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D3.7 Mobility monitoring solutions

WP3, Task 3.7

Transition of EU cities towards a new concept of Smart Life and Economy

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Project Acronym	mySMARTLife
Project Title	**Transition of EU cities towards a new concept of Smart Life and Economy**
Project Duration	1st December 2016 – 30th November 2021 (60 Months)
Deliverable	D3.7 - Mobility monitoring solutions
Diss. Level	PU
Status	Working
	Verified by other WPs
	■ Final version
Due date	30/11/2019
Work Package	WP3,Task 3.7, Subtask 3.7.1
Lead beneficiary	HAW
Contributing beneficiary(ies)	SNH
Task description	The impact on EV charging processes on the electricity grid and the environment will be monitored. Information about individual charging processes as well as the current grid capacity will be the basis for simulating the impact of a large scale roll-out of electric vehicles in the future. A smart load management will be implemented which considers the cumulative charging power of charging points, the grid connection capability and the current renewable energy production.

Date	Version	Author	Comment
01.06.2019	0.1	HAW	Doc setup and 1st draft for ToC
05.07.2019	0.2	Röper, Mathias (HAW)	Add first draft for Chapter 3.2 and 3.3
17.07.2019	0.3	Yedlapally, Venkata Kalyan Rahul (HAW)	Add first draft for Chapter 3.1 and 4
02.08.2019	0.4	Srivatsa, Nikhil (HAW)	Add first draft for Chapter 5 and 6
10.09.2019	0.5	HAW	Layout harmonisation
20.10.2019	0.6	Yedlapally, Venkata Kalyan Rahul (HAW)	Completation of 3.1 and 4
09.11.2019	0.7	Röper, Mathias (HAW)	Completation of 3.2 and 3.3

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20.11.2019	0.8	Srivatsa, Nikhil (HAW)	Completation of 5 and 6
28.11.2019	0.9	HAW	Implementation of the parts from CARTIF
29.11.2019	1.0	HAW	Translation and proof reading
30.11.2019	1.1	CAR	Final check

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Abbreviations and Acronyms

Acronym	Description
AC	Alternating Current
BEV	Battery Electric Vehicle
CCS	Combined Charging System
DC	Direct Current
DIN	Deutsches Institut für Normung
DNO	Distribution Network operator
EV	Electric Vehicle
mySMARTLife	Transition of EU cities towards a new concept of Smart Life and Economy
SGAM	Smart Grid Architecture Model
SNH	Stromnetz Hamburg (Destribution network operator in Hamburg)

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1. Executive Summary

The expansion of charging infrastructure together with incentives to buy e-cars will also lead to an increasing number of charging stations in housing estates in the future. In order to limit the charging time of one's own e-car to a few hours, high power outputs are necessary. These can double or triple the connected load of a single-family house (in Germany according to DIN 18015-1; 14.5 KW). The influence of such an expansion on the distribution network depends on the network topology and the network components, as well as on the number, capacity and simultaneity of the charging stations. This deliverable describes an investigation of a section of a distribution network and how the state of the network could change due to the additional load.

The aim of the work analyses the electrical impact of the EV's in a distribution network. Bergdorf is chosen as the location to analyse due to the expected increase in EV's in the region in the years to come. The substation study is done for actual scenarios in conditions with the percentage of the EV penetration on the grid. Expansion of grid is analysed with topology, SGAM layer study, smart charging and, hence, forth analysis is conducted with the help of Panda power. The load profiles, voltage lines, cable losses are analysed with and without smart charging. Different scenarios are considered to analyse the impact of EV's taking into account the different percentage of households with the same charger and simultaneity factor. The hourly peak loads with conversion factor is considered for all the different scenarios. Several considerations are made with regards to data basis of the simulation list in the methodology part with relevant explanations.

The charging infrastructure is at Level 2 - Charger considered generally used for public private places which ranges from 3.7 kW to 22 kW AC power. This consideration is on current feasibility and density of available charging stations in Doktorberg region.

