Article

Characterization of Load Centers for Electric Vehicles Based on Simulation of Urban Vehicular Traffic Using Geo-Referenced Environments

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Abstract: The current desire for people to reduce the environmental impact of their current lifestyle, as well as the variation in the prices of fossil fuels, has materialized in a rising trend for electric vehicles (EV). These vehicles are increasingly making inroads in the automotive market and positively contributing to reducing environmental pollution by greenhouse gas emissions; therefore, they improve energy efficiency. For the success of this innovation, it is necessary to correctly identify the effective places where the charging centers for electric vehicles (CCEV) will be placed, which will contribute significantly to its development, allowing us to guarantee the autonomy of electric vehicles with a charging supply. Thus, the present work proposes a vehicle traffic simulation process using the “SUMO” simulator interface. The study’s objective is to locate sites for electric vehicle charging centers or stations, taking as the primary variable the vehicular traffic that has a strong relationship with this type of research. Consequently, the study evaluates the existing resources in geo-referenced scenarios and has analyzed the vehicular flow considering the distances of the routes. As follows, the simulation becomes a tool to recommend the location and quantity of CCEV, guaranteeing users a nearby place where they can charge their vehicle and thus achieve adequate autonomy.

Keywords: electric vehicle charging stations; urban mobility; traffic control; SUMO

1. Introduction

The fuels currently used in the automotive fleet are qualified as non-renewable resources. The observed increase in fuel prices has incorporated global trends towards alternative propulsion technologies. Consequently, a large percentage of the investment made by the automotive industry is focusing on the commercialization of plug-in electric vehicles (PHEV) and all-electric vehicles (EV). Electric vehicles are considered “a green solution” because they are emission-free, clean, and quiet; for this reason, their popularity and expectations are on the rise. Additionally, electrification of transportation is seen as one of the solutions to global warming, sustainability, and geopolitical concerns of fuel availability. Thus, there are many conventional fueling stations; however, the analyses performed to determine their location cannot be applied for CCEV. One of the main problems of electric vehicles is the short driving range due to their batteries’ limited energy storage capacity [1].

With the massive inclusion of electric vehicles, an expansion in the infrastructure of charging stations or centers is expected. For this reason, more CCEV should be progressively located, and the appropriate location should be determined as a priority; however, the installation of charging stations is costly, and if there is not a significant number of customers, i.e., demand, private companies will not see a business opportunity. Then, the participation of the public sector is necessary to incentivize the acquisition of these
environmentally-friendly vehicles. EV have attracted attention in the last decade, but they need to be complemented with appropriately located CCEV; these EV have a shorter driving range concerning combustion engine vehicles; thus, having adequate CCEV will make them efficient, economical, and convenient options. The availability of charging infrastructure is a crucial agent for the reception of EV [2]; consequently, the design of the CCEV must consider improvements in cost-effectiveness, as well as a reduction in the impact to the electricity grid [3]. In addition, in analyzing the costs and benefits with the implementation of CCEV, a significant impact on environmental, economic, and social factors would be achieved [4]. Therefore, to ensure the future of EV, the CCEV network should be able to cover not only the current EV fleet, but also ensure the new EV that will enter the future. The growth trend of EV is positive, so efforts should be intensified to accelerate the deployment of technologies that contribute to achieving this goal. It has already been mentioned that, for proper operation of EV, appropriate charging infrastructures and suitable locations are necessary; on the other hand, optimal operation and utilization of CCEV would have a positive impact on electricity grids, and EV charging strategy can be planned to help load management and demand response in the grid. CCEV can also improve grid reliability, and support load demand in the electricity outage [5].

2. Related Works

Currently, the primary constraint of EV is a reduced range due to low charging powers; however, these disadvantages can be overcome with the correct deployment of CCEV in conjunction with a study of vehicle traffic behavior. CCEV are broken down into several categories, mainly by charging speed; the two most common types are: (1) with AC alternating current, described as “slow charging”, where the vehicle carries a charger inside that converts from AC to DC direct current (needed to charge the batteries); (2) with DC direct current, described as “fast charging”, provides direct current electricity directly to the EV; charging times range from 30 min to 20 h, depending on some variables such as type of CCEV, battery type, and energy capacity, among others [6–8].

Figure 1 shows the importance of designing an entire infrastructure for the vehicular flow of EV as, beyond the construction of the CCEV, the area where they will operate must be known, and the road network must be analyzed. The user should be able to decide which CCEV will be the best located concerning the initial point of the EV; this refers to the closest location considering the distance and the demand for flow in the area, which would considerably improve the uncertainty of the user concerning the autonomy of the vehicle, reducing the range restriction due to battery discharge.

The correct location of the CCEV is closely linked to the correct number of units geographically deployed in a defined area. A number lower than the ideal would cause coincidences in the recharge and, therefore, long waits for the service. In this sense, these same coincidences would cause a commotion in the electrical system due to high consumption in the same area and, as a consequence, the other sectors would be affected, with a decrease in reliability and power quality; on the other hand, an excessive number of CCEV would incur in unnecessary CCEV infrastructure construction costs.

