MATSim-based assessment of fast charging infrastructure needs for a full-electric passenger car fleet on long-distance trips in Sweden

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SHORT SUMMARY

This paper assesses the fast-charging infrastructure requirements to satisfy all long-distance trips by fully electric passenger cars. The main goals of this study are developing an accurate model for electric vehicle (EV) owner trips and their charging behavior, identifying candidate charging station locations and the number of chargers per station for fast charging infrastructure based on the developed model. The transition to EVs is gaining momentum, but the success of this shift relies heavily on the availability and accessibility of charging infrastructure. Several aspects of the fast-charging infrastructure planning problem are investigated based on the developed multi-agent model of EVs' usage using MATSim. The main contribution of this study is the introduction of a novel methodology to identify candidate locations for fast-charging infrastructure needs based on the missing energy event (MEE) in the MATSim EVcontrib and its application to assess the fast-charging infrastructure needs for passenger cars in Sweden.

Keywords: Electric vehicles, Fast charging infrastructure, Long-distance trips, MATSim.

1. INTRODUCTION

There is no doubt that transportation is a major contributor to greenhouse gas emissions, but electric vehicles (EVs) offer solutions for a more environmentally friendly way of transport. The popularity of EVs is growing due to their potentially environmental-friendly energy sources' usage that reduces dependence on fossil fuels. Several factors are preventing EVs from becoming widely used, including the limited range, long recharging time, and lack of charging infrastructure.

The EVs range refers to how far they can travel on a single charge. Many EV owners can charge their EVs at home enough to complete their daily trips. It is estimated that 90% of European Union trips do not exceed 80 km, whereas the typical range of an EV is higher than 200 km (Metias et al., 2022).

Charging times for EVs vary depending on the battery size and charging power used. For a typical EV with a 60kWh battery, it takes just under 8 hours with a 7kW charger to charge it from empty to full, which is suitable for overnight charging, or about 30 minutes with a fast charger (> 150 kW) while on the route.

The availability and accessibility of fast-charging infrastructure are paramount for the widespread adoption of EVs, especially for long-distance travel. Since the cost of such infrastructure is high, it is important to carefully choose their location and size to maximize the number of EVs they serve. There are several studies on the matter.

(Liu et al., 2021) proposes a strategy for placing EV charging stations along German motorways, considering cost and driver satisfaction.

(Baltazar, Vallet, & Garcia 2022) provides a multi-perspective analysis of the potential of EVs for long-distance mobility, highlighting the interest in assessing environmental impacts, user behavior, and EV diversity and proposing general suggestions for EV deployment, including the need for real-world traffic data and consideration of the diversity of EVs and their states of charge (SOC).

(Ge and MacKenzie, 2022) investigates the factors that determine EV users' charging behavior on long-distance trips, using data from a stated choice experiment. The study found that EV drivers' decisions to charge are mostly influenced by their battery SOC and the ability to reach the next station without deviating from their original travel plan, in addition to other secondary factors such as charging cost, time, detour time to reach a station, and amenities at the station.

The main goals of this study are developing an accurate model for EV owner trips and their charging behavior, identifying candidate charging station locations, and the number of chargers per station for fast-charging infrastructure based on the developed model. To achieve that, a novel methodology to identify candidate locations for fast-charging infrastructure is proposed. The developed approach is based on using missing energy event (MEE) in the Multi-Agent Transport Simulation (MATSim) EVcontrib (Horni, Nagel, & Axhausen, 2016) to assess the fast-charging infrastructure needs for passenger cars in Sweden.

2. METHODOLOGY

In this paper, the MATSim tool is used for modeling electric passenger cars' owner trips and their charging behavior based on the previous Sweden case study (Bischoff et al., 2019; Márquez-Fernández et al., 2019; Márquez-Fernández et al., 2021). Using MATSim, every EV movement on the transportation network, its energy consumption while driving, and each charging activity can be modeled and tracked. These results can later be aggregated for each vehicle type/fleet as well as for a certain type of charging infrastructure or for a specific geographical area.

