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Public charging infrastructure planning, charging gap as a data-driven indicator

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Summary

The global need to reduce transportation emissions will lead to the short-term decline of internal combustion engines in mobility systems. Charging infrastructure development is crucial to electrify the current transportation systems. Charging infrastructure planning uses electric vehicle supply equipment (EVSE) to electric vehicle (EV) ratio as a planning indicator. A more comprehensive indicator that balances electric mobility infrastructure supply and demand is proposed with a power and spatial perspective (kW/km^2). This indicator was based on EV registrations and EVSE distribution. The charging gap is mapped in Milan using QGIS and the suitability of the placement is analysed via nearest neighbour analysis.

Keywords: EVSE (Electric Vehicle Supply Equipment), EV (electric vehicle), Municipal government, Policy, case-study.

1 Introduction

The stringent emissions directives pushes forward zero emissions mobility [1]. Dedicated supporting infrastructure is required to accelerate the transition towards electric transportation [2, 3].

As charging EVs requires more time than refuelling conventional vehicles, the increasing usage of EVs requires strategic planning to ensure an efficient infrastructure with minimal charging queues [4].

Planning of charging infrastructure, should consider the size of the EV fleet but there are no established guidelines, on the EVSE to EV ratio [5]. As presented in Table 1, the different European member states have dissimilar values of public EVSE per EV.

The EVSE to EV ratio can be a deceptive indicator since it doesn't consider the distribution in the territory and the demand of charging facilities. To fill this gap this work proposes an energy driven investigation of the charging network and EV fleet. A more comprehensive indicator denominated as “charging gap” is thus introduced to identify imbalances between EVSEs and EVs currently present in Milan.

Table 1 : EVSE to EV ratio in Europe, source [6].

Country	EVSE to EV ratio
Norway	1/24
Italy	1/8
Netherlands	1/5
Sweden	1/18
Portugal	1/22

2 Case study

The case study of this work is Milan, to examine the Milanese context the first belt municipalities were also included making a total of 105 analysed municipalities. Relevant studies done in a similar region can be found in [7, 8].

Except for the municipality of Milan where its low motorization rate leads to most trips being made by public transport, in the more broader Milanese Urban Region the majority of work commutes are with the car (Regione Lombardia, 2015) meaning that is a strongly car dependent area.

Also, about the region is that Milan has the highest density of electric vehicles and Lombardy amounts for one fifth of the whole Italian EV fleet.

Policy wise, the Milanese municipality gives incentives to the acquisition of an electric car, free parking and free access to the congestion charge area (area C), also in the Milan Sustainable Urban Mobility Plan (SUMP, 2018) there are transport policies supporting electric mobility.

In this context, Milan can be a relevant case study of electric mobility charging supply and demand since it represents a contemporary urban region in the transport electrification transition.

3 Methods

The placement and planning of charging points has been described in literature, an overview of the different methodologies can be found in [9].

Charging infrastructure planning should guarantee that supply can cover effectively demand without overinvesting resources [10]. In an ideal scenario, planning of new EVSE installations would include data of future charging demand in energy terms with a fine spatial and temporal resolution. That would require an extensive dataset of EV adoption rates, mobility patterns and charging behaviour [11]. The approach here described attempts first to describe the current charging situation in Milan before forecasting demand and supply.

In this study, the charging demand is defined as the amount of power needed to charge the fleet of electric cars and supply as the amount of power provided by the EVSEs. To compare them the common unit – kW/km^2 is used. The data was aggregated at a municipal level (smallest scale electric vehicle registrations were available) with the administrative borders of the municipalities being extracted from ISTAT (The Italian National Institute of Statistics), the results were then mapped in QGIS. This part of the study tries to answer at a macro scale the research question, “how many chargers are needed?” and identify in Milan the most critical areas regarding charging development.

To look at where these chargers should be located an assessment at the location suitability is also made recurring to a nearest neighbour analysis.

