EVS30 Symposium
Stuttgart, Germany, October 9-11, 2017

On the distribution of fast charge stations in urban environment

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Summary

Drivers of BEVs feel the range limit as a problem and are requiring BEV equipped with always more large battery capacity. Spreading models with large batteries will bring fast charging (FC) to have even great influence outside home in long trip. Slow charging infrastructures will remain useful at home or wokplace in order to reduce the fast charging rate. In this work GPS data, on the behaviour of a conventional vehicle sample in Rome, are used to evaluate where, when and how much FCs are needed.

Keywords: charging, fleet, GPS, mobility, BEV

1 Introduction

A remarkable technology development in electric battery design and manufacturing has permitted to extend the range of battery electric vehicle (BEV) over 400 km. Today, however, we are still unable to meet all the travel needs. The use of FC therefore becomes an inevitable necessity to overcome this problem. The FC begins to have a good diffusion in Europe, but unfortunately it is divided into 4 different Charging Standards: CHAdeMO, Tesla Supercharger, CCS and GBT [1]. The CHAdeMO system is a Japanese standard in direct current, that charges at 50kW. Currently, at April 2017, with its 4.052 Charger is the most common in Europe [2], [3]. While the Tesla "Supercharger" (120 kW) in Figure 1, at January 2016 is the second most popular standard with 590 stations in the world (73 in Europe) and 3,419 charging points [4][5].

Figure 1: Tesla charging in a supercharger station

The third system is the CCS (Combined Charging System), standard of the European and American manufacturers. Currently in Europe there are 2,376 charging points [6]. Finally there is the Chinese standard: GBT, limited to China.

Very often we talk about FC as the ideal solution to deal the long distance demand. This will surely be true for the extraurban journeys that exceed the BEV range. In the urban context FC stations will be able to provide partial charges, in a *really* limited time.

2 Scope of work

FC is a charging mode that is strictly necessary to ensure extended range to the BEVs. However the time requirement by current FC, with the exception of the Supercharger Tesla, is not exceptional. In fact a 50 kW FC station takes about 30 minutes to recharge the old model of Nissan Leaf at 80% of its 24 kWh battery capacity, ensuring a further 120 km of trip. In future the 50 kW FC station will be not suitable to charge high battery capacity in short time and more than 100 kW could be needed. So in this transitional phase it is necessary to know what FC's real needs are both in quantity and in location. This will allow us to deploy an adequate number of fast and easy-to-install charging station, achieving an optimum level of service. In order to do a good planning it's important to know the power profiles required to supply BEVs. In this case there is the advantage of using peak shaving or load shifting operations to additionally reduce impacts on electric network. Aim of this paper is to verify the real demand of FC in urban area on the hypothesis to replace conventional vehicles with BEVs. Present work is based on data originated by a large GPS data base of about 30.000 conventional vehicles monitored for a whole year.

3 Database description

The data provided by a specialized company [8] include the recording of annual journeys performed by a sample of 30,396 vehicles registered in Rome. After cleaning the raw data, spurious data was removed so that the database was reduced to 391,161,607 records and 29,867 vehicles. For each vehicle, the main and the second homes have been found. Figure 2 shows the differences between the traces of vehicle journeys on February 12 (left) and August 18 (right), 2013.

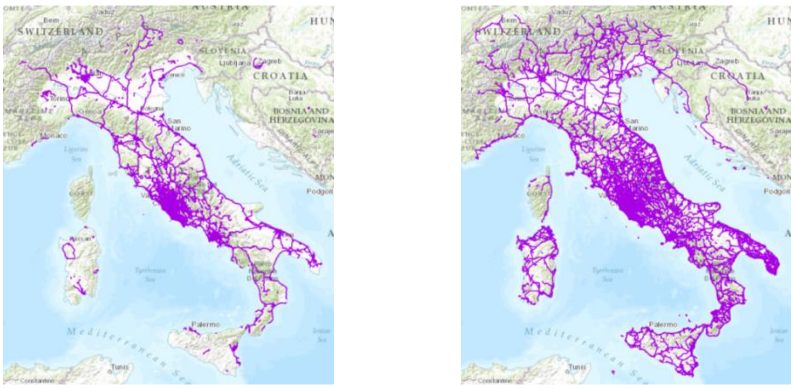

Figure 2: GPS Tracks on February 12, 2013 (left) and August 18, 2013 (right)

It is defined ñtripò the one separated by a stop lasting at least 5 minutes. The relative frequencies of trip length (left) and trip time (right), for the whole month of May, are shown in Figure 3. The average trip length is 9.9 km while average trip time is 20.6 minutes.