For the purpose of a preliminary investigation, a simplified representation of the grid with regard to the network topology has been used. With all the households catered to by each substation, being represented by a single node. Likewise, each substation is taken to consist of two nodes with a 2-winding transformer connecting the two and the low voltage of 0.4kV downstream of it. For the purpose of simulation, the medium voltage 10KV grid is considered a slack node and similarly a second external grid has been appended to the very last substation comprising the network.

The implications of accommodating charging the 22 KW on the existing distribution network on the transformers have been tabulated and elaborated upon in section 5 of this report. In short, for the base case 1 where only 3% of the households are assumed to own such charging stations, the transformers are revealed to be loaded within limits deemed largely acceptable, however this changes dramatically in case 3 where the figure of households rises to 7%.

In particular, Substations (represented by “Transformers”, for the sake of modelling) 1 and 6 exceed their rated capacities. In view of this, appropriate measures such, but not restricted to, expansion of the existing grid infrastructure would need to be undertaken and further investigated.

2. Introduction

2.1 Purpose and target group

The Deliverable is aimed at power grid operators and municipalities. It describes the data basis, local conditions and results of a network simulation. The aim was to investigate the impact of the increasing number of charging stations in a network section with predominantly residential buildings with regard to grid congestion and voltage band. Assumptions were made about the development of the number of electric cars and charging stations, but also about the performance of the charging stations

2.2 Contributions from partners

The following Table 1 depicts the main contributions from participant partners in the development of this deliverable.

Table 1: Contribution of partners

Participant short name	Contributions
HAW	Main developer of the deliverable, modelling, simulation and results of the EV impacts on grid.
SNH	Data provision

2.3 Relation to other activities in the project

The following Table 2 depicts the main relationship of this deliverable with other activities (or deliverables) developed within the mySMARTLife project and that should be considered along with this document for further understanding of its contents.

Load management has also been implemented in mySMARTLife. As it represents a possible solution for the identified impact in this deliverable, it should be mentioned here. A detailed description is contained in D3.8.

Table 2: Relation to other activities in the project

Deliverable Number	Contributions
D3.8	Development of new Mobility Services and Intermodality Strategies

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3. E-mobility and charging infrastructure in Hamburg

3.1 Analysis of the charging infrastructure in Bergedorf

The increasing demand for electricity in the district Bergdorf in the years to come with expected increase in the number of electric vehicles and its charging demand, a study is conducted for an extensive expansion of the existing distribution network not only meet the demand in the future but also provide the customer with safe, green and economically viable power supply. Feeding in electricity at lower voltage levels increases the consumption. Hence, maintaining grid stability with no congestions is necessary [1][2].

The primary objectives of the study are:

- Grid expansion if needed without grid congestions based on load flow analysis, permissibility and limitations, re-enforcement, planning assumptions, coupling of sectors if necessary, cross-level network planning.
- Cost reduction by using innovative methods.
- Giving reasonable recommendations to the Distribution Network Operators (DNO) [1][3].

Electro mobility increase in future would contribute to increase in the charging stations and, hence, proper infrastructure fulfilling the above mentioned objectives is necessary. It is a systematic approach considering several factors like charging infrastructure, comparison of new and old vehicle concepts, its compatibility with the charging infrastructure, current and future battery concepts, stationary storage with mobility concepts. A user friendly cum reliable charging infrastructure combined with well-communicated service operators, and easy billing techniques is expected in the future [1].

Several researches carried out in the past to build up an efficient charging system with interoperability ensuring safety, quality and efficient use of the resources. Combined charging system (CCS), see Figure 1, is once of such systems that has three main parts AC charging, DC charging and a communication interface (EV and charging station). It is a standard system in Europe. Depending if it is a private or a public charging infrastructure, the regulatory aspects might differ [4][5]. As well, two typologies are possible as described below and in Figure 2.

Platform A

This type of platform enables restricting the users and it is contractually based.

Platform B

This type of platform acts as data hub with economical connections and hence it is not restricted ensuring minimal necessities.

However, further standardization of the existing technology and services is required, ensuring reach to everyone in an efficient way. Particularly in Hamburg, a pilot project laying strong emphasis on trade, local fleet, integration into public transport was emphasized by the Federal Government [4].