Synthetic population

The Sweden study case is based on the SAMPERS (Sveder, 2002) aggregated travel demand model modified to account only for passenger car flows on roads. To be able to use it in MATSim, the flows in the SAMPERS model have been disaggregated into individual agents using the original origin and destination (OD) information combined with Corine Land Cover Data to determine specific OD locations for each agent (Bischoff et al. 2019). Only trips that are estimated to be longer than 150 km are considered, shorter trips are assumed not to need fast charging.

In cases where the travel distance exceeds 400 km and a round-trip on the same day is improbable, the model results are translated directly, without any adjustments, and for travel distances ranging between 150 km to 400 km, the model included a probability of scheduling a same day return trip for the agent, which decreases as the distance increases.

Regarding departure time selection the following cases are considered: if the distance of the trip is more than 1000 km then the departure time is selected randomly between 8 am and 10 am. For shorter trips, private trips start between 5 am and 12 pm in 70% of cases, between 12 pm and 4 pm in 20% of cases, and only 10% of cases after 4 pm. Business trips start between 5 am and 10 am in 80% of the cases and the rest of the cases start after 10 am.

Charging activity

Apart from the general plans, each agent is also assigned specific charging activities before every iteration in MATSim.

For each long-distance trip, the shortest route and the corresponding energy consumption profile are established. This, together with the capacity and initial SOC of the EV battery allows for determining the locations for the charging activities along the route. Charging activities are included in the plan according to: in 80% of cases, a charging activity is considered when the SOC reaches a value between 20 - 30% (randomly selected); for the rest 20% a charging activity is considered when the SOC reaches a value between 30 - 50% (randomly selected).

Charging activities are integrated into MATSim's activity-based modeling, but they do not provide any positive score (utility function of each agent in the MATSim model). The estimated time required for charging the vehicle defines the duration of each charging activity and in this model, it depends on the desired SOC after charging the EV battery capacity, and the rated power of the charging station.

At this point, the EVs' movements and their charging activities are established in the model, but the location of charging infrastructures and their specifications must be defined. For each charging station the total number of chargers, their type, and rated power must be defined. In the next part, an approach for finding candidate fast-charging infrastructure is introduced.

Candidate Fast Charging Infrastructure

The flowchart of the proposed strategy for finding candidate locations for fast-charging infrastructure is shown in Figure 1. First, it is assumed that there are no charging stations on the road and that all EVs start their long-distance trips with an initial SOC (SOC_{init}) distributed as follows: in 50% of cases $SOC_{init} = [90\% \quad 100\%]$, in 30% of the cases $SOC_{init} = [70\% \quad 90\%]$ and and in 20% of the cases $SOC_{init} = [50\% \quad 70\%]$ (randomly assigned except for the first step of proposed approach at Figure 1 where the lowest value is used).

Then the locations where the energy level of the EV battery runs down to zero are identified using the MEE. Afterward, the MEEs are aggregated in an area within a 30km radius. These areas are ranked based on the frequency of MEEs and the first 100 top ranks of them are selected as the selected candidate locations for charging stations. In the next step, the developed MATSim model is run with these 100 charging stations in place, and their impact is assessed based on the % of successful trips (the long-distance trips do not contain any MEEs). If this percentage is lower than 90%, more fast-charging station is added and the simulation reruns again until the required performance is achieved.