Figure 4 shows the frequency for the daily distance travelled (left) and the daily travel time (right) of Wednesday, May 15. In both graphs, the cumulative frequency is shown (scale on the right). Vehicles have different behaviours depending on their residence, whether in the suburbs or in the center, or on the month that is being analyzed . Figure 5 shows that average daily travel distance varies from about 57 km in August to 39 km in January for all vehicles (blue). The same curve is drawn separately for vehicles' residing inside the GRA ring road of Rome (green) and outside (red). Vehicles belonging to the inside area travel about 10 km less than vehicles belonging to the outside area, except for the month of August where the distances travelled are identical.

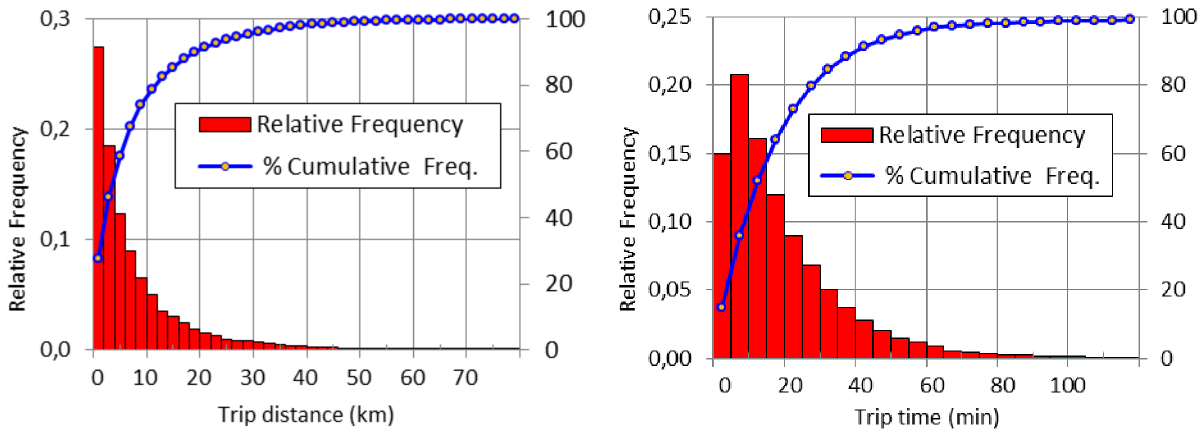

Figure 3: Relative frequencies of trip length (left) and trip time (right) in the month of May

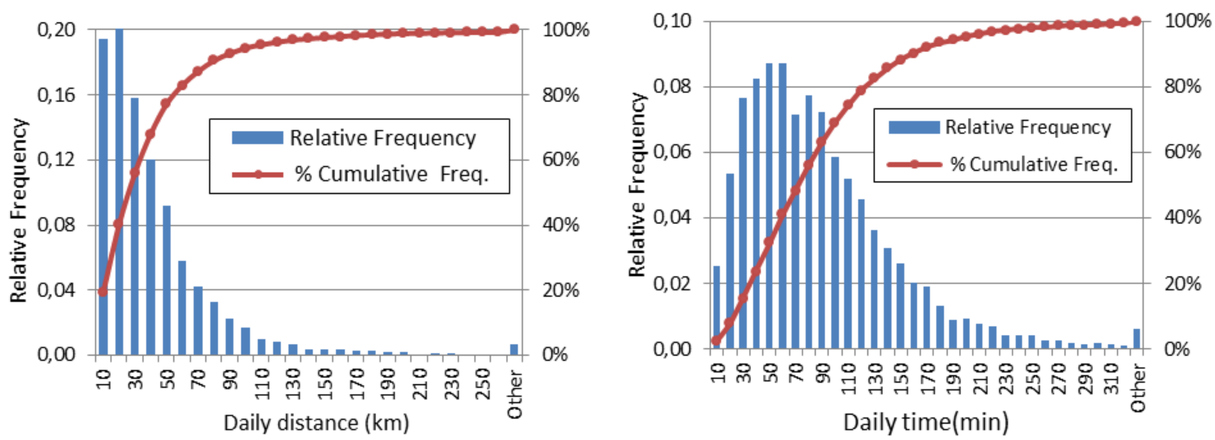

Figure 4: Relative and cumulative frequencies of distance travelled (left) and travel time (right) on Wed, May 15th.