It is essential to know the types of charging for EVs currently available. Consequently, to counteract the problems of the limited autonomy capacity of EVs, several options have emerged to recharge these vehicles’ batteries, the type of charge will depend heavily on the type of EV battery. The duration of this is linked to the type of load that is subjected to the types of load we can divide into conventional charging and fast charging; these types of load have a different impact on the life of the battery of EVs and the cost for charging [9].
Figure 1. Model for EV charging station deployment.

The different types of charging and their most relevant characteristics are shown in Table 1. Slow charging is the simplest of these and can be applied to all EVs, does not require complex installation, and can be completed at home during the night. Semi-fast charging manages to recharge the battery in a much shorter time; however, it does not cover any eventuality, as this type of charging must be scheduled because the charging time is still high [10]. Fast charging comes very close to covering the user’s need to charge their EVs at a convenient time; however, it demands a complex infrastructure that is intended for the recharging service of these vehicles [11]. On the other hand, ultra-fast charging has high recharging power, providing the shortest recharging time, even compared to the time of conventional vehicles.

Table 1. Types of EV charging. Source: [12].

<table>
<thead>
<tr>
<th>Type of Load</th>
<th>Slow</th>
<th>Semi Fast</th>
<th>Fast</th>
<th>Ultra Fast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power (Kw)</td>
<td>4–8</td>
<td>22</td>
<td>44–50</td>
<td>350</td>
</tr>
<tr>
<td>Time of Charging (min)</td>
<td>300–480</td>
<td>60–90</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>230</td>
<td>230</td>
<td>500</td>
<td>600</td>
</tr>
<tr>
<td>Current (Amp)</td>
<td>16</td>
<td>32–63</td>
<td>63</td>
<td>250–400</td>
</tr>
<tr>
<td>Type of Current</td>
<td>AC</td>
<td>AC</td>
<td>AC</td>
<td>DC</td>
</tr>
<tr>
<td>Load Level (%)</td>
<td>100</td>
<td>50–80</td>
<td>50–80</td>
<td>50–80</td>
</tr>
</tbody>
</table>

2.1. Electric Vehicle Charging Station Locations

This paper aims at the optimal deployment of CCEV for EVs based on urban traffic analysis; however, several factors are involved in EV integration. These are only mentioned for didactic purposes, as they are not included in this paper: the impact on the electric grid, charging modes, commercial relations, prices, time of use, policies, and regulations, among others which are mentioned in [13]. The cost of construction and cost of operation is cited in [14]. The wrong size and location of CCEVs could be a detrimental factor in the growth of EVs; therefore, in [15,16] the importance of considering environmental factors and service radius of CCEV for proper initiation in detecting optimal sites is indicated.

A significant increase in EVs would cause a considerable impact on electricity generation and distribution; EV loads vary over time, and EVs cause geographically mobile demand. Therefore, EV requirements could coincide with the peak of overall consumption,
as well as the impact of large-scale insertion of such vehicles discussed in [17]. Additionally, other works have taken the transportation network as the principal agent, such as Ref. [18], where driving patterns and load behavior are analyzed, and Ref. [19], where a longitudinal dynamics model of a specific electric vehicle type was developed. As discussed, both the power grid and the transportation network are determining components when determining the optimal locations; for such a reason, these two factors are considered in relevant works such as in [20,21].

Several factors are involved in the correct location of the CCEV; the present research focuses on the transportation network, specifically on urban traffic, where agents such as traffic flow, urban roads, geographical characteristics, traffic jams, and EV user behavior are considered. Several kinds of research have considered vehicular traffic as an essential agent, such as Ref. [22], where the problem is formulated as a mixed-number nonlinear problem (MINLP); the drawback solves it using genetic algorithm technique to determine the optimal location and capacity of CCEV, where they calculate the location and capacity based on the daily urban traffic flow. In [23], a binary beam search algorithm (BSA) is proposed, where they consider geo-referencing, battery state of charge, road traffic density, and grid energy losses.

In [24] the optimal location and size of CCEV were solved by the particle swarm optimization algorithm, proposing an improved media clustering method to determine the service region of each charging station and solve the optimal location problem using the genetic algorithm. The origin–destination lines and Voronoi diagram are selected to calculate the traffic flow and service region of each charging station, respectively; on the other hand, a novel CCEV location planning method that considers operators, drivers, vehicles, traffic flow, and power grid together is presented in [25]. The contributions that each research provides can be seen in the table below. The most relevant articles in this study have been taken into account.