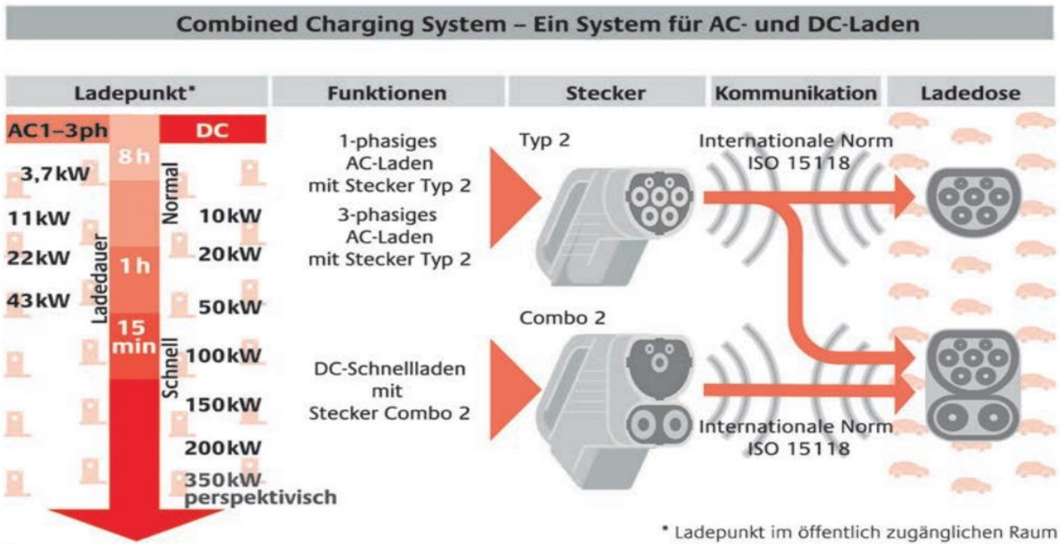


Figure 1: Example of a Combined Charging System (CCS) [4]

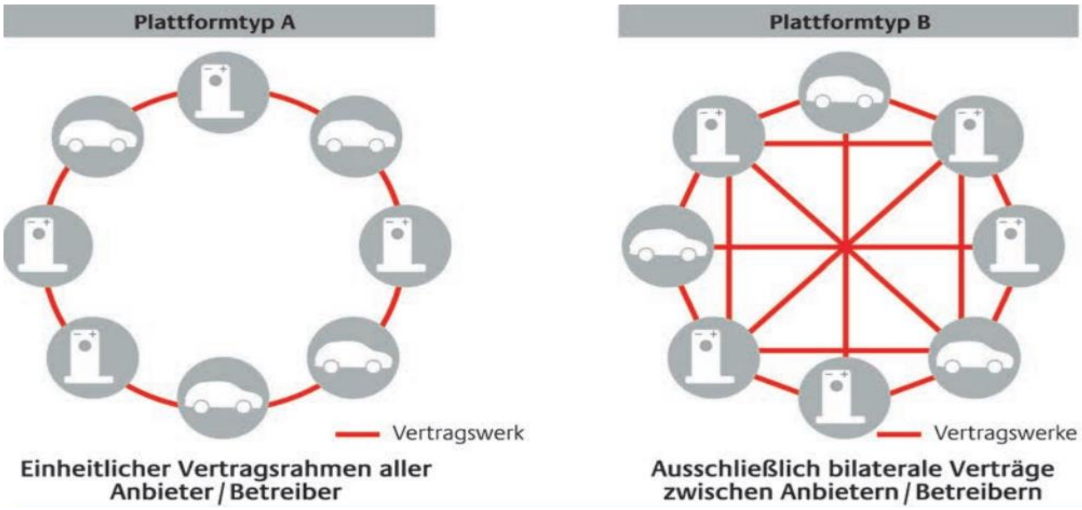


Figure 2: Basic Network of Platform A and Platform B [4]

Apart from the above mentioned objectives, primarily by 2025, the goal is to achieve the technological development of battery systems, generations 3 and 4 with energy density per volume is about 280-300 watt hours per litre (Wh/ltr). Also, several other factors listed below are to be considered:

