infrastructures

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Conceptual Design of Public Charging Stations for Freight Road Transport

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Abstract: We present a comprehensive methodology for a two-step approach to address the task at hand. The first step involves the optimal placement of charging stations, while the second step focuses on determining the necessary capacity of the charging stations based on traffic factors. This methodology is applicable to countries, states, or specific areas where the placement and optimization of charging stations for truck road transport are being considered. We identify the key inputs required for solving such a task. In the results section, we demonstrate the outcomes using a model example for the Czech Republic.

Keywords: electric freight transport; charging station; infrastructure; freight transport charging

Citation: Hospodka, J.; Sadil, J.; Bínová, H.; František, K.; Oldřich, H.; Magdalena, H.; Kristýna, N. Conceptual Design of Public Charging Stations for Freight Road Transport. *Infrastructures* **2024**, *9*, 7. https://doi.org/10.3390/infrastructures9010007

Academic Editors: Hugo Silva and Joel R. M. Oliveira

Received: 27 October 2023
Revised: 17 December 2023
Accepted: 24 December 2023
Published: 27 December 2023

1. Introduction

This article is focused on developing a methodology for the placement of charging stations for battery electric freight trucks (CHS). The specific task at hand involves designing charging stations with parameters different from those used for personal transportation, where demands on parking spaces and charging power of charging stands are lower, while facilities and services are planned for a higher number of people. Principles for the planning of public charging infrastructure for personal battery electric vehicles (BEV), including a literature review, are discussed, e.g., in [1,2]. Detailed technical guidelines are provided in [3].

Given that freight transportation entails distinct traffic patterns and typically covers larger distances, the allocation problem for locating these charging stations becomes a novel and specific challenge. Currently, almost no publicly accessible infrastructure for heavy-duty electric vehicles is available in the European Union. The most advanced exception is a 600-km road stretch between the Rhine-Neckar and Rhine-Ruhr metropolitan areas in Germany, built to boost the logistical sector along one of the busiest freight routes in Europe. Till the end of the year 2023, it is supposed to contain eight ultra-fast public charging locations.

Considering the commitment of countries to reduce CO_2 emissions, a shift in traction within the freight truck industry can help achieve these goals. However, the "chicken-and-egg" problem persists in implementing electric freight transportation. This problem arises from carriers' reluctance to invest in electric freight vehicles due to the lack of an adequate charging network. Simultaneously, private operators hesitate to invest in charging stations as there is currently no demand. Thus, the role of the government appears indispensable in facilitating the establishment of charging stations. Since the impetus for change comes from a higher level, namely the state, it is possible to plan and execute it optimally.

Consequently, in this case, the placement of charging stations should not be random, based solely on available space, but rather systematically designed to ensure maximum coverage of existing transportation flows in the automotive freight industry. This entails locating the minimum number of stations with sufficient capacity to achieve the desired coverage. Recently, several studies have been published aimed at the design of future charging infrastructure for electric road freight transport. Speth et al. [4] use traffic count data as input and combine them with on-site queueing models to obtain a fast-charging network in Germany with a 100 km distance between locations. Speth et al. [5] define a network of stations on a European highway network based on synthetic transport flow data. However, the location selection does not take into account the suitability of the location for a charging area. We find it important to incorporate more inputs, including parking area availability, power grid connection, and other aspects of the analysis.

To address the task at hand, we present a comprehensive methodology for a two-step approach. The first step involves the optimal placement of charging stations in three stages corresponding to the years 2025, 2030, and 2035. The first two stages are based on the Alternative Fuel Infrastructure Regulation (AFIR) [6], which requires charging stations for freight vehicles in urban nodes and at regular intervals along the TEN-T road network. The last stage, corresponding to the original proposal of AFIR by the European Commission [7,8] and the broadened version proposed by the European Parliament for trilogue negotiations), concludes the basic coverage of the whole network.

The second step of the methodology focuses on determining the necessary capacity and other parameters of the charging stations based on data related to traffic in the catchment area, the specific electricity consumption of considered types of vehicles under the given conditions, the ratio of BEV and the ratio of public charging, parameters of BEV, charging outlets and data on the electrical network. Sources for this data depend on available information in the investigated country/region. For the model example of the Czech Republic discussed in Section 2.2, data on traffic were obtained from the national traffic census [9], which provides traffic intensities of various types of vehicles (including five different categories of freight vehicles above 3.5 t) on work/weekend days, day/night-time, peak periods etc. This census data also includes geographic information on individual segments, allowing for the computation of traffic output (vehicle-kilometers per day) on main and other routes in catchment areas of particular stations, used subsequently for the assessment of the number of charging vehicles and their output [10]. Further, the document [11] provides data on daily, weekly, and yearly variations of traffic intensities.

To assess the specific electricity consumption of different types of vehicles in the conditions of the Czech Republic, the set of open simulation programs SUMO (Simulation of Urban Mobility), together with its extension PHEM, was used for modeling a substantial part of the traffic network in the Czech Republic, simulation of traffic flows and calculation of energy and fuel consumption for present types of vehicles and for various possible future scenarios [12]. Other approaches can also be used, as described e.g., in [13]. The assessment of spatial requirements was based on data from Technical Conditions 171 [14], including dimensions of vehicles from considered categories and the norm [15] specifying minimal distances between parked vehicles. The estimation of the ratio of BEV and the need for public charging is based on scenarios discussed in studies [16,17] that also take into account statistics of trip lengths in different countries. This ratio includes the fact that vehicles use the energy earned from depot chargers to get to the highway network, and vice versa; returning to the depot can be connected with a battery depletion even below a level that is safe for travel on highways. Data on the electric network and available capacity of transformer stations were obtained from electricity providers (ČEZ distribuce, PRE distribuce, and EG.D.).

The proposed methodology determines the course of the required power, load diagrams, numbers and occupancy of charging outlets, and space requirements of the charging infrastructure stations. It also evaluates free distribution capacity and specifies the choice of the station battery. It is applicable to countries, states, or specific areas where the placement and optimization of charging stations for truck road transport are being considered. We identify the key inputs required for solving such a task. In the results section, we demonstrate the outcomes using a model example for the Czech Republic.

2. Methods

The conceptual design of truck charging stations presented in this paper consists of two main steps: Expert design of the location of charging stations in the network (see Section 2.1) and power and spatial needs calculation based on traffic demands for individual charging stations (see Figure 1 and Section 2.2).

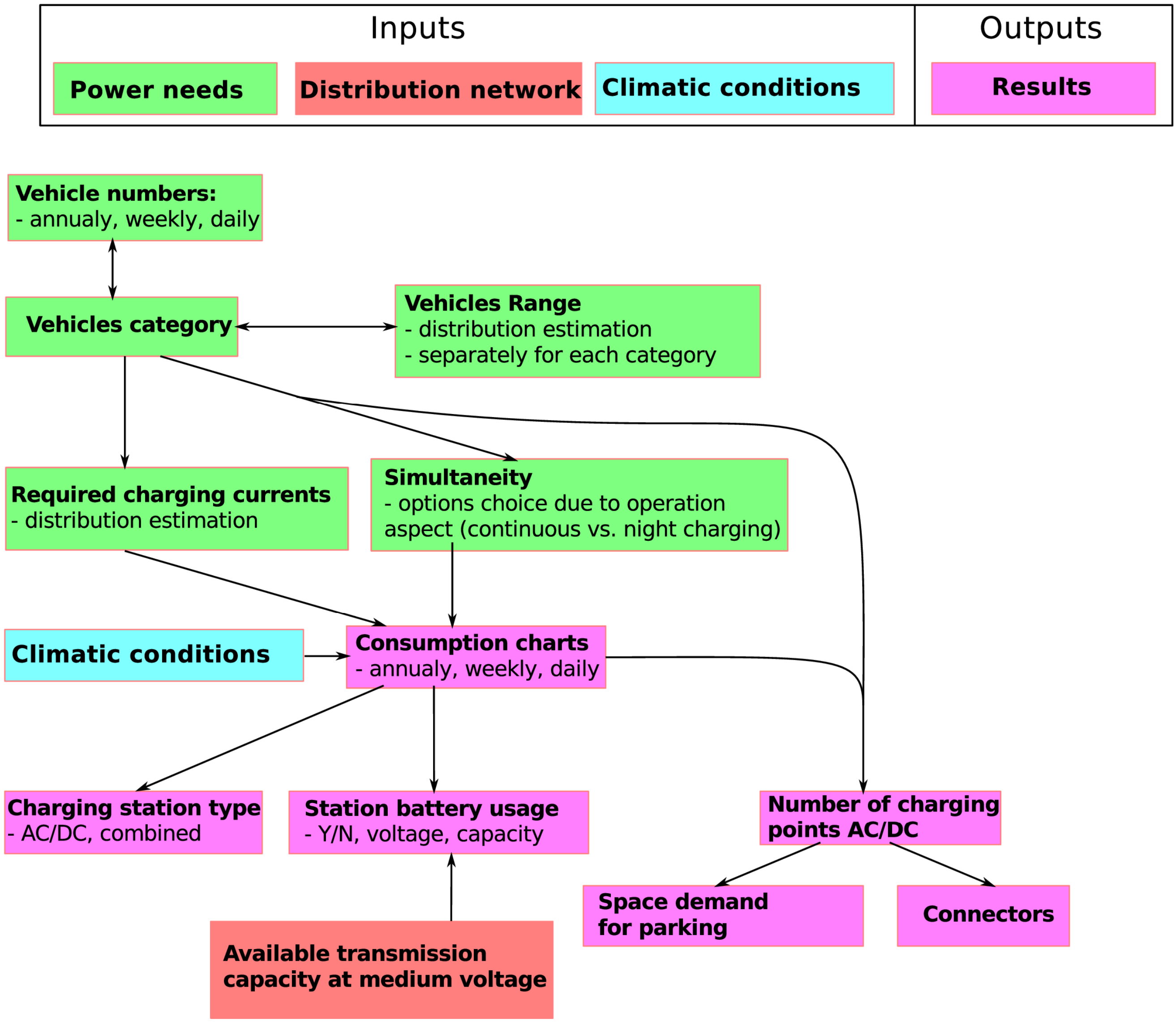

Figure 1. Architecture of the proposed methodology—Step 2: Calculation.