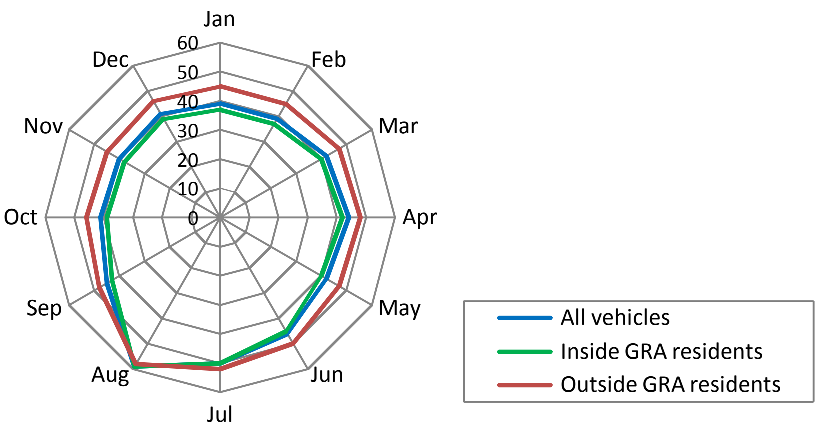

Figure 5: Variation over the year of the average daily travel distance

4 Description of the activities

The work presented in this paper was carried out into 3 steps. In the first one we evaluated the need for FC, both as a frequency and as energy demand. In the second step, we determined how FC's time distribution changes in a day or how varies within different weekdays or various days of the month. Finally, in the third step, we analyzed how the FC requests are geographically distributed.

In the first phase of the work, three EV types with different battery capacity and specific consumption were selected, while in the second phase the charging strategy was established. At the end each selected EV was used to run the same paths as the database vehicles and determine the need to recharge the battery.

4.1 Selecting EV model

The EV type choice was made by selecting the 3 most popular ones from the market [10], for the 3 different classes: small, medium and large. For small vehicles, the Citroen C-zero was chosen, on the left in Figure 6, equipped with a 14.5 kWh battery. The choice for medium vehicles has fallen on the Nissan Leaf, shown in Figure 6 on the right, being the most sold EV. It has been equipped with the new 30 kWh battery since 2016. For large vehicles, the Tesla version S has been chosen with a 60 kWh battery, even if there are even more expensive versions up to 90 kWh batteries. The main features of these vehicles are given in Table 1.

Figure 6: Citroen C-Zero (left) and Nissan Leaf

The table 1 also shows the consumption according to the European Cycle NECD (New European Driving Cycle) [11] and those measured by the American EPA agency in urban and extra-urban mixed use. The range, shown in the table, in contrast to what is indicated in [10], was calculated using the entire charge by applying both NCED consumption and mixed EPA consumption. The range value, using only 80% of the battery, is reported in parentheses. In this analysis SOC never falls below 20%. NECD consumption was used to calculate the amount of battery discharge during travel.

Table 1: Data of the 3 selected vehicles

			Citroen C0	**Leaf 2016**	**Tesla 60 S**
Weigth		[kg]	1,065	1,516	2,108
Lar x H x Len		[m]	1.47 x 1.61 x 3.47	1.77 x 1.54 x 4.44	1.96 x 1.44 x 4.98
Torque		[Nm]	196	254	430
Power		[kW]	49	80	283
Max. Speed		[km/h]	130	144	190
Acc. Time	0-100 km/h	[s]	15.9	11.5	6.2
Battery	Weigth	[kg]	-	294	353
	Capacity	[kWh]	14.5	30	60
NEDC	Consumption	[Wh/km]	126	150	188
	Range*	[km]	115 (92)	200 (160)	319 (255)
EPA Comb.	Consumption	[Wh/km]	-	186	219
	Range*	[km]	-	161 (129)	274 (219)

* The value in parentheses refers to a use of only 80% of the battery

4.2 Charging strategy and other considerations.

Differently by FC the slow charging (SC) is possible at home, at work or where BEVs take a break quite long. Generally it does not involve route deviations and above all does not require extra waiting time, as is the case for FC. For this reason, basic charging is made in slow mode, while FC will come up only if necessary. Given the shortage of the FC stations it is assumed that a FC operation will be take when battery SOC is between 20-25% (5% SOC is the energy reserve to go at closest FC station when SOC limit is detected). SC power level is assumed 3 kW at home and 6.6 kW at work. In addition, BEVs can have "other recharges" at 3 kW, distributed at exchange parks, malls or more. In all these cases charging is carried out only when the stops last for more than one hour. In summary, four different SC modes were considered:

- only at home
- at home, work and "*other recharge*"
- only at work
- at work and "*other recharge*"

For the first two charging modes, the entire sample of 29,867 vehicles was used, while for the last two charging modes, a reduced sample of 6,109 vehicles was take in account, consisting of those who go to the workplace for at least 100 days a year.

5 Results

The results obtained from the analysis of the sample fleet are shown as the number of FCs required and also as their distribution over time and space.