- Quick Chargeability of 80 % in less than 15 minutes.
- Approximately 1200 cycles of life.
- Material sustainability for high voltages
- Cathodes materials durable to low temperature and high energy and high power densities

- Innovative and greener recycling and re-use concepts. [5] [6]

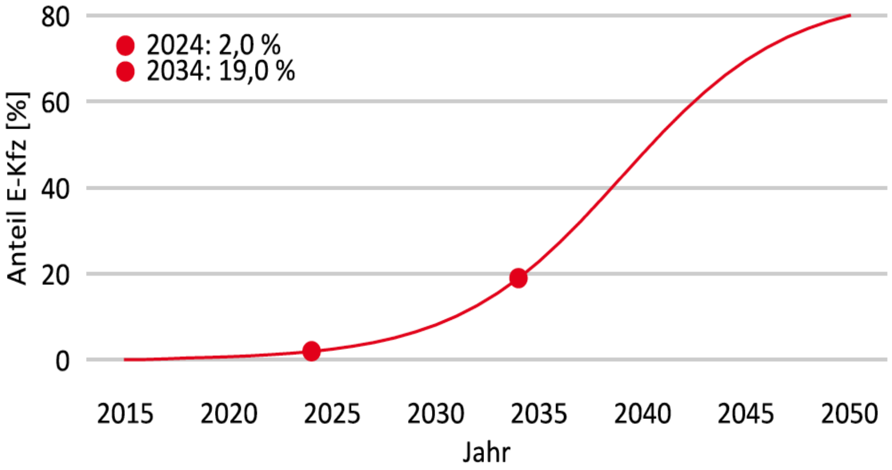


Figure 3: Technology diffusion curve for e-cars [5]

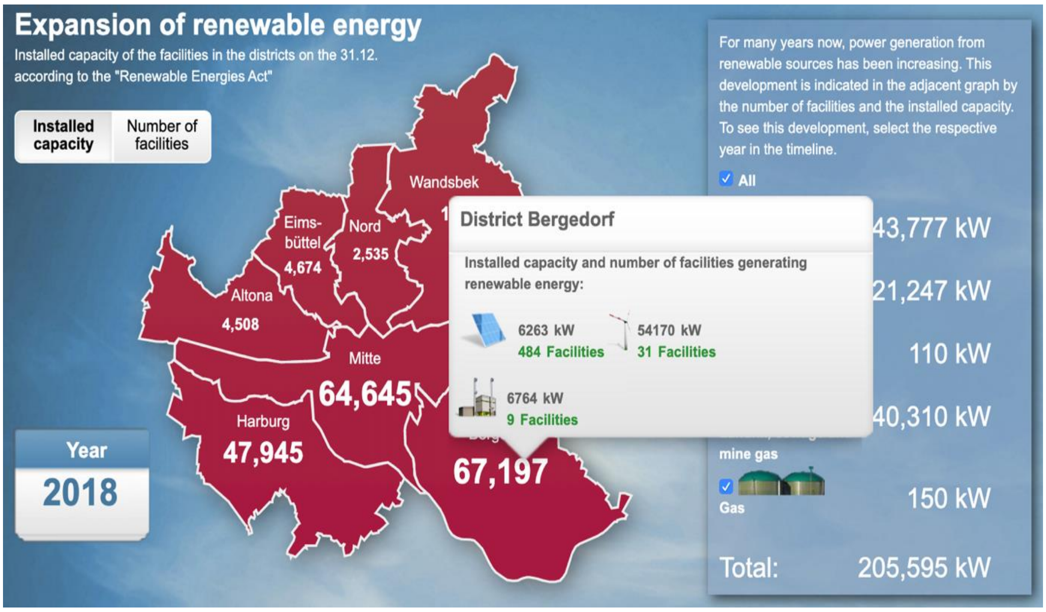
Based on the technology diffusion curve for the e-cars (Figure 3) and the required power demand assumption, an indication of close to 8% increase in the development e-car share by 2024 and 19% increase by 2034 can be observed.