The fundamental aspect of a charging station is its location. In a given area, the total traffic in all directions is considered. Free transformer capacity of the nearest very high/high-voltage transformer station is then found.

The methodology uses vehicle categories monitored by the national traffic census [9]. The relevant categories for heavy road transport are SN, SNP, TN, TNP, and NSN; these categories cover the categories N2 and N3 according to European directive 2007/46/ES.

2.1. Location of Charging Stations

The placement of charging stations is based on the legislative package of the European Commission Fit for 55, in particular, the amendments to the legislation in the field of freight transport on land communications, which obliges individual member states to create a basic network of charging stations for freight transport. According to the proposal of the European Commission for the year 2021 [7], publicly accessible charging stations for freight transport are to be deployed on the roads of the Core TEN-T network at maximum distances of 60 km and in important urban nodes by the end of the year 2025. In the second stage, by the end of the year 2030, charging stations on the Comprehensive TEN-T is to be built at a maximum distance of 100 km, and the performances of the stations on the Core TEN-T are to be strengthened. In the third stage, the performances of the stations on the Comprehensive TEN-T network are also to be strengthened. The new version of AFIR [6] accepted in 2023 requires the deployment of charging stations along at least 15% of the length of the TEN-T road network till 2025 and 50% till 2027.

To satisfy the requirements as well as to cover the area, the target distances of ca. 50 km are considered. We are convinced that we cannot rely on the expectation of a significant breakthrough in the volume and mass capacity of charging cells in the near future, and a higher density of charging stations is necessary to ensure truly safe charging for freight transport throughout the country.

Besides the legislative conditions, the methodology is based on a detailed overview of all rest stops on the European TEN-T network (in the considered country/region), including stationing, the capacity of parking spaces for trucks and possibilities of its extension, the connection of directions, the existence, the size and the possibility of extension of electrical connection, distances from nearby charging stations, including those on other roads, and the existence of facilities for the driver or the possibility of their additional construction.

Charging stations are lined up at indicated distances on the respective main roads, with the lining up starting at the main communication hubs of city centers, especially Prague and Brno. This also corresponds to the requirement of deploying charging stations in important urban nodes in the first stage. Charging stations for the city center and the first charging points of the TEN-T network are located on city bypasses. These stations often overlap or are located at minimum distances. For example, Prague is the main communication hub of the republic; the stations are located at the exits from Prague at the rest stops on the D1, D11, D8, and D5 highways as Core TEN-T roads, as close as possible to the Prague Ring Road D0. Additional charging stations on the Core TEN-T follow every 50 km from these first charging stations. For the location of charging stations on the TEN-T comprehensive, the length of the Prague Ring Road, approx. 88 km, must be considered; the circuit is divided by stations into four approximately equal, 22 km long sections. This distance must be taken into account when leaving the circuit on the radials of the Comprehensive TEN-T network. The first charging stations on the Comprehensive TEN-T starting from Prague are, therefore, approximately 30 km from the Prague Ring Road. Furthermore, they are, of course, at distances of 100 and 50 km, respectively. On the other hand, the stations have to cover the network up to the frontiers, facilitating the transfer between neighboring countries (in any case, the distance of the last station from the frontiers should be smaller than 30 km); in the model example of the Czech Republic, this distance was minimized.

2.1.1. Phase 1: Urban Nodes and Core TEN-T

The location of charging stations on the Core TEN-T network (marked in blue) is based on urban nodes where the charging stations (marked in red in Figure 2) are expected to be built by 2025.

Due to the closeness of the deadline of the first phase, the uncertainty regarding the supply of electric vehicles and their price, and the uncertainty regarding the availability and price of electricity, it is proposed to split the construction of stations on the Core network into the first two stages. Thus, in the first stage, a network of charging stations for Core TEN-T would be built, but at distances of 100 km, which still meets the requirements of [6].

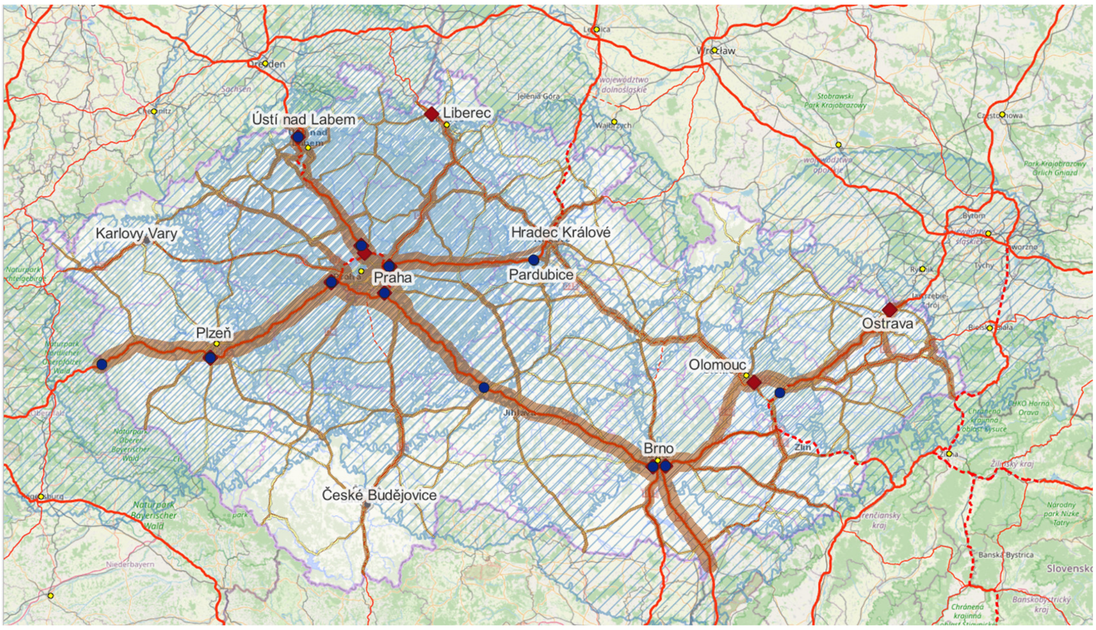

Figure 2. Phase 1, Urban nodes (red) and basic coverage of the Core TEN-T (dark blue).

2.1.2. Phase 2: Densification of the Core TEN-T Network and Basic Coverage of the Comprehensive TEN-T Network

For the second phase until 2030, the Core TEN-T network charging station distances will be densified to 50 km. See in Figure 3. In addition, the construction of a network of charging stations on the Comprehensive TEN-T is planned. Here, according to European recommendations, the distances between stations should be a maximum of 100 km.

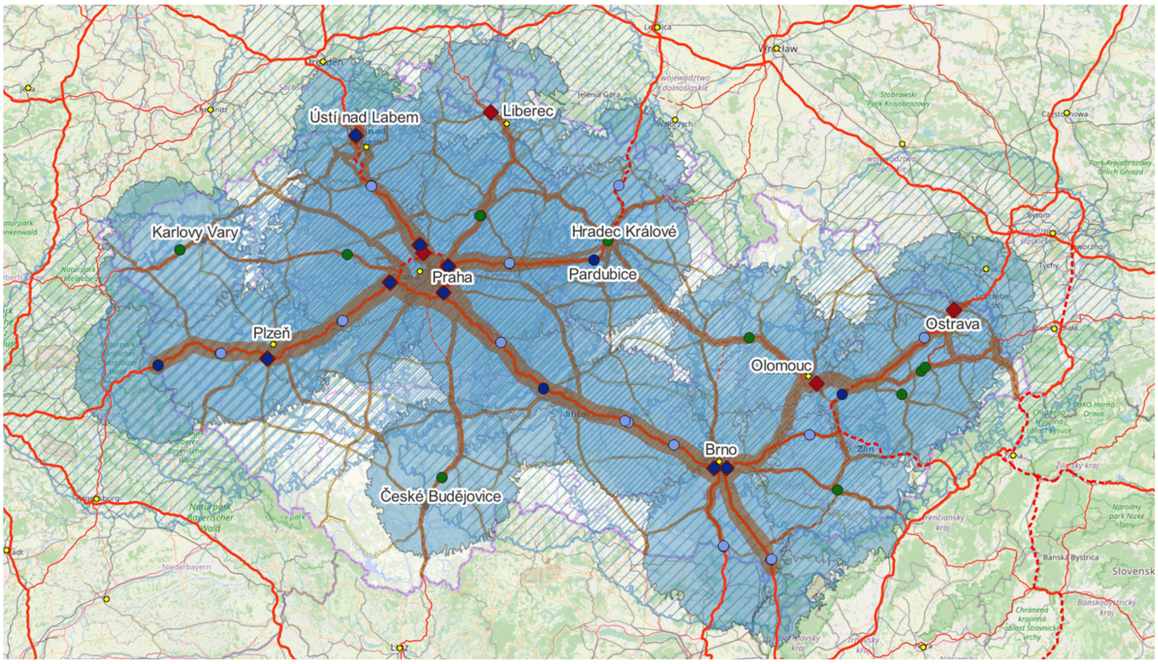

Figure 3. Phase 2, Densification of the Core TEN-T network (light blue) and basic coverage of the Comprehensive TEN-T network (dark green).

2.1.3. Phase 3 (Figure 4): Densification of the Comprehensive TEN-T Network, Additional Coverage of the Czech Republic

For the third phase until 2035, the Comprehensive TEN-T network charging station distances would be densified to 50 km to ensure truly safe charging for freight transport throughout the entire territory of the Czech Republic, without the need to rely on a significant breakthrough in the volume and energy density of traction batteries.