5.1 Evaluation of the number of the FC requests

In order to determine the number of FCs potentially needed, it is assumed that all the vehicles of the sample will be iteratively replaced by one of the three vehicle types listed in Table 1, each one with fixed battery capacity and energy consumption. It is therefore easy to simulate the state of the battery because each trip corresponds to an electrical consumption that reduces its charge. During the stops the battery can be recharged with a SC according to one of the 4 modes. The FC is used along the travel, only when the vehicle is no longer able to run due to lack of charging. For example, suppose that "*only at home* " charging mode is selected. Once the vehicle leaves its residency, it may return at home if the whole distance covered does not exceed its range. Otherwise, a FC is done as soon as the vehicle SOC falls below the reserve level of 25%. FC is halted at 80% of battery SOC. If only one FC is not enough to complete the return trip, another one or more additional FCs will be done when reserve condition occurs. Once the vehicle has reached its residence it can fill up the energy with a SC.

This process, iterated for the 3 types of EV and the 4 selected SC strategies , gives an evaluation of the actual FC requirement. The annual frequency of FCs is shown in Figure 7, for each of the 3 vehicles and for each of the 4 SC modes.

A month-to-month evaluation pointed out that results are not uniform but are very variable as Figure 8 shows for the Leaf test and SC mode "only at home". In the figure on the left we see that in some months vehicles that charge more than 4 days a month are about 5% while in August they are about 21%. This is due to the greater number of long trips due to summer holidays. In Orange, the percentage of vehicles that do not need FC pass from 43% in August to 70% in January and February. The right bar-graph shows the energy partition between SC at home and FC during the trip. The trends follow the charts of the left: in August, the FC's energy is virtually double compared to that of the winter months.

Similar results as those shown in Figure 7 were also obtained from other authors such as the "Rapid Charge Network" [13] project, on a sample of 40 EVs circulating in the UK. In the area containing the network of FCs in the project, it was found that home-charged power is 71% [14] and only 15.9% the percentage of power charged at FC stations. Of the remaining energy, 3.5% is charged in public stations and the remaining 9.5% in other private stations including those at work. The work proposed by Gonzáles and others [15] reports that in Belgium, about 1 million vehicles analyzed, 81% can circulate in electric power with only night charge, and if it is added to the possibility of an intermediate charge during the stops, the percentage rises to 92%. Only the remaining 8% of vehicles need a recharge while traveling. At last, the above-mentioned report of Idaho National Laboratory [7], reported that 97% charging were done at home or at work and only 8% of away-from home charging events was performed using FC.