Also, a division of the e-cars based on whether they are battery operated electric vehicles or plug-in hybrid electric vehicles is pivotal [4].

The assumption on the number of charging stations required is done based on

- Home Charging
- Public Charging
- Private Charging (Company or Firms)
- Partly Public Charging
- Long distance Charging [5]

Bergdorf, with a current population of 1.3 million and an area of 154.8 km2, counts on a total number of 524 facilities with renewable power. The annual peak decentralized feed-in is 131 MW. The figures below indicate the installed capacity as well as the current energy generation [5].



Expansion of renewable energy

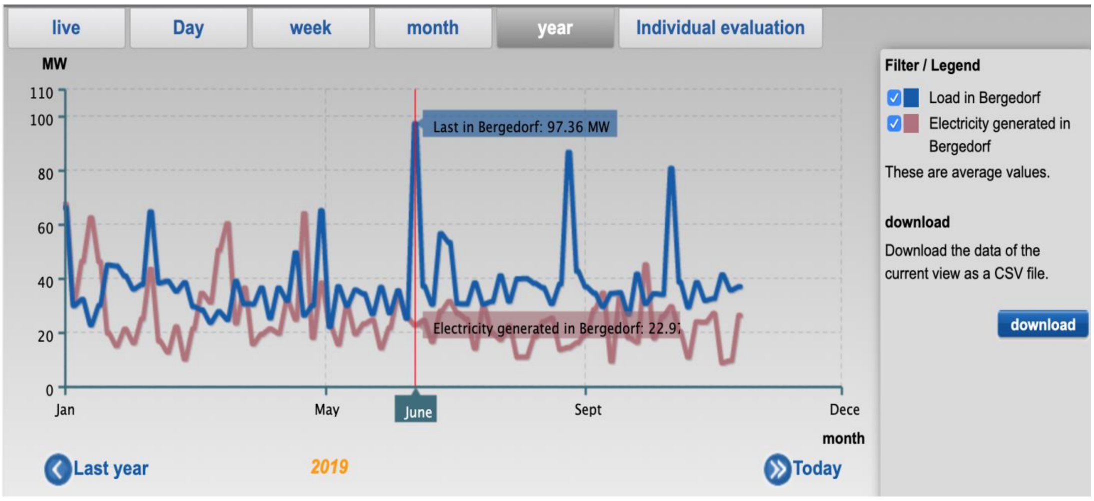
Installed capacity of the facilities in the districts on the 31.12. according to the "Renewable Energies Act"

For many years now, power generation from renewable sources has been increasing. This development is indicated in the adjacent graph by the number of facilities and the installed capacity. To see this development, select the respective year in the timeline.

District Bergedorf

Installed capacity and number of facilities generating renewable energy:

Figure 4: Installed capacity for the region Bergdorf [6]



These are average values.

Download the data of the current view as a CSV file.

Figure 5: Current energy generation and load for the current year in Bergdorf [6]

The Figure 5 above indicates the current energy generation in the Bergdorf region with the blue line indicating the load and light brown line indicating the electricity generated. The numbers remarked in the figure are the peak load and peak electricity generation of the region in the year so far [6].

With 834 public charging stations currently in Hamburg, Bergdorf has 7 charging stations in and around closely to Doktorberg and is considered to be adequate currently considering the demand. The number of charging stations helps to analyse the load profiles [6].