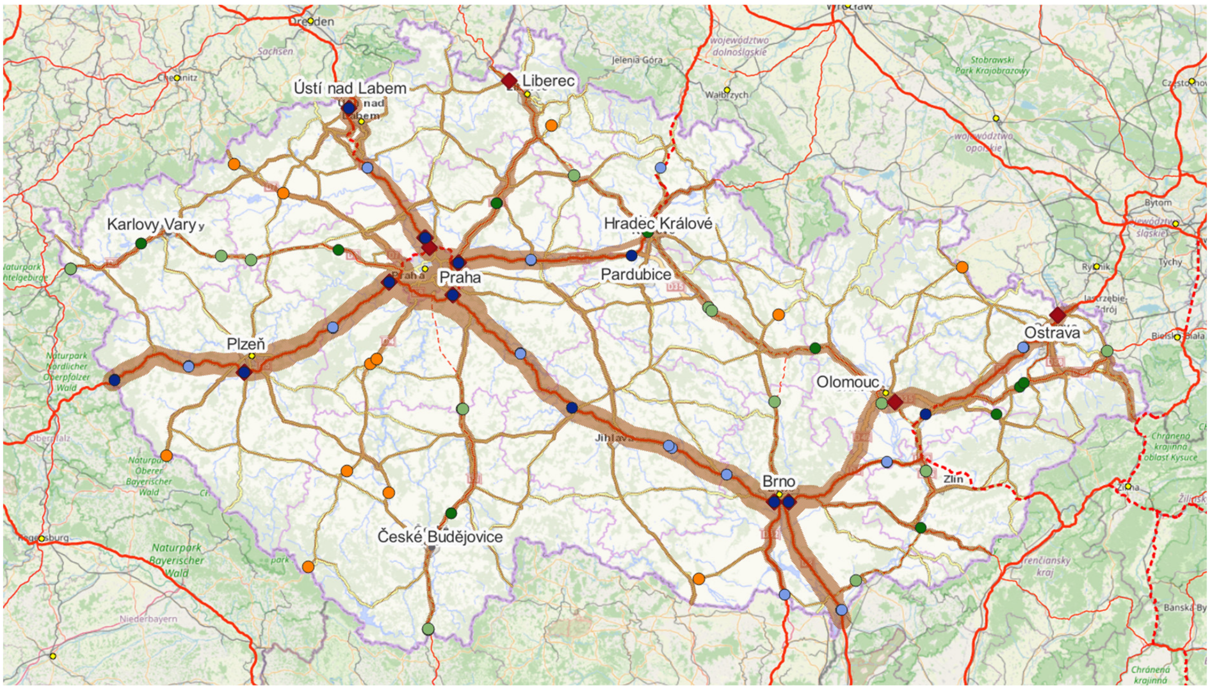

Figure 4. Phase 3, Densification of the Comprehensive TEN-T network (light green) and additional coverage of the traffic network of the Czech Republic (orange).

2.2. Methodology of Choosing the Concept of Charging Stations for Road Freight Transport

This is the second step in the process. This step takes place after the task "Location of charging stations in the network" described in Section 2.1 is completed. The schematics of this step are described in Figure 1. The aim of this methodology is to systematically establish suitable concepts of charging stations for road freight transport for the given location of the charging station. The methodology will determine the course of the required power, load diagrams, numbers and occupancy of charging outlets, and space requirements of the charging infrastructure stations; it will evaluate free distribution capacity and specify the choice of the station battery.

2.2.1. Input Parameters

The methodology assumes the following input parameters, and we provided the sources which we used, for example, the case of the Czech Republic:

- Traffic intensity in the area on workdays [9],
- Data from Technical Conditions 189: daily, weekly, and yearly variations in traffic intensity [11],
- Data from Technical Conditions 171: dimensions of vehicles in each category [14],
- Data from ČSN 73 6056: minimum distances between vehicles in each category in perpendicular parking [15],
- Traffic output of main and other routes in the catchment area [10],
- Electricity consumption [12],

- The ratio of battery electric vehicles (BEV) and the ratio of public charging, in the form of scenarios (sets of parameters),
- Probability of overnight charging of BEV, if the vehicle arrives at night,
- BEV parameters: range, charging current of the traction battery in xC units, Current stated in units of a multiple of the battery capacity.

The methodology assumes the following input parameters of the charging station:

- Selected power of charging outlets (e.g., 43, 170, 350 kW),
- Free capacity of the nearest transformer station (MVA),
- Distance to high-voltage power lines,
- High-voltage level,
- Dimensions of the charging stand structure.

2.2.2. Calculation

The basic time step in the calculation of daily courses of the quantities is 1 min. One day corresponds to 1440 samples (discrete time intervals).

2.2.3. Load Diagrams

Daily, weekly, and yearly variations of traffic intensity are determined for each vehicle category based on data from [11]. Based on daily traffic intensities corrected for weekly and yearly variations and based on the number of charged BEVs in the catchment area of the charging station, moments of arrival of individual vehicles at the charging station, the required charging distance (Distance of BEV ride within its range and which corresponds to the respective charge of the traction battery at the charging station), charge, charging current and the duration of discharge are determined. The course of the power of individual BEVs is summed up to determine the necessary momentary power and the reserved capacity (Reserved capacity is the power determined as the energy per a period of 15 min divided by 15 min). The results are determined for the worst-case day in the year. Figure 5 shows an example of the course of the power required together with the reserved capacity during the day in the given month.

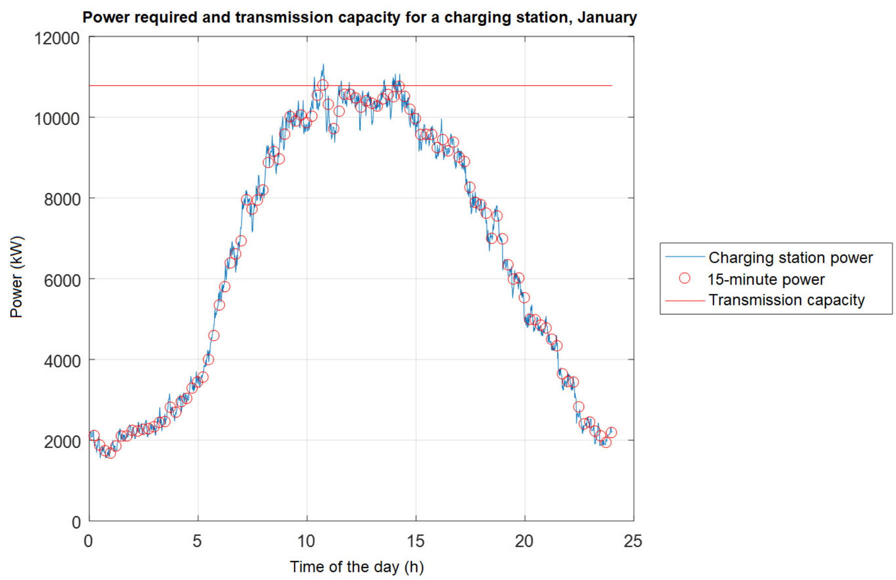

Figure 5. An illustrative example of required power and reserved capacity of a specific charging station of a specific month.

2.2.4. Occupancy

In each time step, it is found out which new vehicles have arrived to be charged, and they are allocated to a charging outlet according to the required power. In the case of a lack of sufficient charging outlets of the required power level, a charging outlet is added. The occupancy of charging outlets of each power level and the usability of the power of the charging outlet is monitored.

2.2.5. Climatic Conditions

Temperatures measured at the meteorological station in the Clementinum, Prague, are considered [18]. The average minimum values of average daily temperatures over the past 20 years are determined for each month in the year. It is assumed that the range of a BEV is lower and the consumption is higher due to heating in lower temperatures. A decrease in battery capacity is not considered; it is assumed that the station battery is placed in an air-conditioned space.

Load diagrams (Figure 5) are determined for individual months in the year while respecting climatic conditions. Occupancy calculation is done separately for each month in the year. The highest occupancy of all months of the year is determined for each 15 min interval.

2.2.6. Estimation of Reserved Capacity

Values of reserved capacity for individual months (Figure 6) are determined. In the case of variance of the parameters of the uniform distribution, the calculation is repeated. Power and occupancy are calculated repeatedly, and the 90th percentile of the results is determined. The reserved capacity for the worst-case day in the year is determined and compared to the free distribution capacity in the very high/high-voltage transformer station, which is closest in terms of power lines.

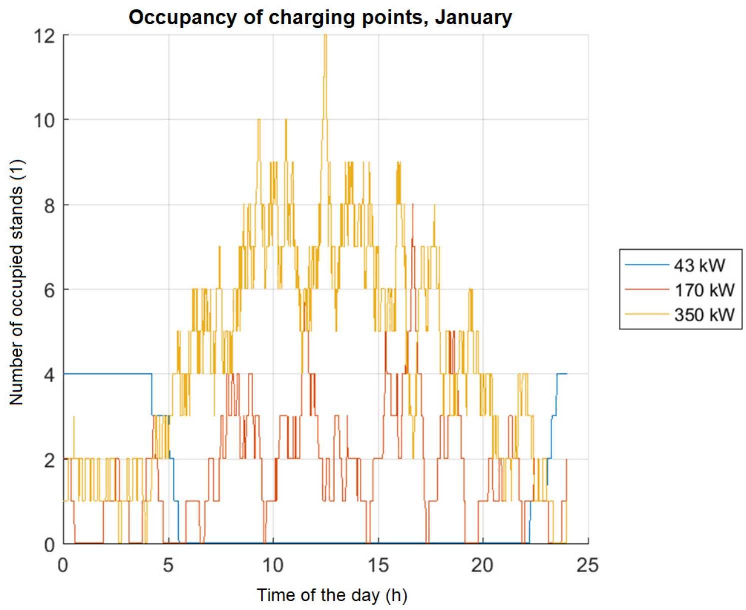

Figure 6. An illustrative example of occupancy of charging points of power levels of a specific charging station in a specific month.

2.2.7. Station Battery

After evaluating the free distribution capacity, it is determined whether it is advantageous to use a station battery in the given month. If the use of the station battery is recommended, the basic parameters of the battery are designed.

2.2.8. Space Requirements

The calculation of space requirements is based on the dimensions of vehicles in each category, the smallest distance between vehicles in each category, and the size of the charging outlet structure. Only perpendicular parking is considered. The calculation does not include the space requirements of the high- and low-voltage substations, the space for safe operation of the stands, the dimensions of the pavement and access roads, and the turning envelope of the vehicles. The required area of parking is assigned to the charging outlets of the given power level based on the knowledge of their occupancy by each category of vehicle. A maximalist approach is considered when calculating the parking area, going from the category with the largest vehicle dimensions to the smallest ones. The area required for the charging stand is calculated from the knowledge of their total number and the dimensions of their structures.

3. Results

After the two aforementioned steps, the following results are achieved.

3.1. Results of Location of Charging Stations (Step 1)

This section contains the results of the placement of charging stations for a model example of the Czech Republic.

