPS data can support the evaluation of impact on the grid by CVs replacements with EVs.

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