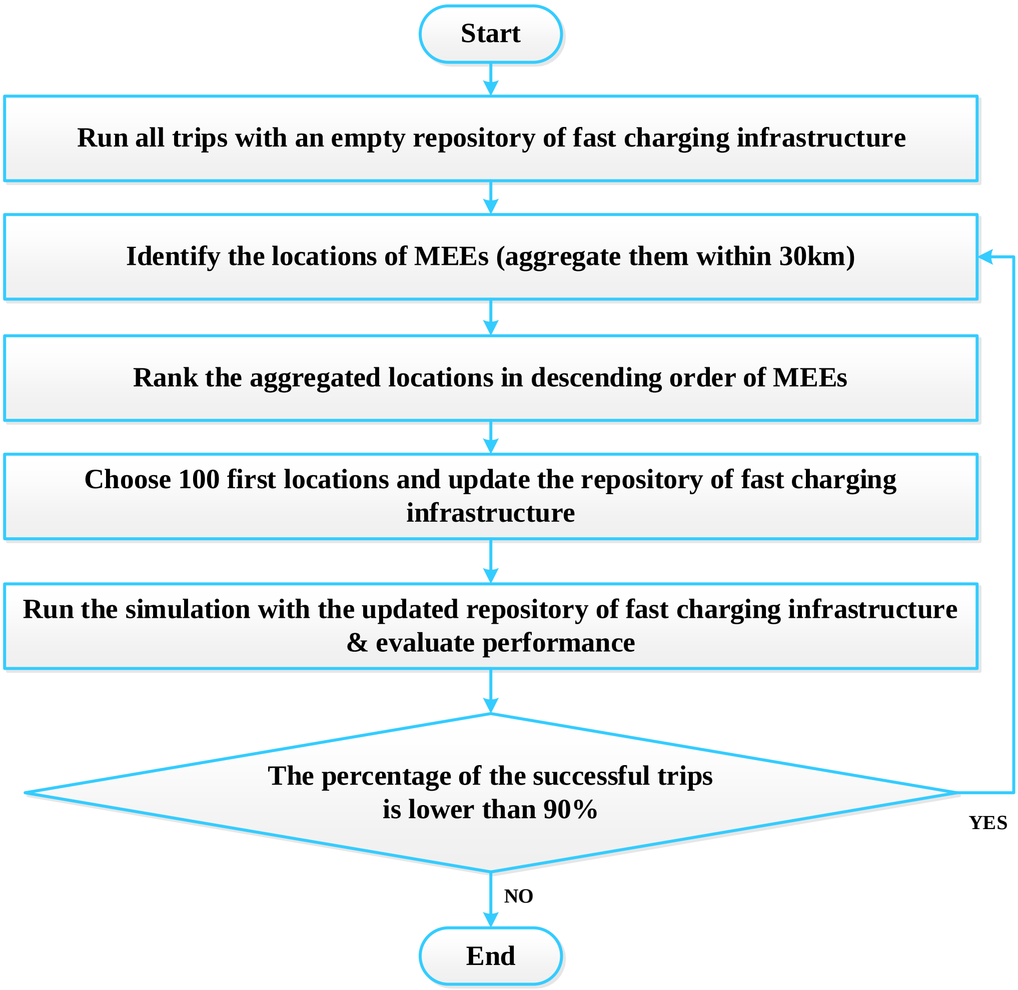

Figure 1: Flowchart of the proposed approach for identifying fast charging infrastructure locations.

Figure 2. shows the distribution of aggregated MEEs in a hexagonal network within a 30 km radius. This distribution results from running the developed MATSim model without any fast-charging infrastructure. As expected, a high number of MEEs occur on the route between Gothenburg (the second-largest city in Sweden) and Stockholm (the capital and largest city of Sweden). There is also a high number of MEEs near the border between Sweden and Denmark and around Malmo (the third-largest city in Sweden).