Table 2 summarizes the state-of-the-art that has contributed to this article. In this sense, previous works have been published on the deployment of charging centers for electric vehicles have been evaluated. Some works have considered models based on optimization considering linear programming due to the reduced number of vehicles or geo-referenced area considered for the study. The issue of optimal resource allocation has been considered regarding the minimum number of charging centers required to be incorporated in a city. The reason for locating a minimum number of charging centers for electric vehicles to meet the demand of vehicles must be planned, as it involves costs related to the re-powering of the distribution network. Thus, research that evaluates all the variables involved in the location of a charging center is justified, and mainly this work focuses on the simulation and behavior of vehicular traffic and its impact on the planning models. While it is true that the autonomy of electric vehicles has increased, it is not possible to consider that all users have previously charged the vehicle before moving from one place to another, as happens in a gasoline vehicle, which is why they must find a charging center outside their home or workplace. Consequently, this work will contribute to the optimal planning models to consider a previous characterization of the behavior of the city as a restriction, to be served with multiple charging centers and not to generate growth with economic impact and over-dimensioned to the demand. On the other hand, when increased, the autonomy of electric vehicles directly favors long trips that users make and in which they have considered their previous charging. However, this particular process will not always be considered due to different user factors.
### Table 2. Summary of proposals for electric vehicle charging station locations.

<table>
<thead>
<tr>
<th>Author</th>
<th>Cost</th>
<th>Vehicular Traffic</th>
<th>Chargeability</th>
<th>Scalability</th>
<th>Charging Time</th>
<th>Planning</th>
<th>Assignment</th>
<th>Cost</th>
<th>Capacity</th>
<th>Coverage</th>
<th>Traffic</th>
<th>Cost</th>
<th>Assignment</th>
<th>Urban Zone</th>
<th>Technologies</th>
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<td>Huang [24]</td>
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<td>Tan [27]</td>
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### 2.2. City Traffic Simulation

The continuous growth of vehicles is a common problem in most cities worldwide, as it is causing an increase in traffic flow and therefore an increase in traffic congestion. A simulation model allows us to discover the traffic behavior in different scenarios. The variables involved in an urban traffic simulation are mentioned in [29–32].

The variables involved in the traffic simulation used in the reviewed literature are compiled in Table 3; these are the ideal ones to guarantee the excellent performance of the procedure; therefore, mobility is nowadays one of the essential ingredients of modern society. The realization of simulations, and especially the analysis of their results, allow us to draw significant conclusions that can lead to a better understanding of the traffic situation in a city.

The increase in the number of vehicles in the cities, together with poor road network management and bad driving behavior, produces traffic congestion, which affects the flow of travel leads to slower speeds, long queues of vehicles, and longer times to reach planned destinations. The experimental data obtained are analyzed to obtain a clear picture of the collective traffic behavior of the study area, which is helpful for several improvements such as road safety, a decrease in environmental pollution produced by combustion vehicles, and a significant increase in road capacity, and, therefore, of traffic.

### Table 3. Variables involved in an urban traffic simulation.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Traffic Flow</td>
</tr>
<tr>
<td>2</td>
<td>Origin–destination determi</td>
</tr>
<tr>
<td>3</td>
<td>Velocity (m/s)</td>
</tr>
</tbody>
</table>
Table 3. Cont.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Acceleration (m/s²)</td>
</tr>
<tr>
<td>5</td>
<td>Travel time (s)</td>
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<tr>
<td>6</td>
<td>Waiting time (s)</td>
</tr>
<tr>
<td>7</td>
<td>Lost time (s)</td>
</tr>
<tr>
<td>8</td>
<td>Departure delay (s)</td>
</tr>
<tr>
<td>9</td>
<td>Distance traveled (m)</td>
</tr>
<tr>
<td>10</td>
<td>Safety distance (m) (m)</td>
</tr>
<tr>
<td>11</td>
<td>Number of vehicles (m)</td>
</tr>
<tr>
<td>12</td>
<td>Number of stops</td>
</tr>
<tr>
<td>13</td>
<td>Number of nodes</td>
</tr>
<tr>
<td>14</td>
<td>Number of vehicles in queue</td>
</tr>
<tr>
<td>15</td>
<td>Road capacity</td>
</tr>
<tr>
<td>16</td>
<td>Vehicle density</td>
</tr>
<tr>
<td>17</td>
<td>Congestion shock wave congestion</td>
</tr>
<tr>
<td>18</td>
<td>Atmospheric Emissions</td>
</tr>
</tbody>
</table>

3. Problem Formulation

The main problem to be solved is the need to find the optimal locations of charging centers, which in turn is induced to be the minimum number of stations in a given area that allows the autonomy of EV users; this is experimental research, as it employs simulation techniques, so planning is a typical location problem.

The simulation carried out in the SUMO programming environment provides us with certain variables, which are shown in Table 4 with their respective notations; these are obtained after finishing the simulation and are of utmost importance, as obtaining them from a geo-referenced environment with an exemplary traffic flow provides data very close to reality. It is a significant point to understand the travel behavior of an EV in different scenarios of traffic flow load, and thus to obtain the keys for the correct location of CCEV that support the load demand of EVs, without affecting the flow of the trip and therefore the comfort of users, who generally prefer to travel on the route with the shortest distance between origin and destination.

The work carried out aims to locate and deploy CCEV within a study area to eliminate the user’s anxiety about mileage; therefore, the criteria for the selection of candidate sites, which will later be chosen for the deployment of CCEV, must be clear. The evaluation of vehicular traffic is the central theme of the study; researchers also analyze the problem from vehicular traffic, as in [25,33], where they recommend specific criteria; consequently, these criteria are shown in Table 5 and followed for the location and deployment of CCEV.