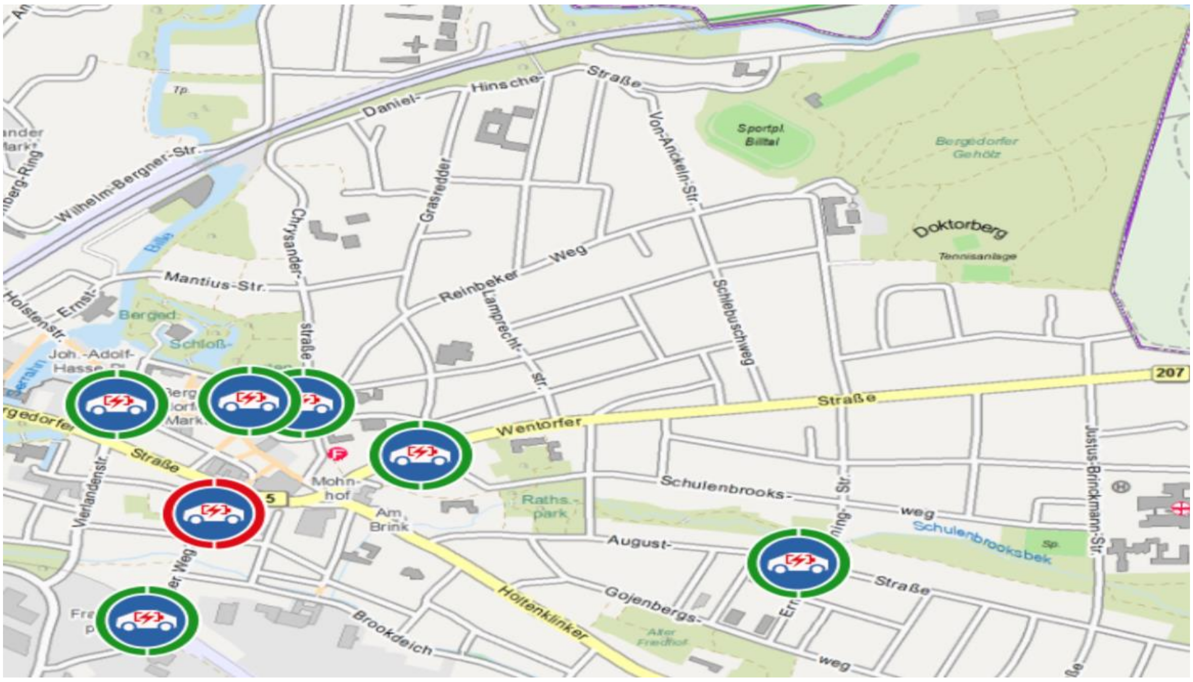


Figure 6: Charging stations in Doktorberg-Bergdorf [6]

Figure 7: Location with dotted lines in the map is Doktorberg in Bergdorf for the required analysis [6]

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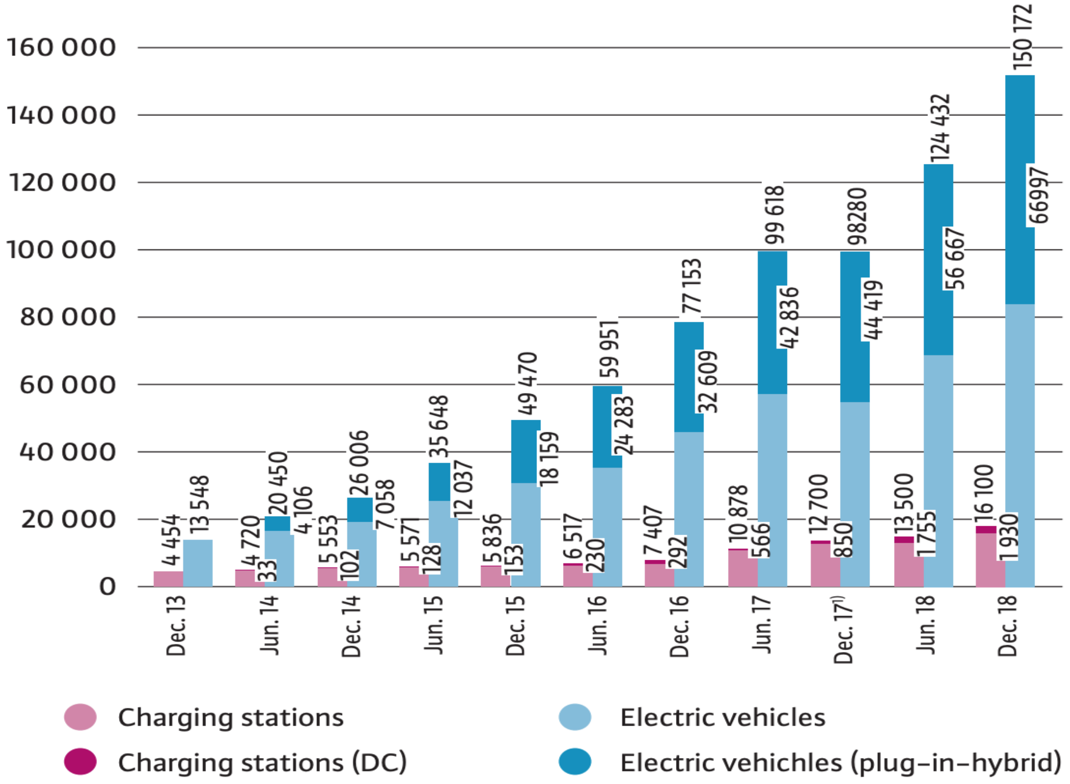