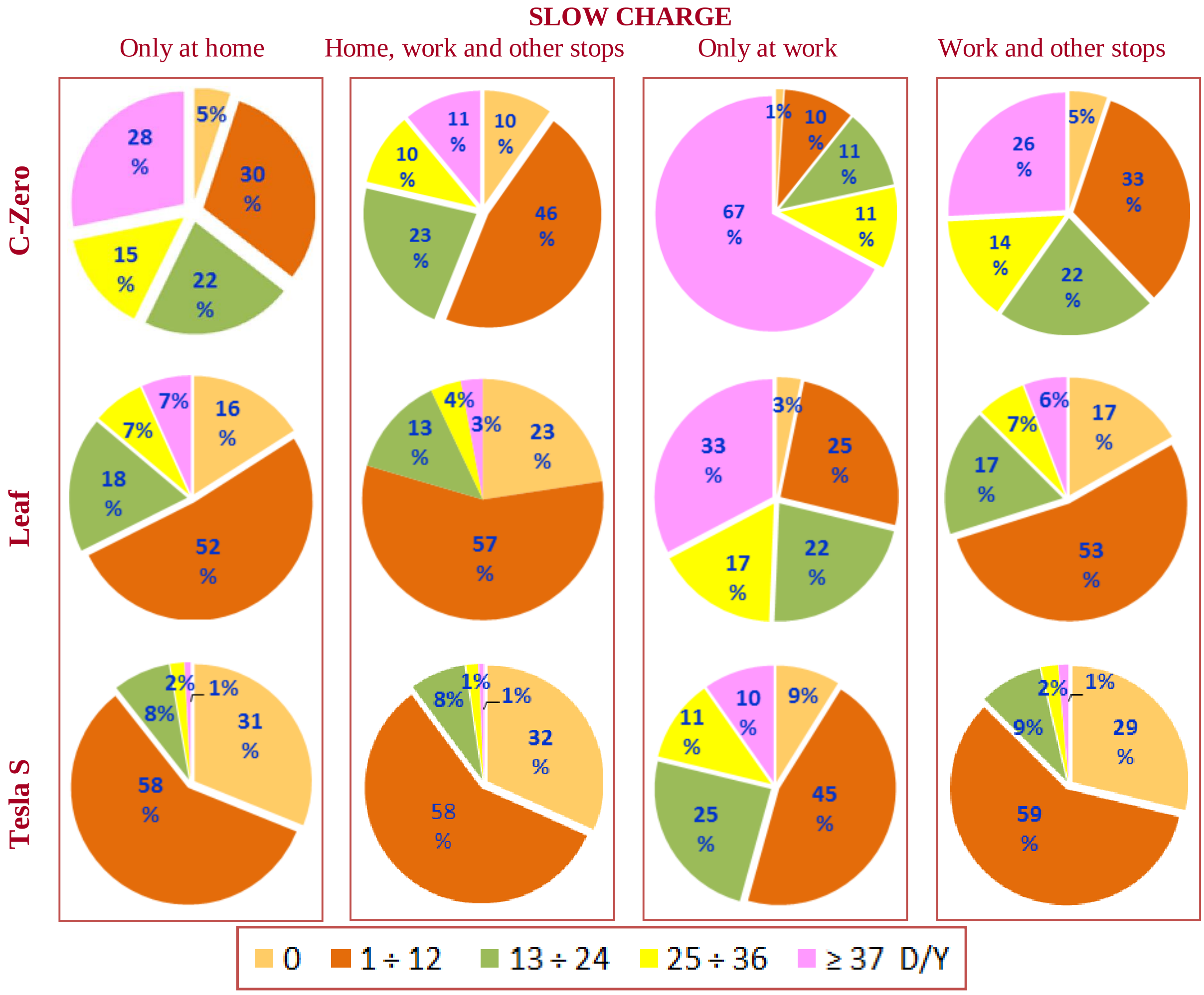

Figure 7: Annual frequency of FC carried out during the travel for: C-Zero, Leaf and Tesla

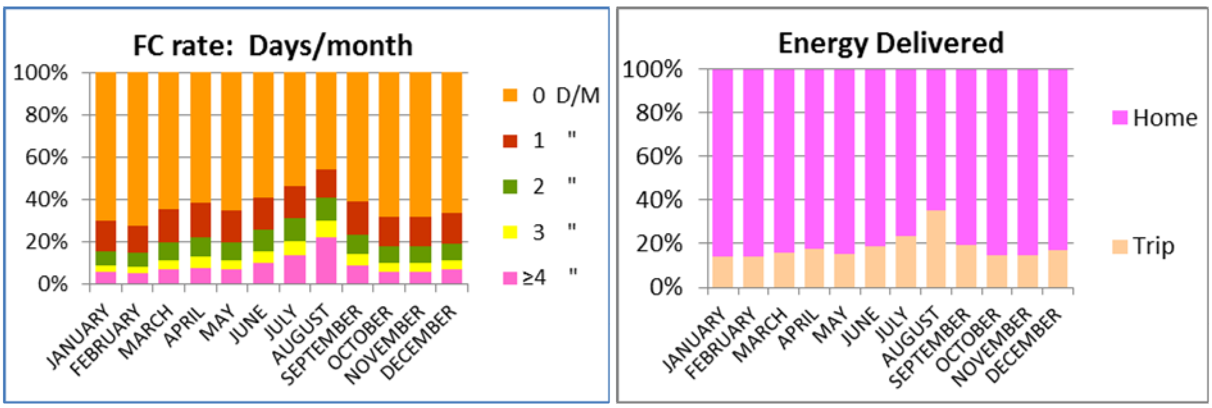

Figure 8: Percentages of the No of days with FC per month (left), and where the energy is taken (right), for the Nissan Leaf with SC only at home.

5.2 Distribution in time of the FC delivered energy

This analysis has been carried out only for the medium type of EV. The Nissan Leaf is chosen because, unlike small vehicles, it is more suitable for medium and long journeys and, at the same time, it has a moderate vehicle cost compared to that of Tesla. From the analysis on the Nissan Leaf we are able to identify all the trips for which the destination cannot be reached due to insufficient battery charge. Depending on the missing kms, and knowing that FC will be done at 80% of the SOC, it is easy to determine the number of FCs required to complete the trip. In Table 2, the FCs needed for the whole sample and for a whole year are shown. Since it is unlikely to have more than 3 recharges for a trip, it is assumed that trips requiring more than 3 recharges are going to be carried out with other means of transport. In this way the amount of eliminated trips would be 12,000, 2.6% of the total, which represents less than one trip per vehicle a year. About 80% of the total number of trips requires only one FC.

Table 2: Mean value of FC operations.

N° FC	N° trips	Total FC
1	364,782	364,782
2	71,776	143,552
3	21,391	64,173
Ó4	12,225	56,390
TOTAL	**470,174**	**628,897**

In one year a vehicle requires, on average, 19.2 FCs for an overall duration of 7.42 hours while the average number of trips, for each vehicle, requiring one or more FCs are 15.3, as shown in Table 3. The energy supplied is 12.1 kWh, on average, for each FC and lasts 23.2 minutes, where 34 minutes and 16.5 kWh are required for a complete FC.