The phasing is proposed by authors and goes as follows:

3.1.1. Year 2025: Phase 1

Core TEN-T network with maximum distances of 100 km (near-term, uncertain BEV availability) in significant urban nodes, see in Figure 7.

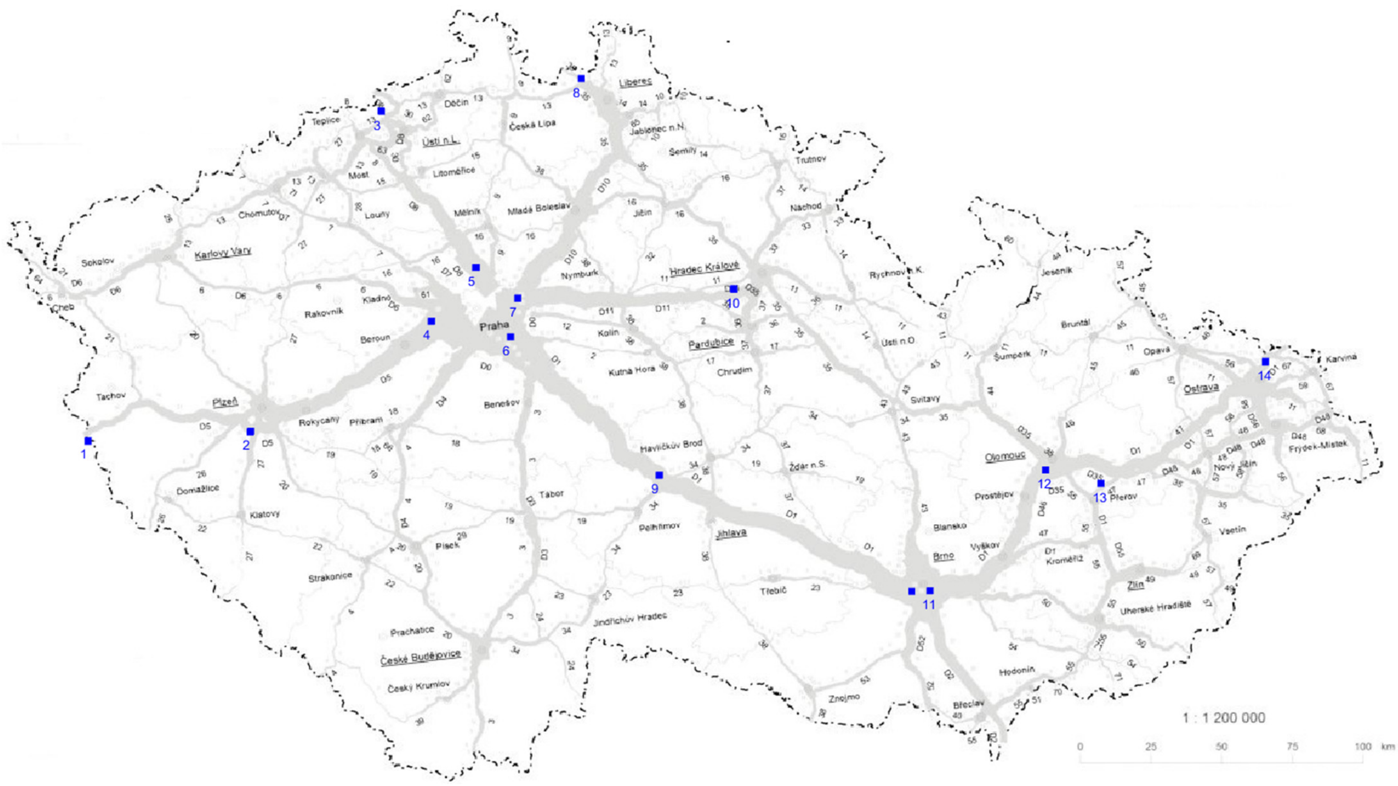

Figure 7. Map depicting 14 charging stations in Phase 1.

3.1.2. Year 2030: Phase 2 (Figure 3)

Core TEN-T network with maximum distances of 50 km.

Comprehensive TEN-T network with maximum distances of 100 km. See in Figure 8.

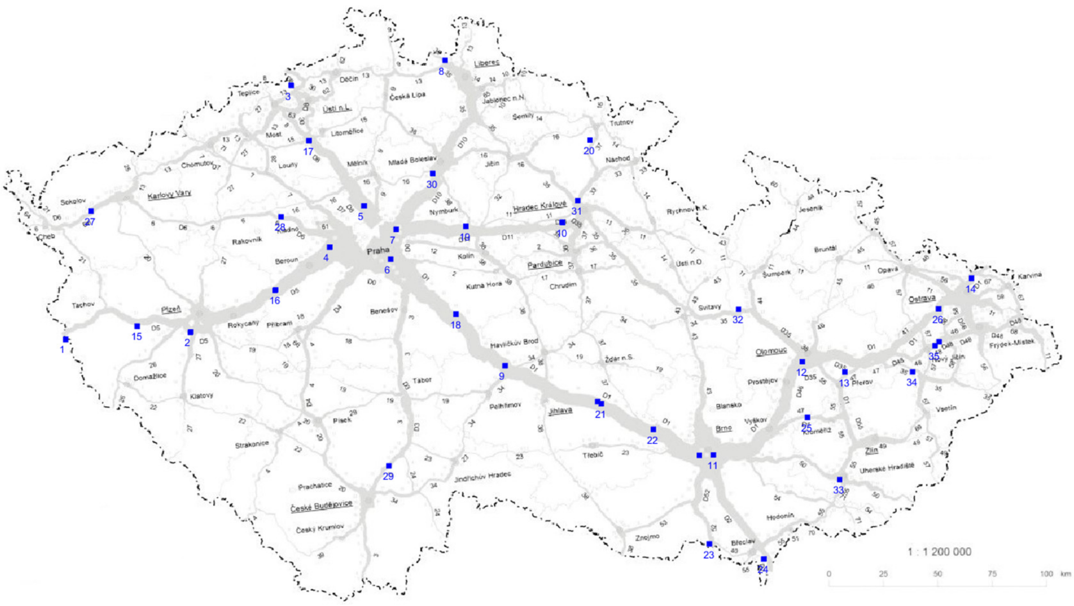

Figure 8. Map depicting 35 charging stations in Phase 2.

3.1.3. Year 2035: Phase 3

Comprehensive TEN-T network with maximum distances of 50 km.

Coverage of the transport network in the Czech Republic outside the TEN-T network.

Determination of P [MW] and n_(≥350 kW) for each phase based on the methodology results [19].

Phase 2 corresponds to the spacing requirements for charging stations (CHS) as specified by AFIR for the Core TEN-T and Comprehensive TEN-T networks. Phase 3 introduces additional CHS beyond the requirements set by AFIR. See in Figure 9.

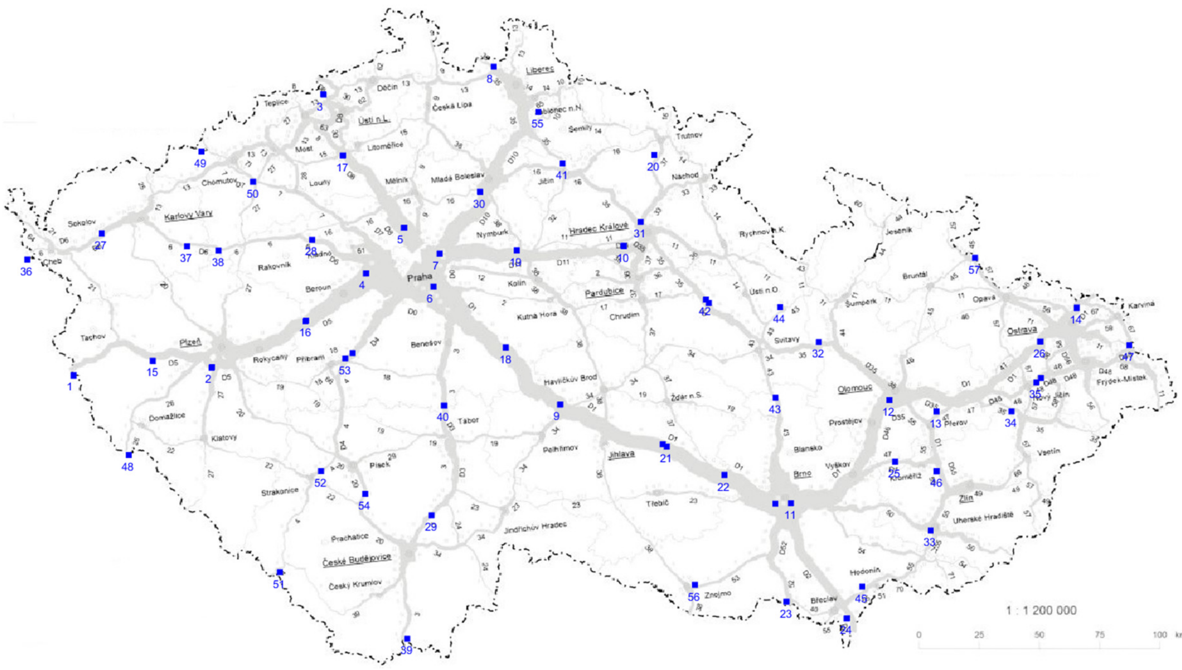

Figure 9. Map depicting 57 charging stations in Phase 3.

3.1.4. Charging Stations Overview

The following Table 1 summarizes the list of proposed charging stations for phases 1 to 3 described above.

Table 1. Summary of the main attributes of the proposed charging stations for phases 1 to 3. Shortcuts used in the table: CHS—charging station, TR—transformer station, Lon.—Longitude, Lat.—latitude, capac.—capacity, mv—medium voltage, comp—comprehensive.