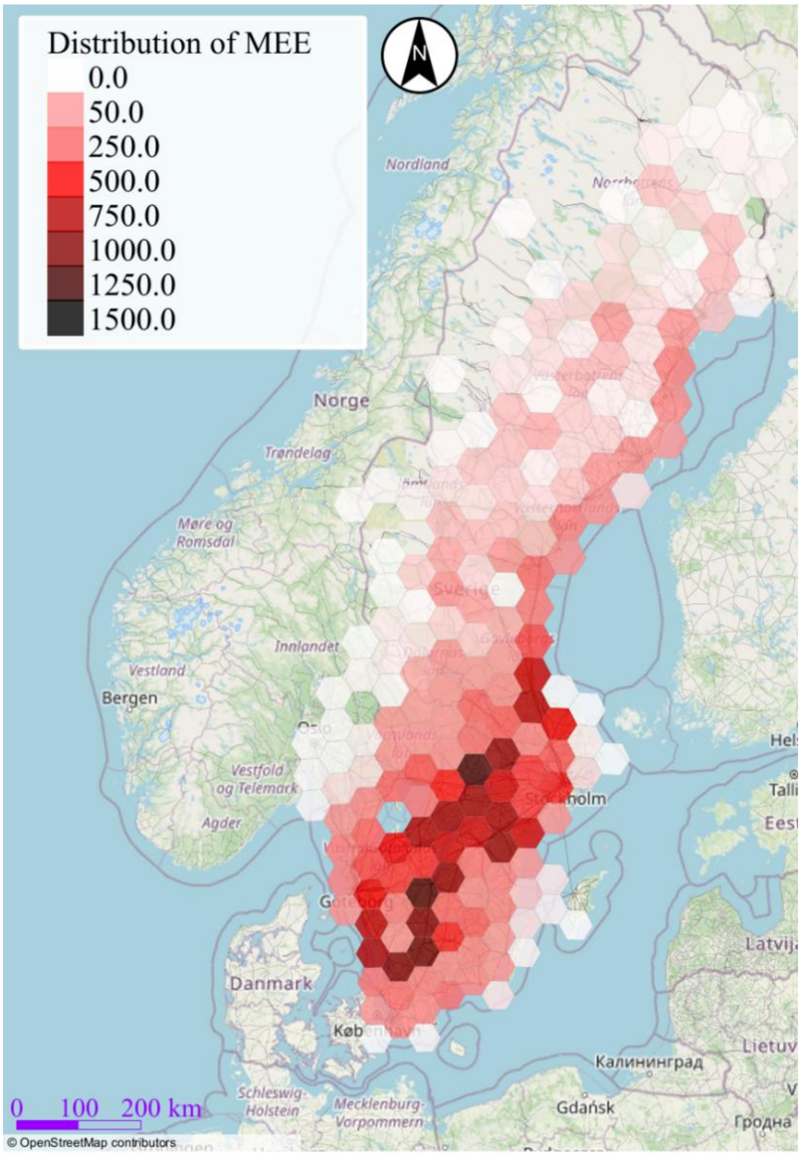

Figure 2: The Distribution of MEEs in the hexagonal network with a 30 km radius.

3. RESULTS AND DISCUSSION

In the simulation setup, the first part that must be defined is the mix of EVs fleet and their related specification which are mentioned in Table 1. The initial energy level of EV batteries (SOC_{init}) and the starting time of the trips are already mentioned in previous sections.

Table 1: Assignment of EVs

Vehicle Type	Battery Capacity kWh	Fleet Share %
Small	60	15
Medium	80	50
SUV	100	35

However, to make the simulation more manageable, a standard practice of utilizing a 10% sample of the population (the total number of trips in the MATSim model) is employed.
In the next step, the location of charging infrastructures must be introduced as input to the model. In Figure 3, all candidate locations are achieved based on the first step of the proposed approach (no-charging station scenario of developed MATSim model) and the 100 selected locations are shown based on the distribution of aggregated of MEEs in Fig 2. The total number of candidate locations is equal to 350. For the first iteration, charging stations are placed at the 100 locations with the highest number of MEEs. Each of these stations is equipped with an unlimited number of chargers, so every vehicle reaching the stations will be allowed to charge.