Figure 8: Number of EV's and number of charging stations currently [6]

3.2 Extension plans for the charging infrastructure in Hamburg

The density of charging stations for electric vehicles in Hamburg with 1104 stations per km² (as at 31/12/2019) is the highest of all federal states in Germany, where the average is 168 charging stations per km² (Energiemarkt Deutschland 2019). Furthermore, the total amount of public charging points in Hamburg is the highest of all cities in Germany (as at 31/12/2019) as can be seen in Figure 9.

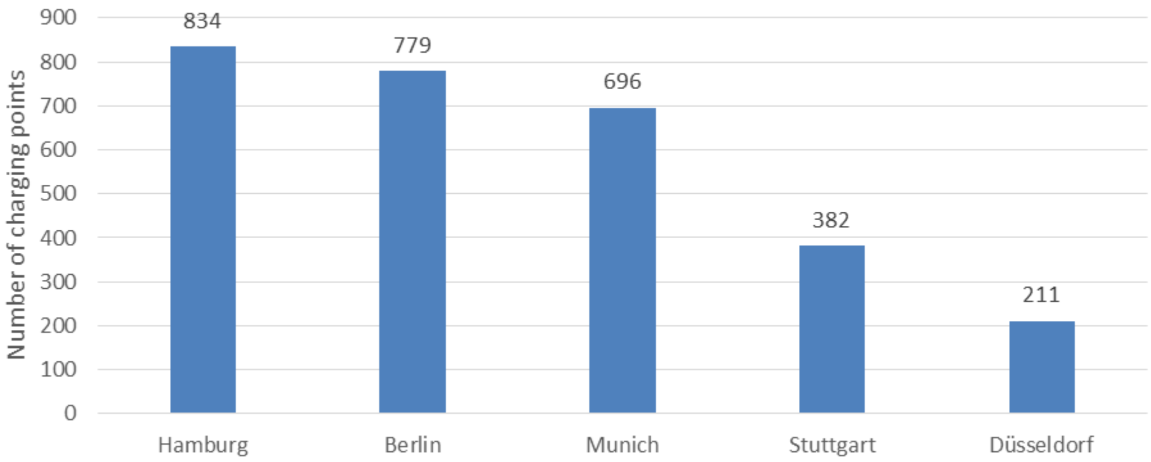

Figure 9: Cities in Germany with the highest number of public charging points for electric vehicles (Source: Energiemarkt Deutschland 2019)

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In 2014, the Senate of Hamburg agreed on a masterplan for public charging infrastructure, which had the goal to increase the amount of public charging points in Hamburg from 138 to 592 until the year 2016 (Bürgerschaft der Freien und Hansestadt Hamburg 2014). The goal was achieved. At the beginning of 2019, 834 public charging points are installed in Hamburg (Energiemarkt Deutschland 2019). Until the end of 2019, more than 1000 charging points will be installed, as stated by Stromnetz Hamburg, the operator of the public charging infrastructure in Hamburg (Stromnetz Hamburg GmbH 2019).

Stromnetz Hamburg GmbH operates and installs the public charging infrastructure in Hamburg. Hamburg Energie GmbH is also a city owned company and the energy provider for the charging infrastructure. The charging power comes exclusively from renewable energy sources, such as photovoltaic or wind energy. Therefore, the charging of electric vehicles at public charging stations in Hamburg causes zero CO2-emissions (Hamburg Energie GmbH 2019).