Phase	Station ID	Type	Road Nr.	CHS Name	CHS Lon. (°N)	CHS Lat. (°E)	TR Lon. (°N)	TR Lat. (°E)	TR Name	TR Capac. (MVA)	Missing mv Line (km)	Parking Places (Pcs.)
Phase 1	1	core	D5	Rozvadov	49.6490	12.5321	49.7920	12.6604	Tachov	5	0.6	218
	2	core	D5	Šlovice	49.6787	13.3289	49.6848	13.4239	Černice	24	0.6	64
	3	core	D8	Varvažov	50.7118	13.9702	50.6866	14.0320	Ustí Sever	10	0.3	71
	4	core	D5	Rudná	50.0336	14.2163	50.0543	14.2120	Chýně	15	0.4	50
	5	core	D8	Klíčany	50.2072	14.4359	50.1340	14.4439	Praha Bohnice	5	0.2	28
	6	core	D1	Nupaky	49.9841	14.6038	49.9952	14.6366	Říčany	1	0.3	120
	7	core	D11	Beranka	50.1083	14.6389	50.0867	14.6145	Běchovice	39	0.2	49
	8	comp	I/35	Chrastava	50.8175	14.9498	50.7895	15.0531	Hrádek n.Nisou	14	0.2	10
	9	core	D1	Humpolec	49.5366	15.3324	49.5462	15.3376	Humpolec	17	0.2	28
	10	core	D11	Osice	50.1371	15.6990	50.1841	15.8235	Hradec Králové	5	1.1	60
	11	core	D1	Brno	49.1625	16.6615	49.1671	16.6313	Komárov	5	1	122
	12	comp	D35	Olomouc	49.5538	17.2282	49.5633	17.2043	Hněvotín	10	1.6	18
	13	core	D1	Osek	49.5105	17.5002	49.5030	17.4981	Prosenice	5	0.6	80
	14	city	D1	Antošovice	49.9024	18.3069	49.8950	18.3367	Bohumín	10	1.1	53
Phase 2	15	core	D5	Kladruby	49.7029	12.9876	49.7640	12.9980	Stříbro	18	0.2	30
	16	core	D5	Záluží	49.8548	13.8713	49.8309	13.8587	Hořovice	1	0	101
	17	core	D8	Siřejovice	50.4808	14.0839	50.4159	14.0485	Libochovice	25	0.2	39
	18	core	D1	Střechov	49.7520	15.0208	49.7017	14.9503	Řimovice	5	0.8	63
	19	core	D11	Vrbova Lhota	50.1204	15.0829	50.0343	15.1724	Kolín západ	7	1.1	160
	20	core	I/37	Výšinka	50.4829	15.8752	50.5766	15.9582	Poříčí	15	0	0
	21	core	D1	Kochánov	49.3775	15.9464	49.3468	15.9977	Velké Meziříčí	11	2.9	42
	22	core	D1	Devět Křížů	49.2698	16.2786	49.2774	16.2348	Velká Bíteš	20	1.1	53
	23	core	D52	Mikulov	48.7895	16.6358	48.8151	16.6238	Mikulov	18	0.2	0
	24	core	D2	Lanžhot	48.7267	16.9842	48.7812	16.9061	Břeclav	2	0.7	122
	25	core	D1	Křenovice	49.3202	17.2610	49.3149	17.4494	Kojetín	1,5	2	48
	26	core	D1	Klimkovice	49.7753	18.0976	49.8107	18.1519	Ostrava Poruba	20	1	166
	27	comp	D6	Staré Sedlo	50.1847	12.6948	50.1607	12.6750	Vítkov	15	0.2	30
	28	comp	D6	Nové Strašecí	50.1611	13.9052	50.1421	13.9751	Tuchlovice	18	0	5
	29	comp	I/3	Švamberk	49.1171	14.5929	49.2097	14.7207	Veselí n Lužnicí	14	0.3	0
	30	comp	D10	Brodce	50.3424	14.8735	50.3076	14.8482	Dražice	1	0.3	19
	31	comp	I/35	HradecKrálové	50.2290	15.7972	50.2511	15.7674	Všestary	5	0	10
	32	comp	I/35	Mohelnice	49.7737	16.8216	49.7496	16.6500	Mor. Třebová	10	0.9	10
	33	comp	D55	Uher. Hradiště	49.0592	17.4665	49.0731	17.4627	Uher.Hradiště	2	0.3	25
	34	comp	I/35	Lešná	49.5109	17.9307	49.4775	17.9580	ValašskéMeziříčí	5	0.3	15
	35	comp	D48	Libhošť	49.6203	18.0737	49.6301	18.1422	Příbor	10	0.25	4

Table 1. *Cont.*

Phase	Station ID	Type	Road Nr.	CHS Name	CHS Lon. (°N)	CHS Lat. (°E)	TR Lon. (°N)	TR Lat. (°E)	TR Name	TR Capac. (MVA)	Missing mv Line (km)	Parking Places (Pcs.)
Phase 3	36	comp	I/6	Pomezí	50.0869	12.2652	50.0969	12.3970	Jindřichov	4	0.4	97
	37	comp	I/6	Verušičky	50.1367	13.1848	50.0638	12.9972	Toužim	12	0.1	16
	38	comp	I/6	Lubenec Ležky	50.1199	13.3670	50.2222	13.3924	Podbořany	20	0	5
	39	comp	D3	Dolní Dvořiště	48.6492	14.4526	48.7323	14.5050	Kaplice	17	0.4	15
	40	comp	D3	Mitrovice	49.5331	14.6632	49.4112	14.6898	Tábor	10	0.8	60
	41	comp	I/35	Jičín	50.4503	15.3473	50.4081	15.3424	Nová Paka	20	0	20
	42	comp	I/35	Vysoké Mýto	49.9346	16.1716	49.9848	16.1918	Choceň	10	1	75
	43	comp	I/43	Letovice	49.5626	16.5727	49.4991	16.6405	Boskovice	3	0	0
	44	comp	I/43	Lanškroun	49.9063	16.5994	49.8923	16.4506	Česká Třebová	15	0	2
	45	comp	D55	Lužice	48.8473	17.0718	48.8781	17.1184	Hodonín	23	0.2	22
	46	comp	D55	Kurovice	49.2847	17.5015	49.3151	17.4491	Hulín	1.5	1.5	80
	47	comp	D48	Chotěbuz	49.7619	18.6091	49.7063	18.6198	Ropice	35	0.15	10
	48	dopln	I/26	Folmava	49.3456	12.8499	49.4505	12.9491	Domažlice	1	0.5	60
	49	dopln	I/7	Hora sv. Šebes	50.4955	13.2678	50.4500	13.4205	Chomutov	10	0.6	4
	50	dopln	D7	Velemyšleves	50.3816	13.5659	50.3808	13.5748	Triangle	25	0.2	33
	51	dopln	I/4	Strážný	48.9017	13.7194	49.0554	13.8056	Vimperk	14	0.5	9
	52	dopln	I/4	Rovná	49.2848	13.9569	49.2966	14.1640	Písek	16	0.4	30
	53	dopln	I/4	Příbram	49.7116	14.0968	49.7021	14.0156	Příbram město	6	0.3	20
	54	dopln	I/20	Protivín	49.1983	14.2110	49.1877	14.3822	Křtěnov	30	0.7	7
	55	dopln	I/10	Malá Skála	50.6458	15.2077	50.7069	15.0898	Jeřmanice	35	0.5	5
	56	dopln	I/53	Znojmo	48.8537	16.1089	48.8382	16.1691	Hodonice	25	0	5
	57	dopln	I/57	Krnov	50.0933	17.7219	50.0822	17.6813	Krnov	15	0	20

3.2. Results of Power and Spatial Needs (Step 2)

3.2.1. Scenarios

The calculation using this methodology was performed for the following scenarios:

- AFIR_EK: The scenario is determined by the requirements formulated in the original proposal of AFIR by the European Commission [7] for CHS in the years 2025, 2030, and 2035 (max charging power 350 kW).
- AFIR_EP: The scenario is determined by the requirements of AFIR broadened by a proposal of the European Parliament for CHS in the years 2025, 2027, 2030, and 2032 (max charging power 700 kW; see report to [8] from February 2022).
- Industry baseline: The scenario is detailed in [16,17].
- EV-Leaders: The scenario is detailed in [16,17].
- Road-2-Zero: The scenario is detailed in [16,17].

Based on the data in [17,20,21] and expertly corrected based on [9], the shares of BEV and public charging are determined for the Industry-baseline, EV-Leaders, and Road-2-Zero scenarios for the observed stages and vehicle categories. The vehicle categories are described in detail in [10]. The shares of BEV (ratio of traffic realized by BEV to the total traffic) are presented in Table 2; the shares of public charging were expertly estimated to be 40% on average (distinguished for each vehicle category).

Table 2. The shares of BEV (ratio of traffic realized by BEV to the total traffic) for individual vehicle categories and years.

Scenario	Vehicle Category According to [10]	Vehicle Class According to ECE	Year 2025	Year 2030	Year 2035
Industry baseline	SN	N2	0.3	3.0	9.7
	SNP	N2 + O	0.3	3.0	9.7
	TN	N3	0.4	3.7	11.7
	TNP	N3 + O	0.7	6.2	19.9
	NSN	N3 + O	0.7	6.2	19.9
EV-Leaders	SN	N2	1.9	7.0	23.9
	SNP	N2 + O	1.9	7.0	23.9
	TN	N3	1.7	7.5	25.6
	TNP	N3 + O	1.0	9.5	32.5
	NSN	N3 + O	1.0	9.5	32.5
Road-2-Zero	SN	N2	3.9	10.5	32.4
	SNP	N2 + O	3.9	10.5	32.4
	TN	N3	3.5	11.0	33.9
	TNP	N3 + O	1.7	12.9	39.9
	NSN	N3 + O	1.7	12.9	39.9

The distinction between AFIR_EK and AFIR_EP lies in the proposed maximum output of a single charging station. However, the final compromise version [6] accepted in 2023 requires an individual power output of only 350 kW. In general, it denotes the Regulation for the deployment of alternative fuels infrastructure, and it sets mandatory deployment targets for electric recharging and hydrogen refueling infrastructure for the road sector, for shore-side electricity supply in maritime and inland waterway ports, and for electricity supply to stationary aircraft. The significant part of heavy-duty vehicles states: “Recharging stations dedicated to heavy-duty vehicles with a minimum output of 350 kW need to be deployed every 60 km along the TEN-T core network, and every 100 km on the larger TEN-T comprehensive network from 2025 onwards, with complete network coverage to be achieved by 2030. In addition, recharging stations must be installed at safe and secure parking areas for overnight recharging as well as in urban nodes for delivery vehicles” [21].