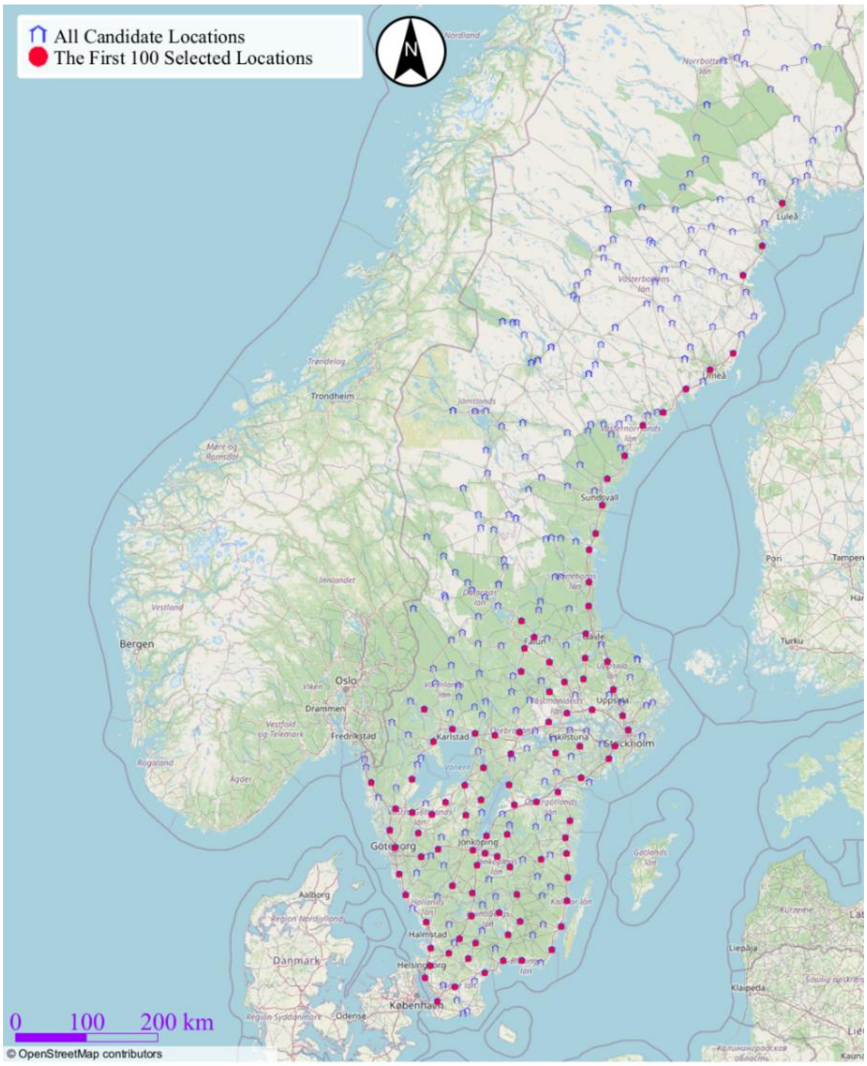

Figure 3: The candidate location and the 100 top-rank selected locations for fast-charging infrastructure based on the distribution of MEEs.

For subsequent iterations, more fast-charging infrastructure locations are added to the charging infrastructure repository of the MATSim model, by a step of 100 new fast charging stations at each iteration. These 100 new fast-charging stations are selected following the same procedure, based on the distribution of MEEs resulting from the previous iteration.
In Table 2, the percentage of successful trips before and after adding candidate fast-charging infrastructures at each iteration of the proposed methodology is shown.

Table 2: The percentage of successful trips before and after adding fast charging infrastructure with an unlimited number of chargers.

Number of fast-charging stations	Percentage of successful trips %
0	9.43
100	85.56
200	88.90
300	89.04
400	89.07

If all candidate locations (350 locations in Figure 3) for fast-charging infrastructure in the first step of the proposed approach are considered, then the percentage of successful trips is equal to 89.28. The reason for the higher percentage of the successful trip with all candidate locations based on the no-charging station scenario compared to the result of 400 fast charging stations based on the proposed method in Figure 1 is that in the no-charging scenario, the distribution of initial SOC is set to lower bound of each case, then the candidate locations are found, but in the proposed approach the distribution of initial SOC is set based on the mentioned range for each case and the new candidate locations are found based on the higher value of initial SOC, therefore since the charging activities are initiated at the higher value of 20% EVs battery capacity the newly found candidate location cannot cover the trips that are started with the lower value of initial SOC and also the improvement in the percentage of successful trips decreases while the number of the charging station is increased.

Another important reason for this result is the consideration of the unlimited number of chargers at each fast-charging station.

Based on the results, it is observed that with 200 fast-charging infrastructure locations almost 90% of long-distance trips by passenger electric cars can be satisfied if there is an unlimited number of chargers in each location.