3.1 Charging demand

In the Milan urban region, the electrification rate of the vehicle fleet is still quite low (0.2% for the region) (2020). Electric vehicles need to be charged according to how much they are driven and the driving conditions. Charging demand in this study is defined as the amount of energy per day per area required to operate the EVs. To calculate the charging demand the following five variables were used, as described in equation (1).

$$De = \frac{Nev * C * D}{T * Ma} \quad (1)$$

Where De is the demand (kW/km^2), Nev is the number of electric vehicles, C is vehicle consumption (Wh/km), D is distance travelled (km), T is time availability to charge (h) and Ma is the municipal area (km^2). The number of electric vehicles registrations per municipality were extracted from the ACI open database opv.aci.it/. The vehicle consumption was estimated with the average travelling velocity. Equation (2) was created based on the driving cycles of the Downloadable Dynamometer Database anl.gov/es/downloadable-dynamometer-database.

$$C = 0.0012\bar{v}^3 + 0.2195\bar{v}^2 - 14.993\bar{v} + 321.7 \quad (2)$$

Where C is vehicle consumption and $\bar{v}$ is average travelling speed. The average car speed travel of each municipality was extracted from ISTAT (2011) database. D, the average distance travelled was also extracted from ISTAT (2011) and it was assumed that the average distance travelled by ICEVs and EVs would be similar[1].

The time availability to charge variable is defined as the available time during a day that an electric vehicle could be plugged, the 8h value was selected from the range of average parking duration described in [13].The municipal area was extracted from the ISTAT administrative shapefiles.

3.2 Charging supply

Charging stations can differ significantly in capacity, some can charge multiple cars with high power while others are limited to slow charging a single vehicle. There are a total of 398 charging stations in the 105 municipalities of the Milanese first belt. In this work, only conductive EVSEs were considered due to the low adoption of other charging technologies [14]. To calculate the charging supply, five variables were used as described in equation (3).

$$S = \frac{Ns * Np * P * U}{Ma} \quad (3)$$

Where S is the supply (kW/km^2), Ns is the number of stations, Np is the number of plugs, P is the power of the EVSE (kW), U is the usage of public charging and Ma is the Municipal area (km^2). The number of stations, electrical power and number of plugs were extracted from the openchargemap.org/.

In the usage of public charging variable, 10% was used as a minorant since according to [6], 10% of Milanese EV drivers recur exclusively to public charging.

3.3 Charging location

Fast chargers clustered along major roadways and slower chargers near destinations are more valuable than poorly located EVSEs. To capture the value of a EVSE location a nearest neighbour analysis is performed. To

[1] EVs drive on an yearly average 5% more than ICEVs according to 12. Erik Figenbaum, M.K., Beate Elvebakk, *Electric Vehicles – environmental, economic and practical aspects. As seen by current and potential users.* 2014..

perform this analysis the same scale and area was selected with Milan and the immediate neighbouring municipalities were selected to allow for a more in-depth look.

A distinction was made regarding the power of the chargers since these indicate different applications. Fast chargers installed along highways and high flow roads, aim to extend the vehicle range analogously to a refuelling station. The goal in this case is to recharge the car in the fastest way possible, enabling the driver to continue his trip. Slow chargers, on the other hand are not so time constrained since they imply that the driver is doing another activity while the car is recharging, staying at home, at work, or participating in a recreational activity like shopping or eating out.

Chargers were classified as fast, when power was superior to 22 kW and slow if the value was equal or below 22 kW. To analyse the sufficiency of the location, a nearest neighbour analysis was produced in QGIS calculating the average distance between chargers (slow and fast), car parks and the road network. The car park data was extracted from OSM and the road network from Municipal open data portal.

4 Results and discussion

To assess the aggregate sufficiency of the supply in comparison to the demand, the charging gap CG (kW/km^2) is created as described in equation (4).

$$CG = S - De \tag{4}$$

The choropleth map of the charging gap over the Milan first belt is displayed in Fig. 2. A colour ramp was used to visualize the charging gap distribution. Negative values represented in red indicate that there is more demand than supply and positive values represented in green indicate the opposite. Values close to zero are represented in brown and indicate a balanced situation. Null values represented in a hatched pattern indicate a lack of both supply and demand meaning that there are no EVSEs and EVs.

4.1 Positive charging gap

Positive charging gap municipalities range from [0,375] kW/km^2 and represent 67% of the analysed territory. The Milan with its metropolitan system has 72 kW/ km^2 charging gap value. This statement contradicts the results shown by Smart Mobility Report E&S (2020) that highlights Milan as having an insufficient charging infrastructure. These opposing statements might be explained by the fact that Milan is the main attractor of workers and travellers at the regional scale, meaning that by only considering resident EV drivers the charging demand values can be underestimated.

4.2 Negative charging gap

Negative charging gap municipalities range from [-0,28, 0] kW/ km^2, and represent 33% of the analysed territory.

It is possible to identify in the map that the negative charging gap municipalities are those more in the periphery of the Milanese belt.