3.2.2. Parameters for Charging Stations

For each charging station and for all stations in our model example in the Czech Republic, the following is determined:

- *CHS* Cap: Maximum monthly reserved capacity of the lines (MVA),
- Energy: Annual energy consumption (GWh),
- Techl./Park. Area: Required area of the charging technology and parking (m^2),
- MissPark: Total missing parking area for all charging stations (m^2),
- MissDistr: Power deficiency of the distribution network (MVA),
- Stat. Batt: Nominal energy of the station batteries of all charging stations (MWh),
- ChPts: Number of charging points for individual power levels.

The following result sets are listed in Table 3:

- AFIR_EK for power levels of charging stations at 170 and 350 kW,
- AFIR_EP for power levels of charging stations at 170 and 700 kW,
- Phase 1, according to the methodology for power levels of charging stations at 170 and 350 kW,
- Phase 2, according to the methodology for power levels of charging stations at 170 and 350 kW,
- Phase 3, according to the methodology for power levels of charging stations at 170 and 350 kW,
- Phase 3, according to the methodology for power levels of charging stations at 170, 350, and 700 kW,
- Verification calculation with 100% share of BEVs and 100% share of public charging for power levels from the set {170, 350} or {170, 350, 700} kW.

Table 3. Summary of the main attributes of the proposed charging stations for phases 1 to 3. Shortcuts used in the table heading are listed above within Section 3.2.2, as well as detailed descriptions of the result set. Other shortcuts used in the table: InB—Industry Baseline scenario, EVL— EV-Leaders scenario, R2Z—Road to zero scenario.

Result Set	Scenario	Traffic Feasibility	CHS Cap (MVA)	Energy (GWh/ann)	Techl. Area (m^2)	Park. Area (m^2)	MissPark (m^2)	MissDistr (MVA)	Stat. Batt. (MWh)	ChPts 170 kW	ChPts 350 kW	ChPts 700 kW	ChPts Total
AFIR_EK	2025	100.000	15.4	0.0	280	4315	0	0.0	3.4	77	11	0	88
	2030	100.000	95.9	0.0	724	24,189	4865	5.0	20.2	468	57	0	525
	2035	100.000	119.0	0.0	745	29,743	10,832	7.5	29.5	578	68	0	646
AFIR_EP	2025	100.000	22.0	0.0	287	3305	0	0.0	8.4	44	0	22	66
	2027	100.000	68.0	0.0	720	9455	1928	0.0	25.3	136	0	68	204
	2030	100.000	137.0	0.0	800	21,068	3947	8.0	50.5	343	0	114	457
	2032	100.000	170.0	0.0	850	26,622	9088	12.0	67.3	442	0	136	578
Phase 1	InB	97.914	10.3	16.7	280	4641	0	0.0	0.0	22	34	0	56
	EVL	97.477	15.6	32.1	280	7572	0	0.0	0.0	40	54	0	94
	R2Z	97.518	22.3	58.8	280	10,847	0	0.0	1.6	57	80	0	137
Phase 2	InB	99.683	54.8	152.8	700	28,148	4479	1.6	3.8	129	224	0	353
	EVL	99.674	78.5	247.4	700	38,416	7849	4.8	4.1	179	305	0	484
	R2Z	99.672	101.5	341.7	733	49,716	11,232	8.2	17.5	236	393	0	629
Phase 3	InB	99.998	149.9	490.9	1168	73,062	18,004	15.3	11.8	327	596	0	923
	EVL	99.997	240.3	844.9	1324	110,470	39,634	37.0	38.4	490	913	0	1403
	R2Z	99.997	294.8	1053.7	1501	132,620	56,929	52.1	76.2	579	1113	0	1692
Phase 3	InB_700 kW	99.997	159.5	490.9	1170	72,885	17,685	16.9	12.4	199	414	300	913
	EVL_700 kW	99.997	251.7	845.0	1336	106,245	38,115	39.6	40.1	304	606	428	1338
	R2Z_700 kW	99.997	305.0	1053.7	1515	123,103	50,121	56.4	78.5	348	706	502	1556
Verif 100%	-	99.998	1736.6	6445.7	6992	655,525	913,340	1185.9	440.3	3961	5257	0	9218
	700 kW	99.998	1758.8	6446.0	7073	549,733	710,376	1211.4	443.2	1730	3509	1967	7206

3.3. Graphical Results

This section contains selected results in graphical form.

3.3.1. Power Distribution Demands

Power distribution demands of AFIR_EK scenario depicted in Figure 10. In the Figure 11 is depicted power distribution demands of Phase 3, and Figure 12 shows power distribution demands of verification scenario with 100% share of electric trucks. Comparison of different scenarios is shown in the Figure 13.

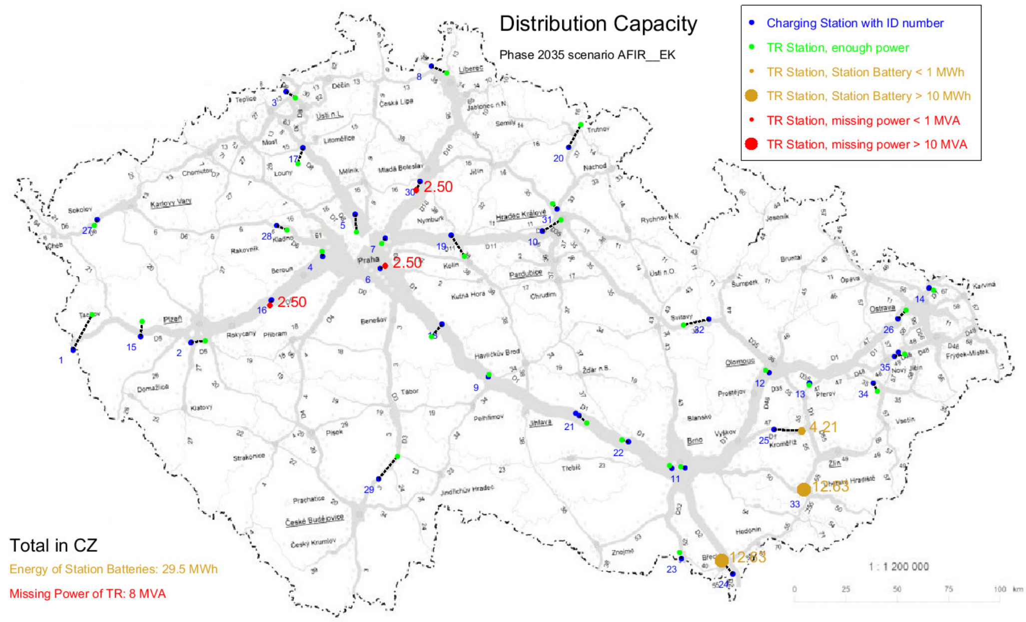

Figure 10. Power distribution demands of AFIR_EK scenario.

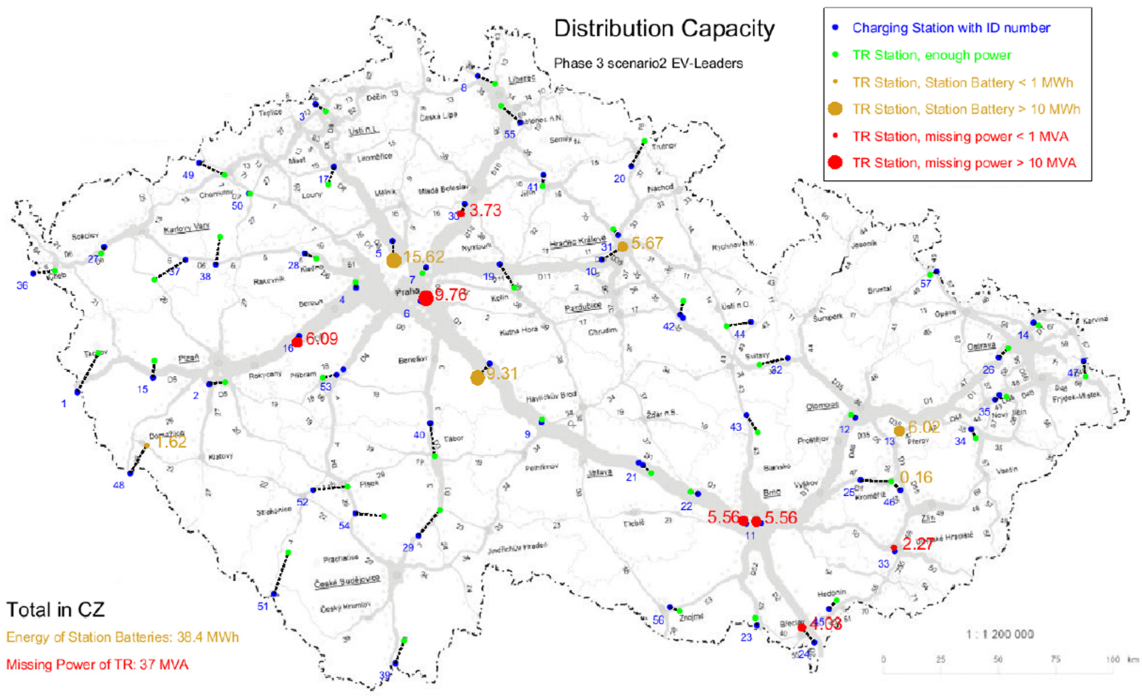

Figure 11. Power distribution demands of Phase 3 EV_Leaders scenario according to the author's methodology.