Table 5 sets out important criteria such as the \( D_{max} \), which refers to the distance between the EV and the CCEV; this must be equal to or less than the driving range of the EV. \( A(e) \) constrains that the CCEVs must be located within the study area, hence the map considered in the simulation. \( S(c) \) gives us the option to evaluate more than one candidate site in order to choose the best one, to satisfy the demand with the ideal amount, and not to incur unnecessary construction costs. \( DCV \) indicates the maximum coverage radius of the CCEV needed to satisfy the service demand, which ensures that EVs with the smallest driving range can travel to the CCEV without running out of power, those with a larger driving range will also succeed. To obtain traffic efficiencies \( R(t) \) CCEVs should not be located at congested intersections and roadways, because this will contribute to increased traffic congestion near the CCEV \( R(c) \). It is not advisable to place CCEVs at sites with very
high traffic flows $F_{max}$, because travel will not be smooth and the time to reach the CCEV $ta$ increases to a level that does not satisfy user comfort, increasing user anxiety.

Table 4. Notations and Variables of the Simulation Process in SUMO.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P$</td>
<td>EV position in real time (m/s)</td>
</tr>
<tr>
<td>$S$</td>
<td>EV velocity (m/s)</td>
</tr>
<tr>
<td>$A$</td>
<td>EV acceleration (m/$s^2$)</td>
</tr>
<tr>
<td>$fs$</td>
<td>Velocity Factor</td>
</tr>
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<td>$tg$</td>
<td>Time interval in the lane (s)</td>
</tr>
<tr>
<td>$wt$</td>
<td>Waiting time (s)</td>
</tr>
<tr>
<td>$wta$</td>
<td>Accumulated waiting time (s)</td>
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<tr>
<td>$tl$</td>
<td>Lost time (s)</td>
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<tr>
<td>$ta$</td>
<td>Travel time (s)</td>
</tr>
<tr>
<td>$t_{CCEV}$</td>
<td>Arrival time at CCEV (s)</td>
</tr>
<tr>
<td>$rs$</td>
<td>Departure delay (s)</td>
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<tr>
<td>$F_t$</td>
<td>Traffic flow (s)</td>
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<tr>
<td>$L$</td>
<td>Electric vehicle (EV)</td>
</tr>
<tr>
<td>$C_c$</td>
<td>Capacity CCEV</td>
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<tr>
<td>$rs$</td>
<td>Exit delay (s)</td>
</tr>
<tr>
<td>$N_v$</td>
<td>Number of vehicles (s)</td>
</tr>
<tr>
<td>$Dist$</td>
<td>Distance traveled (m)</td>
</tr>
<tr>
<td>$n$</td>
<td>Noise [dB]</td>
</tr>
<tr>
<td>$E$</td>
<td>Electricity consumed (Wh/s)</td>
</tr>
</tbody>
</table>

Table 5. Criteria for selection of candidate sites.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{max}$</td>
<td>The distance to the CCEV must not be greater than the range of the EV.</td>
</tr>
<tr>
<td>$A(e)$</td>
<td>The CCEV must be located within the simulation area.</td>
</tr>
<tr>
<td>$S(c)$</td>
<td>There must be at least two candidate sites for the CCEV.</td>
</tr>
<tr>
<td>$DCCEV$</td>
<td>The distance between CCEVs must not be greater than 5km.</td>
</tr>
<tr>
<td>$R(t)$</td>
<td>CCEV should not be deployed on congested intersections and roads.</td>
</tr>
<tr>
<td>$R(c)$</td>
<td>Traffic congestion near the CCEV should not be too high.</td>
</tr>
<tr>
<td>$F_{max}$</td>
<td>Flow should not exceed the demand serving capacity.</td>
</tr>
<tr>
<td>$Rs$</td>
<td>The CCEV service radius should not exceed 5km.</td>
</tr>
<tr>
<td>$ta$</td>
<td>Arrival time to CCEV should not be extremely long.</td>
</tr>
</tbody>
</table>

SUMO (Simulation of Urban Mobility) is a microscopic traffic simulation environment that can handle large road networks, including vehicles of various types, public transport, heavy transport, and even pedestrians, supporting geo-referenced maps. It has the ability of autonomous route choice and to always look for the fastest route; in Figure 2, a flowchart is presented which explains the correct process to generate a suitable simulation, obtaining variables essential for this research.
The large-scale use of EVs in cities with a remarkable traffic load will undoubtedly increase the partial traffic pressure and load; therefore, the planning of CCEV based on traffic flow will be more practical. The continuous driving capability of the EV must be protected; the simulation considers significant variables such as traffic flow, vehicle types, traffic lights, and intersections. Then, the principal idea is that the simulation is as realistic as possible in the chosen site, which has been executed with SUMO for the traffic and OSM for the geo-referenced map. Figure 3 shows different situations within the same simulation; all these details are implemented to create a simulation as close to reality as possible.