Most negative municipalities are completely, or partially, surrounded by municipalities with a positive charging gap, allowing residents to charge at neighbour municipalities. Perhaps more critical is the situation of municipalities like Tribiano (-0,22 kW/ km^2) that are in the centre of negative charging gap municipalities. In these cases, drivers can suffer from a low level of accessibility to public charging station since not only the home municipality but also the surrounding areas are deprived of EVSEs.

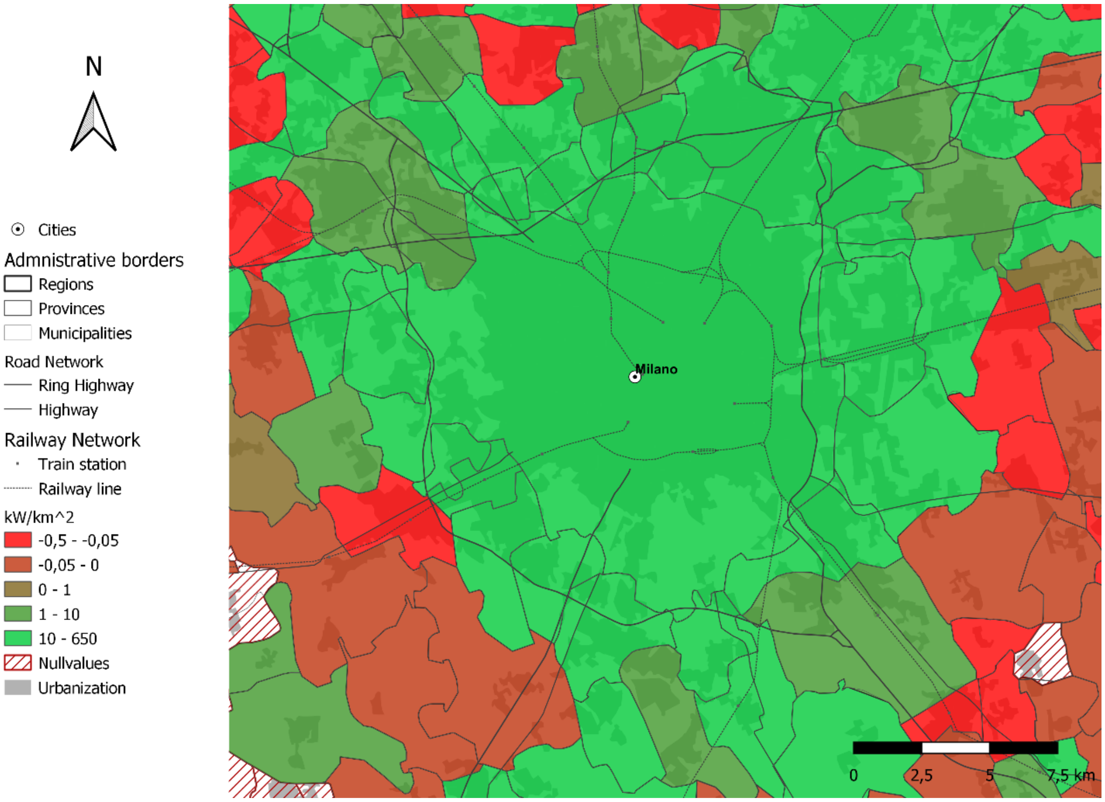

Figure 1 : Spatial distribution of charging gap (kW/km^2) over the Milan neighbouring municipalities.

4.3 Charging location

The hypothesis trying to be validated is that slow chargers are placed near or inside car parks and fast chargers are placed near the main roads. The results from the nearest neighbour analysis are displayed in Table 2. Fast chargers exhibit a smaller average distance to the main roads when compared with the slow chargers, and slow chargers have a smaller average distance to car parks when compared to fast chargers, indicating a preliminary correlation between these variables.

Table 2: Average distance between EVSE, car parks and main roads in Milan neighbouring municipalities

	Fast Charger (>22kW)	Slow charger (≤22kW)
Main roads	1350 m	1590 m
Car parks	582 m	427 m

To complement this, a visual representation is added as seen in Fig. 3. The heatmap displays the slow charging capacity of the region in a spectral colour ramp. By analysing the map, it is evident the clustering of charging power among car parking amenities with the charging capacity hotspots (especially in the centre) being covered by car parks.

For the fast-charging analysis a similar map construction was made and in this case the road network was highlighted. As is possible to observe the two main hotspots are nearby the access of a highway and provincial road, there is also some coverage along the ring highway (with less charging capacity). The visual inspection of Fig. 4 also indicates a possible correlation.