Table 3: Annual average value for vehicle.

N° of FCs	19.2
N° of trips with FC	15.3
kWh x 1 FC	12.1
Hours spent by the vehicle for FCs	7.42
Minutes for one FC	23.2

These values are also in accord with those obtained from the "Rapid Charge Network" [14] project. In fact, here the average charge energy is 8.9 kWh (with 24 kWh old model Leaf battery capacity) compared to our 12.1 kWh (30 kWh new model Leaf).

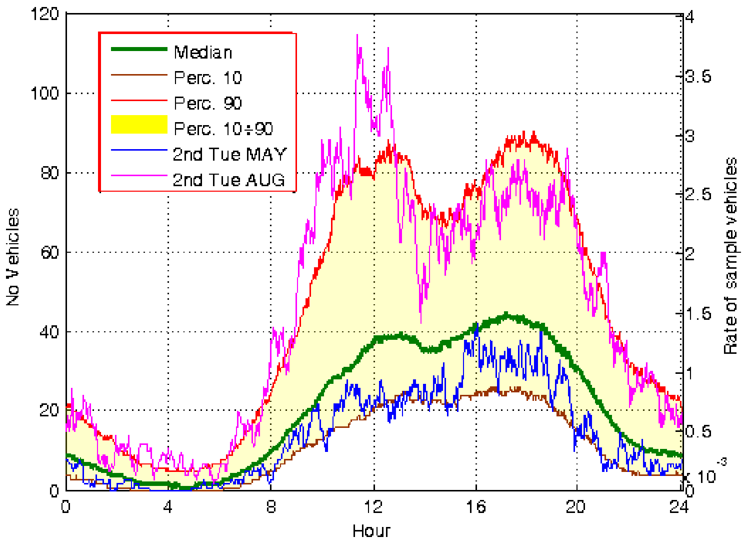

Figure 9: Number of the EV on charge during the day.

The amount of energy that has been charged and the duration of the recharges determine the electrical demand distributed over time, which will be useful to understand how many FC station are needed to meet these loads.
Figure 9 shows the daily trend of the vehicles in charge at the same time for the 2nd Tuesday of May (magenta) and August (blue). On the left-vertical axis, the number of vehicles in charge is shown, while on the right the same value is reported as rate with respect to the sample. As there is a great variation between the various days of the year, the green curve was also reported, which at each point represents the median of the 365 points available. The 10th and 90th percentile lines are also reported.

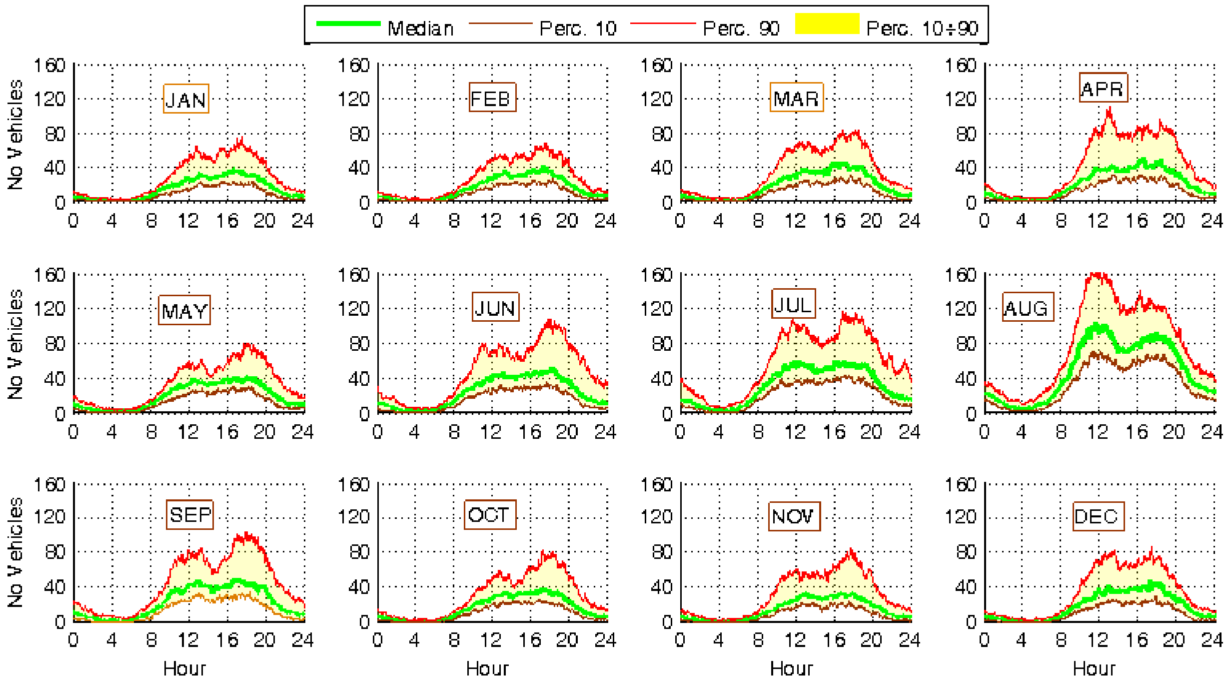

Figure 10: Daily trends in No of EV in charge.