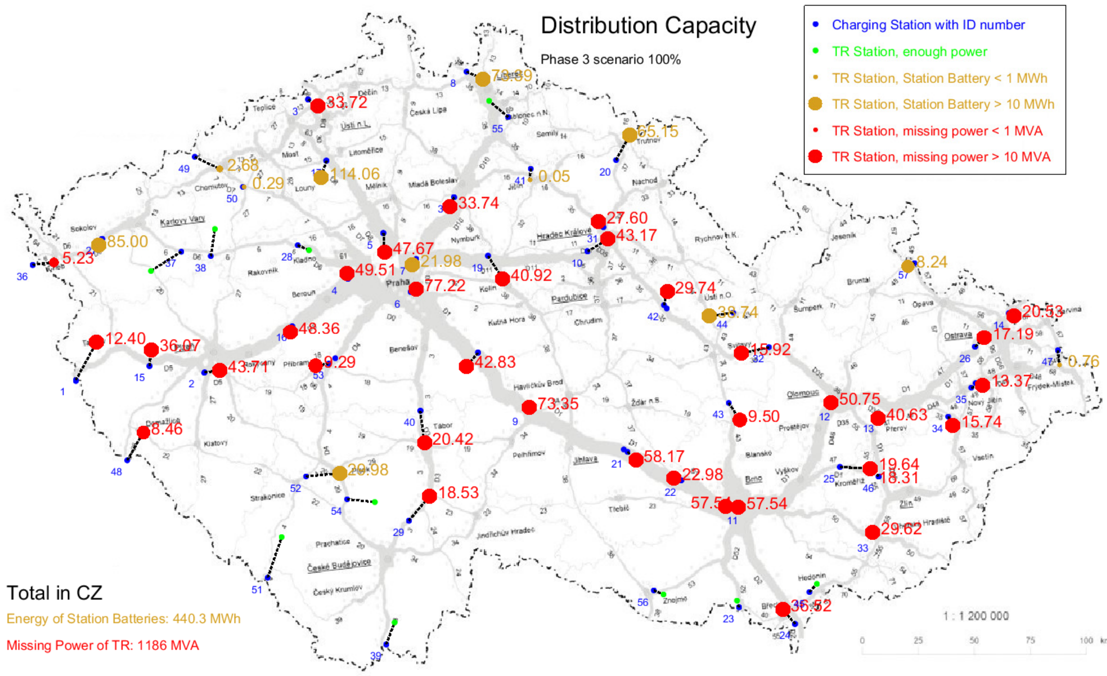

Figure 12. Power distribution demands of verification scenario of 100% share of electric trucks, according to the author's methodology.

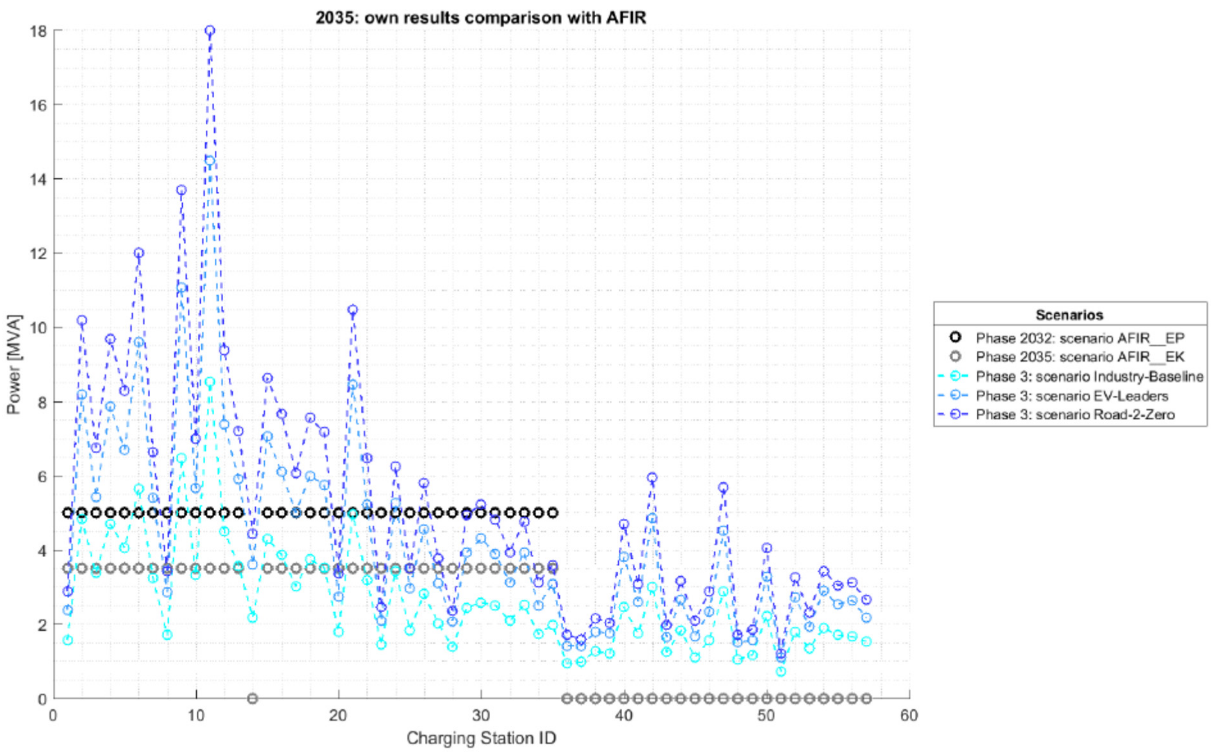

Figure 13. Power distribution demands comparison of different scenarios according to the author's methodology with AFIR requirements.

3.3.2. Spatial Demands for Parking

Following charts show parking space demands for different scenario Figure 14 shows demand for AFIR_EK scenario, Figure 15 shows demand for Phace3 and Figure 16 show demand for of verification scenario of 100% share of electric trucks.

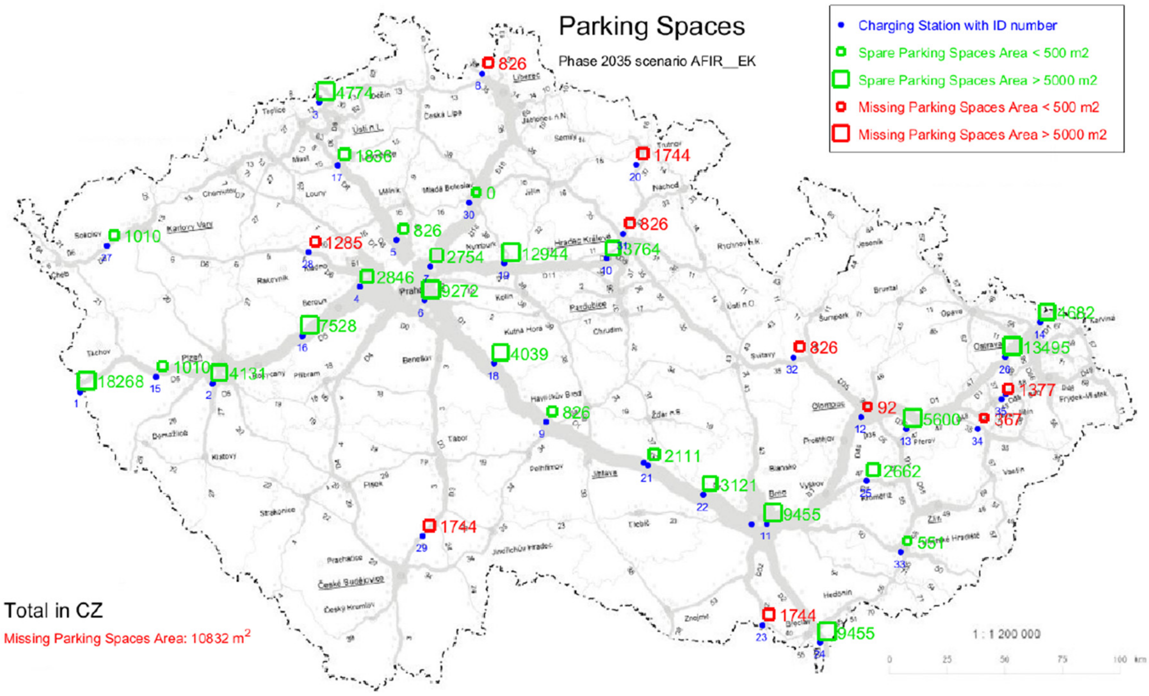

Figure 14. Parking space demands of AFIR_EK scenario.

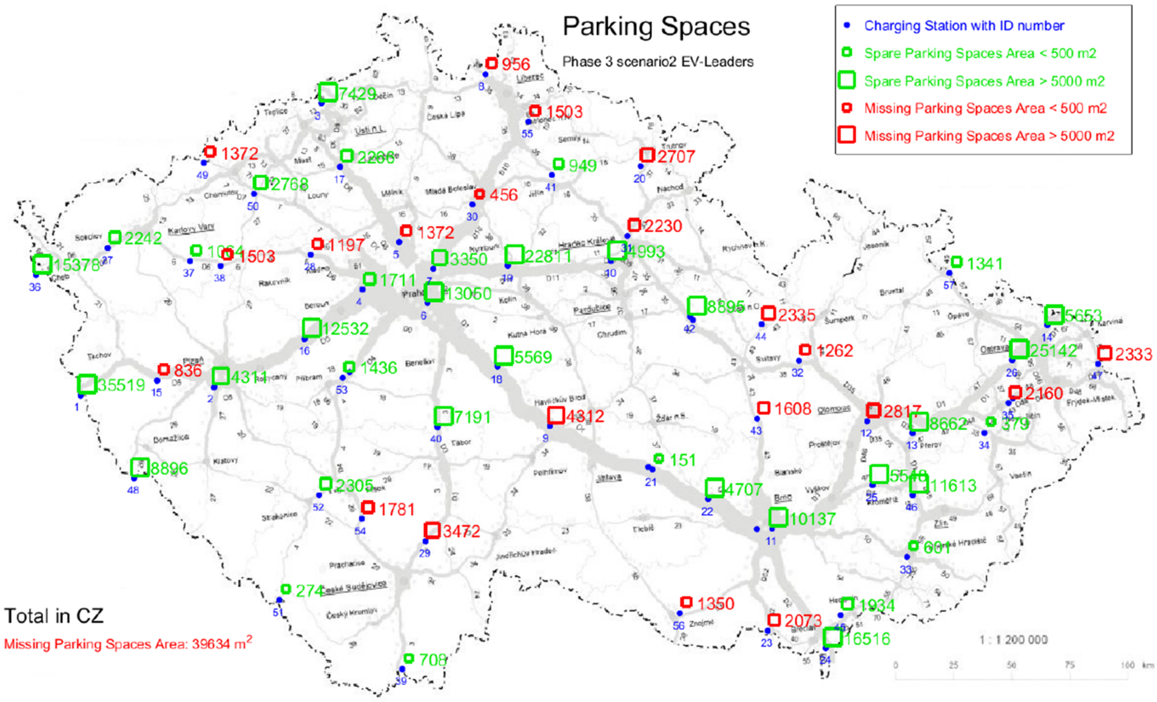

Figure 15. Parking space demands of Phase 3 EV-Leaders scenario according to the author's methodology.