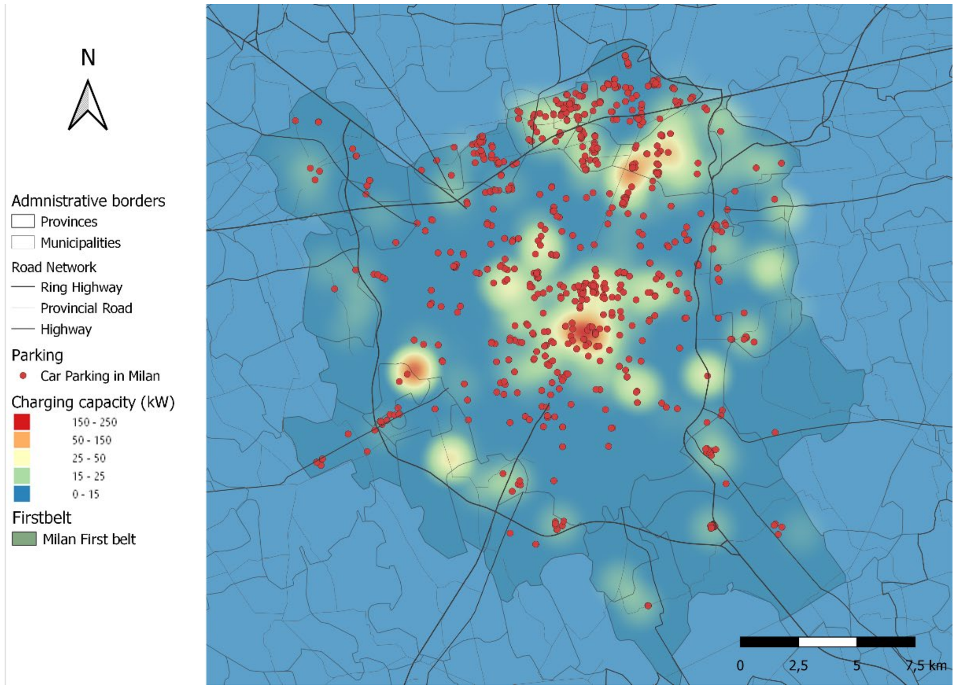

Figure 2 : Slow charging capacity heatmap with Milan's car parking network

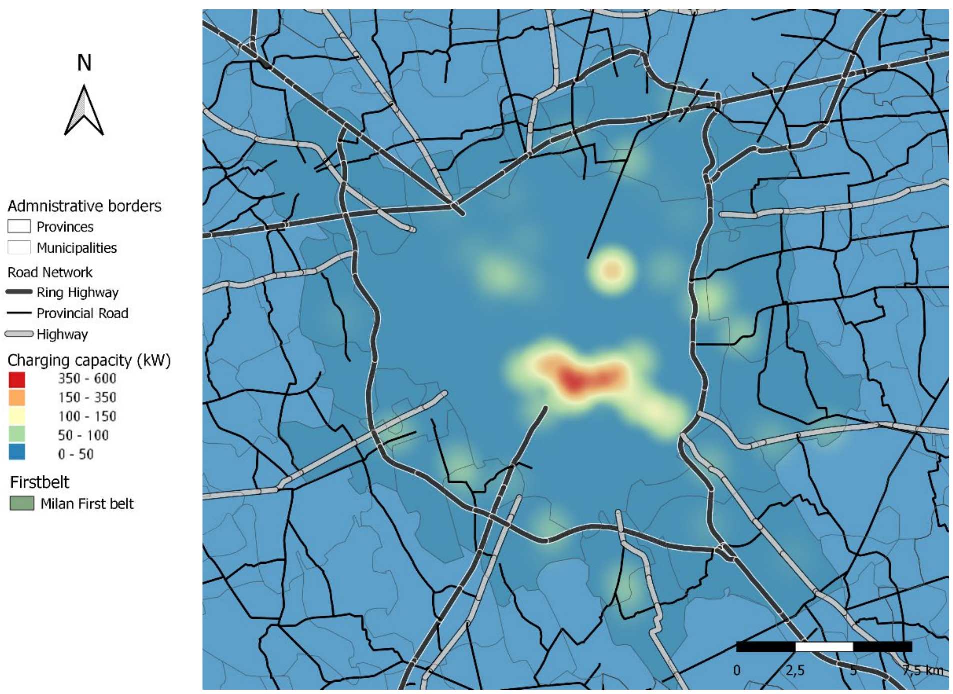

Figure 3 : Fast charging capacity heatmap with Milan's road network.