These distributions agree with the results of the Idaho National Laboratory in the "EV Project" [12].

Variations between different days depend heavily on the month and on the day of the week. The monthly variation is visible in the graphs of Figure 10. In the winter months, like January and February, there is a lower number of claims that increase in the summer months, particularly in August. Unlike the other months, the maximum peak in August is at 12 o'clock, highlighting the presence of intense number of trips in the early hours of the day. In the remaining months, the maximum peak appears in the evening to indicate that the request in part comes from the sum of more mid-distance trips. Weekly trends, in **Errore. L'origine riferimento non è stata trovata.**, show the relative daily variations. In the lower part of the figure the 3rd week of May (blue) and the 3rd week of August (red) are shown. We can see that while the week of May is attending values close to the median, the values of the August week even exceed the 90 percentile line.

5.3 Spatial distribution of the FC energy demand

The results from the work described in the previous paragraph have also been used to perform a spatial analysis to find the points where there is a need for fast charging. The monitoring data used include, for each vehicular trajectory, the geographic locations that have been recorded at a variable sampling rate: every two kilometers on the urban road network and every 30 seconds on the motorway network. Given these geo-referenced data, it is possible to obtain the spatial distribution of FCs occurred over the analyzed area. This is made by identifying the coordinates of the points where the battery SOC falls below the critical threshold. Here, the vehicle recharge only the amount of kWh needed to complete its journey toward home. From the so-identified points in the area, we can get the distribution map of the potential FC demand. In order to quantify spatial variations in event intensity, Geographical Information System (GIS) techniques can be used to create a density surface. Kernel Density Estimation (KDE) technique was used to generate maps, using the tool within the Spatial Analyst extension of ArcGis software [16]. techniques can be used to create a density surface. Kernel Density Estimation (KDE) technique was used to generate maps, using the tool within the Spatial Analyst extension of ArcGis software [16].

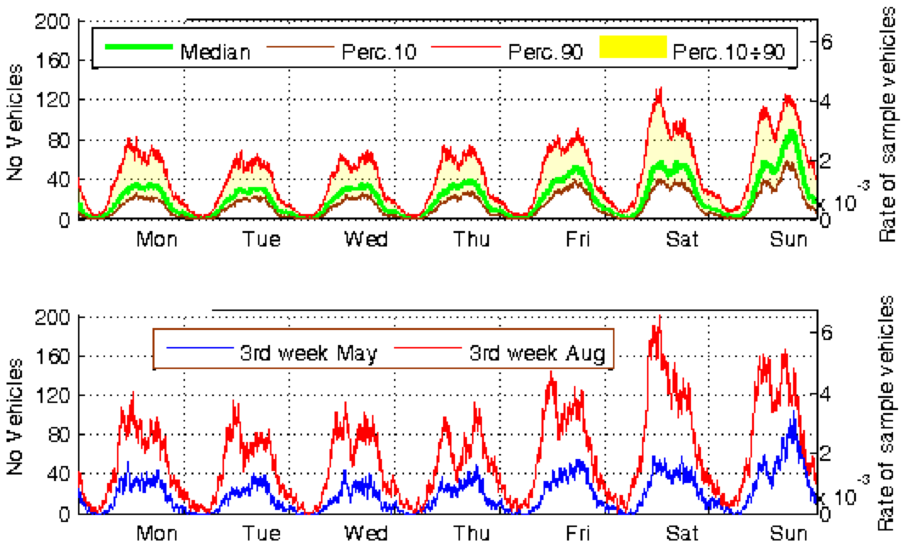

Figure 11: Weekly distribution of vehicles that are using FC.

The study area is discretized in a grid of cells (pixels) and for each cell a density value is subsequently calculated. For each charging point, a circular surface with the maximum value in the point is generated with a kernel function that decreases progressively to zero when the distance from this point reaches a predetermined value (bandwidth). The volume below the surface is equal to the value associated with the point (in this case the amount of charge). The density for each cell is calculated by adding the values of all the surfaces to the center of the cell.

