Minimum-cost fast-charging infrastructure planning for electricvehicles along the Austrian high-level road network

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Overview

Given the ongoing decarbonization of the transport sector, the share of electric vehicles (EVs) in the passenger car fleet will grow substantially in the upcoming decades. This growing uptake of electromobility needs to be supported by means of a densification of public charging infrastructure. In particular, increased deployment of fast-charging infrastructure is important to counteract the phenomenon of range anxiety and support long-distance travel with EVs. One of the most important places of fast-charging stations is along highways and motorways. There, fast-charging infrastructure expansion needs to happen simulatenously with the growth of the share of EVs in the car fleet, to enable traveling long routes with EVs in sufficient time. Against, this background, the core objective of this work is to propose a model with which the required future expansion of the current fast-charging infrastructure along a high-level road network is quantified. Further, we aim to analyse how the requirement for a fast-charging infrastructure change in the face of developments in EV technology and changes in road traffic which are likely to happen due to modal shift effects.

Methods

Within the proposed modeling framework, the high-level road network is conceptualized using graph representation. Based on this, demand is assigned to nodes, which represent service areas, highway junctions and network endpoints. The assigned demand is calculated based on the energy consumed by the EVs driving between nodes in the network. A mixed-integer linear program was formulated which places the fast-charging stations at service areas along a highway network and sizes these by determining the optimal number of required fast-charging points at a charging station. The fast-charging infrastructure is designed cost-optimaly by minimizing the total charging infrastructure investment costs, defined by:

$$\min_x \left(c_{CS} * \sum_l CS_l + c_{CP} * \sum_l CP_l \right)$$

In this formula, the costs of the installement of one charging station are expressed by c_{CS}, and costs of one charging point by c_{CP}. The decision variable CS_l is a binary variable that indicates wether a charging station is installed at node l (1) or not (0). CP_l is an integer variable that indicates the number of charging points at each node l. The placement of charging stations is determined based on the coverage of charging demand at the nodes which has to be covered within a given radius around a node that is defined by the driving range of an EV.

Results

The required expansion of the existing fast-charging infrastructure along Austrian highways is modeled under different future scenarios for 2030. Figure 1 displays the results of a scenario within which the lowest capacity expansion for the year 2030 is needed. Green charging stations express required capacity expansion at existing charging stations, and orange ones at not-yet-existing charging stations. At least 24 additional charging stations (CS) have to be installed until 2030, and +146 MW of charging capacity. The highest costs of fast-charging infrastructure expansion are yielded within a scenario for which no changes in people's mobility behavior and only minor improvements in driving range and charging power of EVs are assumed. A particular analysis encompassing the alteration of selected input parameters is conducted in order to gain insight into which model parameters exactly cause the high costs of infrastructure expansion in this scenario. Further, sensitivity analyses are conducted, during which the change in requirements for fast-charging infrastructure design in the face of enhanced driving range and size of EV fleet for the configuration is observed.

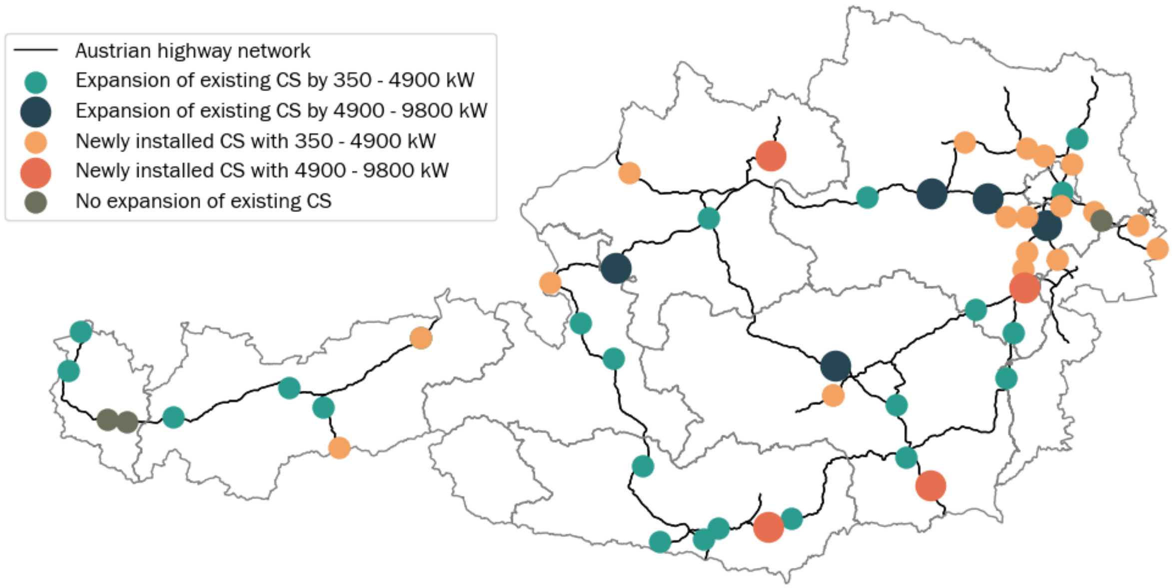

Figure 1: Minimum required expansion of the existing fast-charging infrastructure along Austrian highways projected for 2030.

This study presents one of the first ones specifically dedicated to model required charging infrastructure expansion with the regard to different future developments in EV technology as well as in modal split. We find that all these considered parameters have an effect on the required expansion and need to be considered in the expansion planning. Moreover, the improvements in EV technology have the potential to decrease future costs of fast-charging infrastructure expansion, in particular, enhanced charging power.