![Figure 3. Simulation Scenario through SUMO.](image)

- **(a)** Intersection Traffic
- **(b)** Station Traffic

A complete simulation environment is seen in Figure 4, where the specific description of travel behavior can be used as a basis for analyzing the operating behaviors of EVs. Urban traffic flow patterns are analyzed considering five points:

- Understand the problem;
- Compile data;
- Make selection decisions;
• Execute trips;
• Evaluate feedback after the trip.

As expected, EV travel behavior is complex, as it depends on travel decisions, existing traffic, and carrying capacity; therefore, for research purposes, all EVs will have the same driving pattern in the simulation.

Figure 5 shows the deployment of the CCEV within the simulation in a geo-referenced environment; it is observed that the moment in which the EVs are charging, the EVs have an average maximum mileage of 150–400 km, taking into account that the charging need is less than 20% of the maximum power and considering the traffic obstruction, as well as the battery capacity margin. The factors mentioned above were taken into account to identify the most relevant variables involved in an urban traffic simulation in a geo-referenced environment for the following location of CCEV.

4. Analysis of Results

This section presents the results obtained from the simulations executed in Matlab R2021b and SUMO programming environments together with OpenStreetMap to create the
map in a geo-referenced environment. The scenario chosen for the simulation is the city of Rome in an area delimited with longitude [12.4804 12.5813] and latitude [41.9097 41.8770]. The area includes a transport terminal and has high peak hour traffic. This particularity of the area suggests a consumption of the load for electric vehicles transiting in the area. Evaluating the area in question concerning vehicular traffic will contribute to the projection of the location of the charging center. In this sense, the increase in autonomy favors the user, reduces the cost in terms of resources, and minimizes the impact of the electric distribution network in a defined area; however, the charging time of electric vehicles may be considered in the impact exerted by the electric distribution network for future work on this topic.

It is known that the traffic flow is changing throughout the day, which is a crucial factor in the travel behavior of the EV. Therefore, this behavior will be evaluated in four different scenarios to know how divergent the behavior between them is. In Figure 6, we can see the variation of speed that has the EV along its route from the starting point to its arrival. These metrics show how the traffic load affects the trip; in this case, analyzing the speed, the green metric represents a flow of 50% of very smooth traffic that refers very late at night where the vehicular traffic is light, and the VE reaches an average speed of 8.19 m/s. The blue metric represents a 100% traffic flow with an average speed of 7.96 m/s, found in the morning hours. The magenta metric, therefore, develops in a 150% traffic flow. It can be found in the peak hours of the day with an average speed of 6.69 m/s. Finally, the red metric is developed in a 175% flow of extremely high traffic in which several factors, such as rush hour, traffic accident, and road repair, among other factors, have come together with an average speed of just 2.59 m/s. Thanks to the metrics, we can conclude that the traffic flow directly affects the smoothness of the trip and, therefore, the user’s comfort.

Figure 6. EV speed in SUMO.

Figure 7 shows the behavior of the EV concerning acceleration; therefore, this variable helps us understand the travel behavior. This variable tells us how smooth the travel is, noting the moments where the EV has positive acceleration, negative acceleration, or stops, either due to a traffic light or high load and traffic.

Therefore, the results in Table 6 emphasize the importance of the traffic flow; these values are obtained from the metrics of Figures 6 and 7, as they were taken from the same analysis, performed on VE number 10, from a sample of 100 VEs, where it was concluded that in light traffic the trip is more fluid with more minor speed variations. On the contrary, the more loaded the traffic flow is, the more trip is hindered as the speed variations increase, which directly affects the comfort of the trip.
The simulation provides some variables that are involved in EV travel behavior. It should be noted that the map used for this research is an extract of the city of Rome, Italy. The simulation was loaded with vehicle traffic as close as possible to a real one where private vehicles, trucks, trailers, subways, and taxis are involved; 100 EVs were inserted to determine their behavior within the total sample of approximately 14,525 vehicles of different types. As a result, we have selected four variables that are considered to have the most significant impact in defining the differences in the trip depending on the traffic flow.

Arrival time is defined as the time it takes an EV to travel the distance from its starting point to the arrival point, which includes streets, intersections, traffic circles, bus stops, traffic lights, and slopes within the geo-referenced map.

In Figure 8, it is possible to notice the comparative of the metrics in relation to the arrival time from the beginning of the trip until the arrival at the destination of the 100 EVs analyzed, which indicate that the higher the flow, the longer the arrival time of each EV in the simulation. The curves tend to increase regardless of the scenario; here, the question arises as to why the increase in the arrival time of the first EV (number 1) to the last (number 100). The answer is simple; in a natural environment of a total sample of vehicles, not all start their journey at the same time, and this is replicated in the simulation. As time goes by, the traffic flow becomes more and more loaded; that is why this behavior is observed in the metrics. It is worth mentioning that the starting and arrival points are the same in the four simulation scenarios for all EVs; the only variant is the flow load in the traffic, which is a determining factor for the change in behavior between scenarios.