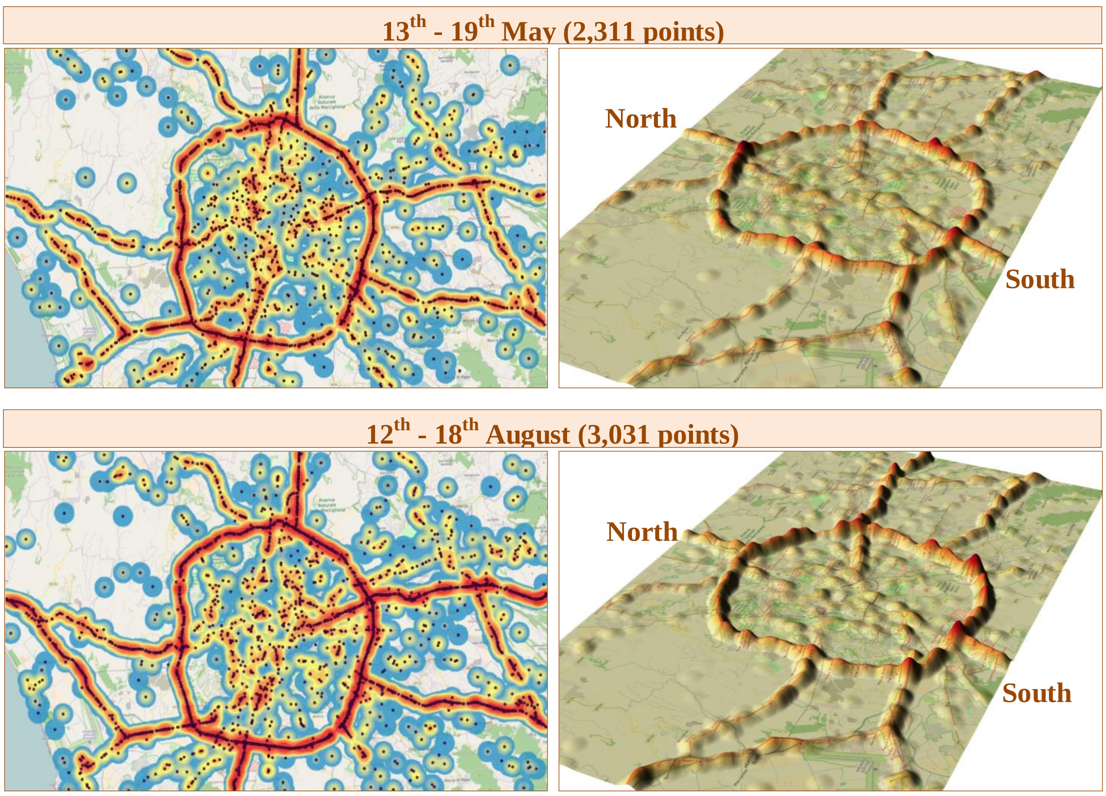

Figure 12: Spatial distribution and energy demand of FC in two different weeks.

For this evaluation, the pixel size used is 50 meters and the bandwidth is 1000 meters.

Figure 12 shows the maps for the area including the GRA ring road plus the surrounding area, for the weeks 13-19 May and August 12-18, and for the Nissan Leaf scenario with SC only at home.

As expected, charging demand focuses on roads where traffic flows related to a medium and long travel distances. Additionally, in the week of August 12-18, there is a significant growth of the number of charging points (3,031 compared with 2,311 in the May), since in this week of August long journeys, from and towards the holiday resorts, increase. If we observe the inside of the GRA instead, we can notice that concentrations in the city are mainly on the primary roads.

6 Conclusion

The availability of a dense network of FC stations would certainly contribute to faster EV development but at the expense of substantial investments that might be partly inadequate for the future. Both the works done here and those collected in literature, agree that quickly recharged energy represents a modest percentage which in the various situations is maintained at around 15% of the total. Although modest, this percentage is the one that solves the critical situations in several cases and even if not used, its presence gives the driver the tranquility of traveling without worrying about lack of energy. Unfortunately, despite the charging speed, almost no one likes to stop for 30 minutes, during the trip, to recharge. And this is the only factor that puts at risk the inadequacy of the current pillars for the future.

Therefore, in these conditions, in the realization of the FC network it is good to aspire/work towards to the optimization of their distribution rather than to a massive diffusion. We must also take into account that what has been experienced with photovoltaic systems has demonstrated that, once the marketing starts, the costs tend to decrease considerably even with performance improvements.

This work has been addressed in the diffusion of quick charging systems by optimizing choices to determine the position and number of predictable columns.

Acknowledgment

This research activity is part of the project on electro-mobility, carried out in the framework of the ñResearch Program on the Electricity Systemò, included in the agreement between the Italian Ministry for Economic Development and ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development.

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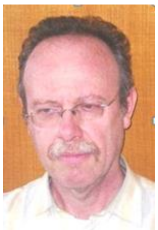

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