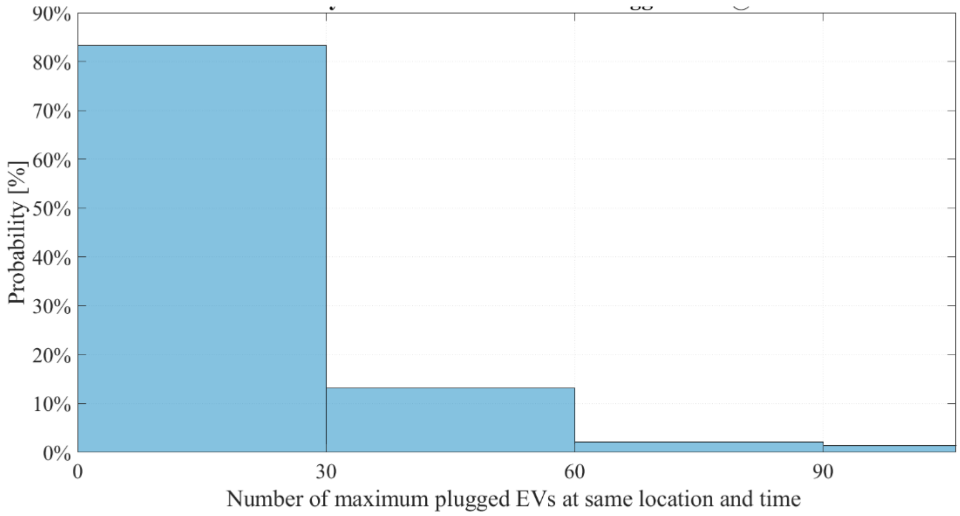

Figure 5: The Distribution of the maximum number of simultaneously charging EVs at a fast-charging station.

As can be seen in Figure 5, in more than 80% of cases the maximum number of EVs that are charging at the same fast charging station location simultaneously is not more than 30 in the scenario with 400 charging stations with unlimited chargers at each location.

Therefore, the limitation of the number of chargers is added to the proposed methodology with the consideration of a maximum of 30 chargers at each fast-charging station in the real world. Since 10% of all long-distance trips above 150km are considered in the MATSim model, each fast-charging infrastructure location is equipped with 3 chargers.
Table 3 displays the success rate percentages of trips before and after the inclusion of candidate fast-charging infrastructures that consist of three chargers at each charging station in every iteration of the proposed methodology.

Table 3: The percentage of successful trips before and after fast charging infrastructure with 3 chargers on each location

Number of fast-charging infrastructure	Percentage of successful trips %
0	9.43
100	46.93
200	53.71
300	59.29
400	61.41

If all candidate locations (350 locations in Figure 3) for the fast-charging infrastructure in the no-charging station scenario are considered with 3 chargers on each location, then the percentage of successful trips is equal to 54.40.
Based on the results of Table 3, after considering 3 chargers at each location the percentage of successful trips based on the proposed methodology (adding new charging stations based on the iterative method Figure 1) is higher compared to considering all found locations in the no charging case is higher.

4. CONCLUSIONS

This paper presents a novel methodology based on the missing energy event concept of MATim EVcontrib to assess the fast-charging infrastructure needs for fully electric passenger cars on long-distance trips in Sweden. The proposed methodology accurately models EV owner trips and charging behavior, identified candidate charging station locations, and assessed them and the number of chargers per station required for fast-charging infrastructure. The results highlight the importance of investing in fast-charging infrastructure to promote the widespread adoption of EVs and pave the way for a sustainable transportation system.
Future research will improve the accuracy of our methodology by refining the synthetic population of the MATSim model for long-distance trips by electric passenger cars. This can involve developing a more detailed representation of EV owner demographics, travel patterns, and charging behavior, and incorporating data on the spatial distribution of charging infrastructure. Such research will provide a more comprehensive assessment of the fast-charging infrastructure requirements for EVs and inform the planning and deployment of charging infrastructure.

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