Figure 9 warns relevant metrics and addresses a crucial variable within the deployment planning of charging stations; this variable is the time lost caused by traffic, as the curves show us. At the same time, there is a more significant load within the traffic flow; more time will be lost in speed reduction and stops, which is directly proportional to the flow.
of travel, which will take longer to reach the CCEV and, in turn to the final destination. This time has an evident upward trend between scenarios and, within the same scenario, when comparing the first EV against the last. This happens because the more time elapses within the simulation, the more vehicles join the traffic and therefore increase the vehicular flow, causing even more time lost due to increased traffic. The trend will continue until the vehicles reach their respective destinations.

![Arrival Time vs Number of EVs](image1.png)

**Figure 8.** Comparison of EV arrival times in different traffic flows.

![Lost Time vs Number of EVs](image2.png)

**Figure 9.** Comparison of lost travel times by EVs.

Another essential variable that will give us a clearer picture within the study is shown in Figure 10, which presents the electricity consumption of the EV along the journey from its departure to its arrival, measured in Wh/s. As the metrics reveal, the higher the traffic flow load, the higher the energy consumption due to traffic, which is directly proportional to the battery level of the EV; these have an average range of autonomy of around 150 km depending on the brand. However, these data are measured in an ideal environment, i.e., in a smooth journey, but what happens when your route is hindered by lack of fluidity...
due to traffic? The metrics show us precisely what happens. Taking into account that all leave from the same starting point and have the same destination, an increase in electricity consumption due to constant stops can be clearly seen. This causes a reduction in the EV’s autonomy in the distance it can travel and in the uncertainty caused to the user by not having an EVCC within reach, therefore, on the day of travel with heavy traffic, the user should opt for recharging in EVCCs as soon as possible to reach the final destination without any setback, and for this a correct location of the EVCCs is critical, considering the urban traffic.

Although in the metrics the difference in electricity consumption is not so overwhelming, we must take into account that, for simulation purposes, the distance traveled by EVs does not exceed 15 km, if we take it to a larger scale where the average range of current EVs is around 150 km, the difference in consumption will be significant in a long-distance trip. Therefore this variable is the most relevant for this study. The area was established between the longitude [12.4804, 12.5813] and latitude [41.9097, 41.8770] with approximately 39 km².

Within the Rome, Italy study area, nine candidate sites, shown in Figure 11, were identified. These sites were located based on certain criteria from Table 5 such as $D_{max}$, $A(e)$, $S(c)$, $DCCEV$, $R(t)$, $R(c)$, $F_{max}$, and $t_a$. However, although the criterion of $DCCEV$ indicates that the distance between CCEVs should not be too great, having them too concentrated is not advisable, as it would result in low service efficiency and unnecessary construction cost. Consequently, the guidelines addressed in Table 5 aim to meet these with the least amount of CCEV deployed in the study area that satisfy the demand of EV users.

Respecting the criteria in Table 5, the candidate sites for the location of the CCEV have been reduced to three; this can be seen in Figure 12. All the CCEV comply with the criterion $R(t)$ that recommends avoiding intersections and congested roads; in Figure 13, it can be seen that the chosen roads have several lanes and little congestion. Consequently, the insertion of the CCEV will not affect the urban traffic, which is what is sought with the correct location of CCEV. Therefore, it meets the necessary parameters to meet the demand for EVs without affecting the overall traffic flow.
Figure 11. Candidate sites for CCEV.

Figure 12. Location of CCEV.

(a) Load Center Location 1

(b) Load Center Location 2

(c) Load Center Location 3

Figure 13. CCEV Located in SUMO.
Table 7 shows data on the located CCEV; when performing a simulation in a geo-referenced environment, the location is very accurate, using latitude and longitude coordinates. Table 7 also provides data such as position in X and Y within the map used for the simulation, several lanes that the selected road has, and the lane where the CCEV is located.

Table 7. CCEV Located.

<table>
<thead>
<tr>
<th>CCEV ID</th>
<th>Coordinates</th>
<th>Position on the Map</th>
<th>Rail ID</th>
<th>Number of Lanes</th>
<th>EVs Attended</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCEV 1</td>
<td>lat:41.901316, lon:12.494034</td>
<td>x:2491.96, y:6742.48</td>
<td>147125844#1_0</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>CCEV 2</td>
<td>lat:41.888575, lon:12.522568</td>
<td>x:4818.09, y:5258.87</td>
<td>22889376#1_0</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>CCEV 3</td>
<td>lat:41.894898, lon:12.565819</td>
<td>x:8426.53, y:5858.18</td>
<td>142981156#1_0</td>
<td>3</td>
<td>100</td>
</tr>
</tbody>
</table>

The work performed evaluates the performance of the deployed CCEV by simulating four scenarios of vehicular traffic flow, where the arrival time to the CCEV of 100 EV was evaluated for each of the deployed CCEV.