5 Conclusion

Despite the bigger overall value of positive charging gap municipalities, still, 33%, of the territory has a negative charging gap meaning that the spatial distribution of supply is not optimal. On the other hand, some municipalities like the centre of Milan have an over dimensioning of supply (high positive charging gap value). This finding can be partially explained by a possible induced demand strategy. Another possible explanation is that since the origin-destination matrixes of the daily travels were not considered, the demand in the most attractive municipalities can be underrepresented.

Regarding policy recommendations, municipalities with negative charging gap should be a priority in terms of charging infrastructure development, especially the ones clustered among other municipalities with a lack of charging infrastructure since in those, EVs are unable to charge at neighbour municipalities. Municipalities with positive charging gap should create policies to support EV diffusion to increase the utilisation and profitability of already existing EVSEs. Municipalities with null values should receive a simultaneous combination of policies to aid EV diffusion and to increase the number of EVSEs, to stimulate electric mobility development.

In terms of the suitability of fast and slow EVSE placement, the nearest neighbour analysis indicates that the planning reasoning of placing slow EVSEs in car parks and fast EVSEs in the main roads is present in Milan. With the current analysis is difficult to assess if the placement is close enough to both these amenities. To fully validate the correlation between chargers and the built environment a more sophisticated method would be necessary like a gravimetric model or an adapted auto-regression to display the statistical relevance.

The expansion of the scale of the case study would provide a more encompassing lens to analyse the mobility phenomena of the region.

Qualitative studies, Forecast of EV penetration, EV mobility patterns, distribution of EVSEs in accordance to point of interests are all open issues for future investigation.

To conclude, the authors highlight that the approach here described could be easily replicable to other cities and territories of a similar scale since the charging points were extracted from a global database.

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References

[1] Coffman, M., P. Bernstein, and S. Wee, *Electric vehicles revisited: a review of factors that affect adoption.* Transport Reviews, 2017. **37**(1): p. 79-93.

[2] Milano, E.F.e.P.d., *Apriamo la strada al trasporto elettrico nazionale.* 2015.

[3] Maia, S.C., H. Teicher, and A. Meyboom, *Infrastructure as social catalyst: Electric vehicle station planning and deployment.* Technological Forecasting and Social Change, 2015. **100**: p. 53-65.

[4] Pallonetto, F., et al., *A Framework for Analysis and Expansion of Public Charging Infrastructure under Fast Penetration of Electric Vehicles.* 2020. **11**(1): p. 18.

[5] Lucas, A., et al., *Indicator-based methodology for assessing EV charging infrastructure using exploratory data analysis.* Energies, 2018. **11**(7).

[6] Group, E.S., *Smart Mobility Report 2021 La sostenibilità nei trasporti: le sfide per una mobilità sostenibile nello scenario post-Covid.* 2021.

[7] Pucci, P., *Spatial dimensions of electric mobility—Scenarios for efficient and fair diffusion of electric vehicles in the Milan Urban Region.* Cities, 2021. **110**.

[8] Balducci, A.F., V.; Curci, F., *Post-Metropolitan Territories. Looking for a new urbanity.* 2017.

[9] Pagany, R., L. Ramirez Camargo, and W. Dorner, *A review of spatial localization methodologies for the electric vehicle charging infrastructure.* International Journal of Sustainable Transportation, 2019. **13**(6): p. 433-449.

[10] Liang, Y., et al., *Optimal planning of charging station based on discrete distribution of charging demand.* IET Generation, Transmission & Distribution, 2020. **14**(6): p. 965-974.

[11] Adenaw, L. and S. Krapf, *Placing BEV Charging Infrastructure: Influencing Factors, Metrics, and Their Influence on Observed Charger Utilization.* 2022. **13**(4): p. 56.

[12] Erik Figenbaum, M.K., Beate Elvebakk, *Electric Vehicles – environmental, economic and practical aspects. As seen by current and potential users.* 2014.
[13] Giorgio, d.G.M.p.E.S.H.M., *Analysis and assessment of the electrification of Urban road transport based on real-life mobility data.* 2013.
[14] Brenna, M., et al., *Electric Vehicles Charging Technology Review and Optimal Size Estimation.* Journal of Electrical Engineering & Technology, 2020. **15**(6): p. 2539-2552.

Presenter Biography

Luis Leal Pinho de Morais obtained his Bachelor and Master of Science from Faculdade de Engenharia da Universidade do Porto in Mechanical Engineering. After that he started as a PhD candidate at Politecnico di Milano in a multidisciplinary program with a research focus on electric mobility.