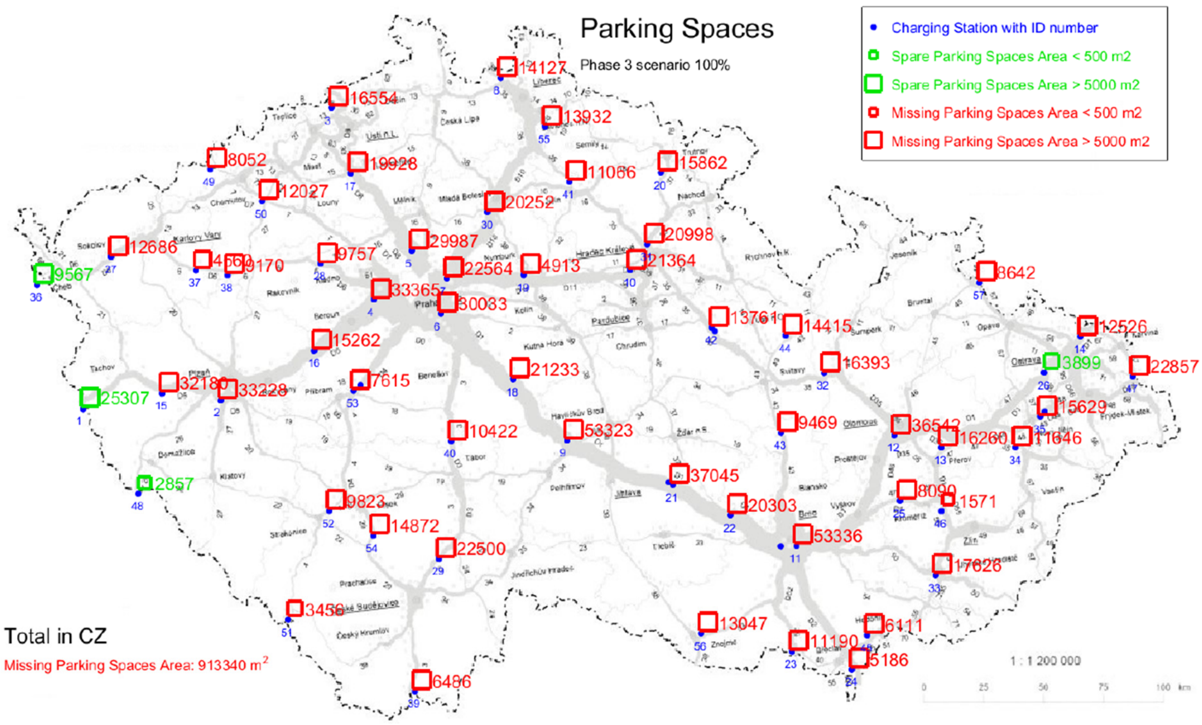

Figure 16. Parking space demands of verification scenario of 100% share of electric trucks, according to the author's methodology.

3.4. Comment on Numerical Results

3.4.1. Scenario AFIR_EK

In the year 2025, the distribution capacity is sufficient, and in one out of the total of 14 CHS, it would be necessary to install a station battery with an energy capacity of 3.4 MWh. Sufficient parking areas are available.

In the year 2030, the distribution capacity would need to be increased by a total of 5 MVA for 2 CHS out of the total of 35. In 3 additional CHS, station batteries with a total energy capacity of 20.2 MWh would need to be installed. Parking areas would need to be increased by a total of 4865 m^2 in five CHS.

In the year 2035, the distribution capacity would need to be increased by a total of 8 MVA for 3 CHS out of the total of 35. In 3 additional CHS, station batteries with a total energy capacity of 29.5 MWh would need to be installed. Parking areas would need to be increased by a total of 10,832 m^2 in ten CHS.

3.4.2. Scenario AFIR_EP

In the year 2025, the distribution capacity is sufficient, and in one out of the total of 14 CHS, it would be necessary to install a station battery with an energy capacity of 8.4 MWh. Sufficient parking areas are available.

In the year 2027, station batteries with a total energy capacity of 25.3 MWh would need to be installed in three CHS. Parking areas would need to be increased by a total of 1928 m^2 in five CHS.

In the year 2030, the distribution capacity would need to be increased by a total of 8 MVA for 2 CHS out of the total of 35. In 3 additional CHS, station batteries with a total energy capacity of 50.5 MWh would need to be installed. Parking areas would need to be increased by a total of 3947 m^2 in five CHS.

In the year 2032, the distribution capacity would need to be increased by a total of 12 MVA for 3 CHS out of the total of 35. In 3 additional CHS, station batteries with a total energy capacity of 67.3 MWh would need to be installed. Parking areas would need to be increased by a total of 9088 m^2 in nine CHS.

3.4.3. Scenario INDUSTRY BASELINE According to the Methodology

In the year 2025, the distribution capacity is sufficient, and no CHS out of the total of 14 would require the installation of a station battery. Sufficient parking areas are available.

In the year 2030, the distribution capacity would need to be increased by a total of 2 MVA for 1 CHS out of the total of 35. In 2 additional CHS, station batteries with a total energy capacity of 3.8 MWh would need to be installed. Parking areas would need to be increased by a total of 4,79 m^2 in seven CHS.

In the year 2035, the distribution capacity would need to be increased by a total of 15 MVA for 4 CHS out of the total of 57. In 3 additional CHS, station batteries with a total energy capacity of 11.8 MWh would need to be installed. Parking areas would need to be increased by a total of 18,004 m^2 in 18 CHS.

3.4.4. Scenario EV-Leaders According to the Methodology

In the year 2025, the distribution capacity is sufficient, and in one out of the total of 14 CHS, it would be necessary to install a station battery with an energy capacity of 0.01 MWh. Sufficient parking areas are available.

In the year 2030, the distribution capacity would need to be increased by a total of 5 MVA for 2 CHS out of the total of 35. In 3 additional CHS, station batteries with a total energy capacity of 4.1 MWh would need to be installed. Parking areas would need to be increased by a total of 7849 m^2 in 8 CHS.

In the year 2035, the distribution capacity would need to be increased by a total of 37 MVA for 6 CHS out of the total of 57. In 6 additional CHS, station batteries with a total energy capacity of 38.4 MWh would need to be installed. Parking areas would need to be increased by a total of 39,634 m^2 in 21 CHS.

3.4.5. Scenario Road-2-Zero According to the Methodology

In the year 2025, the distribution capacity is sufficient, and in one out of the total of 14 CHS, it would be necessary to install a station battery with an energy capacity of 1.6 MWh. Sufficient parking areas are available.

In the year 2030, the distribution capacity would need to be increased by a total of 8 MVA for 3 CHS out of the total of 35. In 3 additional CHS, station batteries with a total energy capacity of 17.5 MWh would need to be installed. Parking areas would need to be increased by a total of 11,232 m^2 in nine CHS.

In the year 2035, the distribution capacity would need to be increased by a total of 52 MVA for 7 CHS out of the total of 57. In 10 additional CHS, station batteries with a total energy capacity of 76.2 MWh would need to be installed. Parking areas would need to be increased by a total of 56,929 m^2 in 24 CHS.

4. Conclusions

The article presents a methodology for the placement of charging stations specifically designed for heavy-duty vehicles. The methodology provides detailed information regarding the spatial distribution and power requirements of the stations. It can be applied in any area where the necessary inputs are available. The study case presented in this article focuses on the specific context of the Czech Republic, reflecting the reality of the country.

Results of the methodology presented in this paper are as detailed as possible, but still, they are conceptual results, not covering such details as, e.g., which part of available distribution power capacity is reserved for which purposes. Only the value of distribution capacity in the area neighboring the respective charging station is evaluated.

Based on the results analyzed in detail in Section 3.4 Comment on Numerical Results, the most feasible considered scenario is AFIR_EK. In the year 2035, the distribution capacity would need to be increased by a total of 8 MVA for 3 charging stations out of the total of 35. In 3 additional charging stations, station batteries with a total energy capacity of 29.5 MWh would need to be installed. Parking areas would need to be increased by a total of 10,832 m^2 in ten charging stations.

AFIR_EP is the more demanding scenario with the necessary increasing the distribution capacity by a total of 12 MVA for 3 charging stations out of the total of 35 necessary station batteries with a total energy of 67.3 MWh and parking places deficit of a total 9088 m^2, in the year 2032.

Results of the author's methodology presented in this paper compare three main scenarios: Industry Baseline, EV-Leaders, and Road-2-Zero in the year 2025, 2030, and 2035. The Industry Baseline scenario is feasible without any modification of distribution capacity or parking areas in 2025, but will require increasing to 2 MVA distribution capacity, 3.8 MWh station batteries, and 4479 m^2 of parking areas in 2030, and increasing to 15 MVA distribution capacity, 11.8 MWh station batteries, and 18,004 m^2 of parking areas in 2035.

The EV-Leaders scenario will require building 0.01 MWh station batteries in 2025, increasing to 5 MVA distribution capacity, 4.1 MWh station batteries, and 7849 m^2 of parking areas in 2030, and increasing to 37 MVA distribution capacity, 38.4 MWh station batteries and 39,634 m^2 of parking areas in 2035.

The most demanding Road-2-Zero scenario will require building 1.6 MWh station batteries in 2025, an increase to 8 MVA distribution capacity, 17.5 MWh station batteries, and 11,232 m^2 of parking areas in 2030, and increasing to 52 MVA distribution capacity, 76.2 MWh station batteries, and 56,929 m^2 of parking areas in 2035.

Author Contributions: Conceptualization, J.H., K.F., N.K., J.S. and H.O.; methodology, J.S., H.O., H.M. and J.H.; software, H.O.; validation, J.H., J.S. and K.F.; formal analysis, J.H.; investigation, N.K.; resources, H.B.; data curation, H.O. and J.S.; writing—original draft preparation, J.H.; writing—review and editing, J.H.; visualization, J.S.; supervision, J.H.; project administration, H.B.; funding acquisition, H.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research has been supported by the grant TA ČR Théta Dynamické dobíjení TK 05010044, CTU in Prague.

Data Availability Statement: Data are contained within the article and referenced materials.

Acknowledgments: Part of this research has been supported by the grant TA ČR Théta 2 TK02010106 Čistá mobilita a její perspektiva v nákladní silniční dopravě. CTU in Prague.

Conflicts of Interest: The authors declare no conflict of interest.

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