The simulation work was performed in a geo-referenced environment. The metrics represented in Figure 14 show the evaluation to which CCEV 1 was subjected, which is located on the left side of the study area whose coordinates are x:2491.96, y:6742.48 | lat:41.901316, lon:12.494034. Therefore, these coordinates can locate the same site within the city under study. Such placement is represented in Figure 13, and the position meets the criteria of Table 5. However, it was subjected to different traffic flow scenarios to assess its performance through the level of congestion as it must ensure a similar level of congestion before and after the insertion of the CCEV. The congestion within the simulation is evaluated using the variable $t_{CCEV}$ time of arrival at the CCEV described in Table 4, which adheres to the pattern the higher it is, the greater the congestion. When analyzing the curves, it was observed that the $t_{CCEV}$ tends to increase when the traffic flow does; therefore, in expected flows, the CCEV meets its objective; however, in higher flows, the $t_{CCEV}$ is very high, which causes drivers’ mileage anxiety. Consequently, we conclude that the total number of CCEV grows in higher traffics.

![Figure 14. Arrival time at CCEV 1.](image)
The next CCEV evaluated is CCEV 2, which is located in the central part of the study area whose coordinates are x: 4818.09, y: 5258.87 | lat: 41.888575, lon: 12.522568. The location meets the criteria of Table 5, the metrics are represented in Figure 15, increasing in the same way that Figure 14 tends to when the traffic flow rises. This CCEV is located in an area where there are several intersections and high congestion roads; consequently, when subjected to the higher traffic flow simulated in this study, the tccEV shoots to very high values concerning the other curves, reflecting that the travel behavior of EVs is closely related to the road network and is affected by the traffic flow. This CCEV satisfies the service up to high traffic flow; one should consider deploying more CCEVs in the area for very high flow.

![Figure 15. Arrival time at CCEV 2.](image)

Finally, the third and last CCEV deployed was evaluated, whose coordinates are x: 8426.53, y: 5858.18 | lat: 41.894898, lon: 12.565819. Its location meets the criteria of Table 5, the metrics are represented in Figure 16. Something interesting that stands out when observing the evaluation metrics of the deployed CCEV is that all of them tend to increase the Tccev when subjected to increased traffic flow. Therefore, they do not share the same characteristics in the curves because the CCEV are located in different areas, which proves that the travel behavior of EVs is closely related to the road network. When analyzing Figure 16 we notice a more homogeneous trend between scenarios, exclusively due to the road network. As, in this area, there are almost no intersections, traffic circles, or congested roads, this CCEV satisfies the demand for all scenarios. During the operation of the CCEV, the constant traffic efficiency is guaranteed.

To evaluate the performance of the deployed CCEVs, they are exposed to four different scenarios because, in reality, traffic varies as the hours go by. Therefore, the behavior of the road network and travel will be different. The evaluation starts with a 50% traffic flow and evaluates the performance of the CCEV under this scenario, after which the traffic flow is increased to 100%, 150%, and 175%, and the same analysis is performed in each scenario in the three CCEVs deployed. The results of the evaluation simulation are shown in Table 8. It collects the data as:

- **Travel time**: how long it took EV from its starting point to reach the CCEV.
- **Lost time**: the sum of the time that the vehicle did not reach a fluid speed or did not move, either due to traffic lights, traffic jams, or long queues due to traffic.
• Arrival speed: the speed at which the EV arrives at the CCEV. This variable helps us determine if there is great vehicular congestion around the CCEV or, on the contrary, the traffic is fluid.

• Speed factor: whether the EV reached a smooth speed along the trip.

• Speed variations: how smooth the trip was. The more variations there are, the shorter the trip was, directly proportional to the traffic.

• Distance traveled: the distance traveled by the EV from its starting point to the CCEV, ideally not exceeding 5km, as this is the service range of the CCEV proposed in this work.

By analyzing the results of Table 8, we can conclude that the deployed CCEV meet the requirements to supply the demand of the simulated EVs, i.e., the travel time. A good arrival speed and speed favor is maintained despite increasing traffic flow, indicating that there are no problems of bottlenecks and large queues of vehicles near the CCEV, which is precisely what is sought for in a location for CCEV.

**Table 8.** Performance evaluation of deployed CCEVs.

<table>
<thead>
<tr>
<th>CCEV ID</th>
<th>% of Traffic Flow</th>
<th>Travel Time X [s]</th>
<th>Lost Time X [s]</th>
<th>Arrival Speed X [m/s]</th>
<th>Speed Factor X</th>
<th>Speed Variations X</th>
<th>Distance Traveled [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCEV 1</td>
<td>50%</td>
<td>3313.65</td>
<td>2951.68</td>
<td>13.08</td>
<td>1.02</td>
<td>32</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>6113.29</td>
<td>5758.89</td>
<td>13.38</td>
<td>1.01</td>
<td>46</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>150%</td>
<td>7626.32</td>
<td>7261.69</td>
<td>13.38</td>
<td>1.01</td>
<td>50</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>175%</td>
<td>8079.17</td>
<td>7704.48</td>
<td>13.27</td>
<td>1.00</td>
<td>59</td>
<td>4.5</td>
</tr>
<tr>
<td>CCEV 2</td>
<td>50%</td>
<td>1715.71</td>
<td>1271.46</td>
<td>13.44</td>
<td>1.02</td>
<td>37</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>1745.37</td>
<td>1297.50</td>
<td>13.37</td>
<td>1.01</td>
<td>39</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>150%</td>
<td>2488.81</td>
<td>2031.63</td>
<td>13.03</td>
<td>1.01</td>
<td>51</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>175%</td>
<td>4802.41</td>
<td>4209.45</td>
<td>12.13</td>
<td>1.00</td>
<td>54</td>
<td>5</td>
</tr>
<tr>
<td>CCEV 3</td>
<td>50%</td>
<td>1429.83</td>
<td>1115.03</td>
<td>13.26</td>
<td>1.01</td>
<td>17</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>1448.14</td>
<td>1133.40</td>
<td>13.22</td>
<td>1.02</td>
<td>21</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>150%</td>
<td>1654.56</td>
<td>1336.43</td>
<td>13.00</td>
<td>1.00</td>
<td>29</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>175%</td>
<td>1744.44</td>
<td>1425.03</td>
<td>13.04</td>
<td>1.00</td>
<td>33</td>
<td>3.5</td>
</tr>
</tbody>
</table>
When purchasing CCEV 1, CCEV 2, and CCEV 3, we noticed that although their results are similar, they are not the same; this makes sense, as each CCEV is located in different areas with different road networks. While all the deployed CCEV fulfill their function, CCEV 3 has the best performance. This is because the road network within its service range mostly lacks intersections, traffic circles, and congested roads, which is an ideal scenario; therefore, after the performance evaluation is performed, it is recommended without any doubt to follow the criteria in Table 5 for CCEV location and deployment.

5. Conclusions

The mobility and vehicular traffic simulation model has allowed us to locate and deploy charging centers for the massive inclusion of electric vehicles considering an open-source, highly portable, microscopic, and continuous road traffic simulation software such as SUMO, which has allowed us to model an inter-modal traffic system including road vehicles, public transport, and electric vehicles.

Consequently, it has been possible to determine the effect of traffic on the travel behavior of electric vehicles and how the insertion of electric vehicles affects traffic flow in general. Together with the road network analysis, it was possible to determine the ideal sites for the location of CCEVs within the study area, considering variables such as maximum service range, vehicular congestion near the CCEV, and being located away from intersections, traffic circles, and congested roads.

The variables involved in the simulation process of urban traffic in a geo-referenced environment have been identified to locate electric vehicle charging centers, with traffic flow, speed, travel time, distance traveled, and lost time among the most important. This allows us to know the travel behavior of the electric vehicle, evaluated in different states of traffic flow; this is a fundamental factor in evaluating the necessary conditions to ensure the charge and, therefore, the autonomy of these vehicles.

A simulation model has been implemented for the location of charging centers for electric vehicles based on the variables traffic flow, speed, travel time, distance traveled, and lost time using SUMO. It is a traffic simulator at a microscopic scale, being able to identify travel patterns in vehicles and their effect on different levels of traffic, and thus make the best decisions when carrying out a project for the mass inclusion of electric vehicles without affecting the fluidity in the journey of all users in general.

The simulation model to locate charging centers for electric vehicles has been evaluated, identifying indicators that relate to an increase in traffic flow starting at 50% with a total of 4150 vehicles within the simulation scenario, 100% with 8300 vehicles, 150% with 12,450 vehicles, and 175% with 14,525 vehicles within the simulation. These increases represent the different traffic scenarios that occur throughout the day, the CCEVs deployed to meet the needs of EVs within the scenarios evaluated. The CCEVs meet the ideal values of traffic flow, speed, travel time, distance traveled, and lost time; consequently, these variables and the recommendations of locating CCEVs away from intersections, traffic circles, and congested roads, and not exceeding a service range of more than 5 km, are the key to obtaining optimal location and deployment of CCEVs.

Considering the present work within an optimization model of an electrical distribution network will contribute to future works. In this way, the analysis and characterization of vehicular traffic and other restrictions of the electrical distribution network will be necessary to plan and locate charging centers for electric vehicles. In addition, it will be possible to know if the electrical network needs to be re-powered at the level of conductors or transformers that provide service in the area where the electrical demand has increased. The variation of traffic flow in this way is considered an essential variable in this type of analysis.

Charging stations have not been massively deployed; in fact, the few that exist have been deployed in shopping malls or gas stations looking at empirical options or evidenced the direct route of connection between cities. In this sense, their impact on the power grid identifies a previous problem that must be solved and thus identify the best ways to
minimize the impact on the power grid. Cities with high traffic have identified the need to locate electric vehicle charging centers ideally. In this sense, although progress is being made every day in the charging autonomy of new electric vehicle models, it would be premature to consider that all users have homogeneous electric vehicles with high efficiency in the energy storage system. Consequently, the deployment of charging centers for electric vehicles is different concerning a gas station that was deployed based on market variables, capital gain, or other specifications.

**Author Contributions:** J.M.: Conceptualization, Methodology, Validation, and Writing—review & editing. E.I.: Conceptualization, Methodology, Software, and Writing—original draft. J.M.: Data curation and Formal analysis. E.I.: Supervision. E.I.: Writing—review & editing. All authors have read and agreed to the published version of the manuscript.

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