3.3 Growth scenarios of electric vehicles in Hamburg

In order to analyse the impact of direct current (BEV) on the low voltage grid in Hamburg Bergdorf, a prognosis for the amount of BEVs until the year 2030 was made.

In the first step, a prognosis for whole Germany was done based on the existing BEV fleet, data of registrations of new cars and the market share of BEV and different prognosis statements.

Each year around 3,440,000 new cars are getting registered in Germany. The number is the 10 years mean value from 2007 to 2017 (KBA 2019).

Since it is very difficult to predict the market share of BEV in Germany, different studies and statements were taken into account. As Table 3 shows, there is no consensus about a market share of BEV in the future. Therefore, the assumption was made that the market share of BEV in Germany is 30% in the year 2030.

Table 3: Prognoses of the market share of BEV in the future (Dietmannsberger et al. 2017)

Source	Market share / %			Market
	2020	2025	2030	
PwC Autofacts	3.6	20.6	48.8	Europe
Kienbaum	7	-	31	Europe
Bloomberg	-	-	20	Worldwide
Volkswagen AG	-	25	33.3	Worldwide
Daimler AG	-	20	-	Worldwide
VDA	-	15-25	-	Germany
AlixPartners	-	-	20	Europe

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An exponential course between the market share of 0,71% in 2017 (EAFO 2018) and 30% in 2030 was calculated. An exponential course can already be seen by looking at the development of the BEV fleet of the last years (Figure 10) and is a common for new technologies. Based on the market share and the registration rate of new cars, the fleet of BEV was calculated.

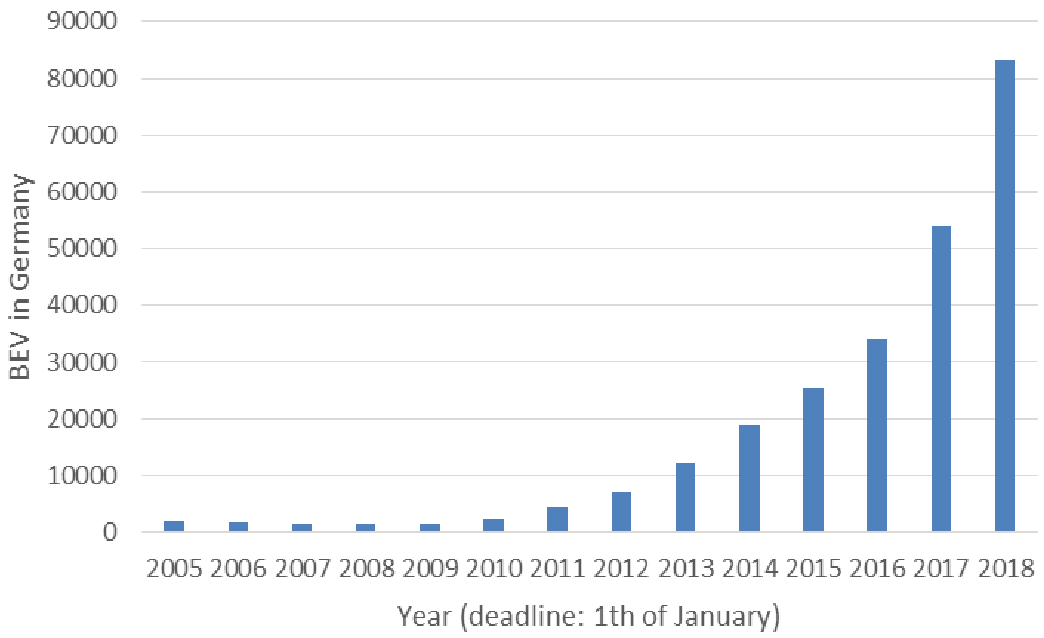

Figure 10: BEV fleet in Germany (KBA 2019)

Figure 11 and Table 4 show the prognosis of the BEV fleet in Germany until 2030. It is clear to see that the political proclaimed goal of one million BEVs until 2020 is impossible to reach. A fleet of one million BEV are accumulated approximately in the year 2026/2027.

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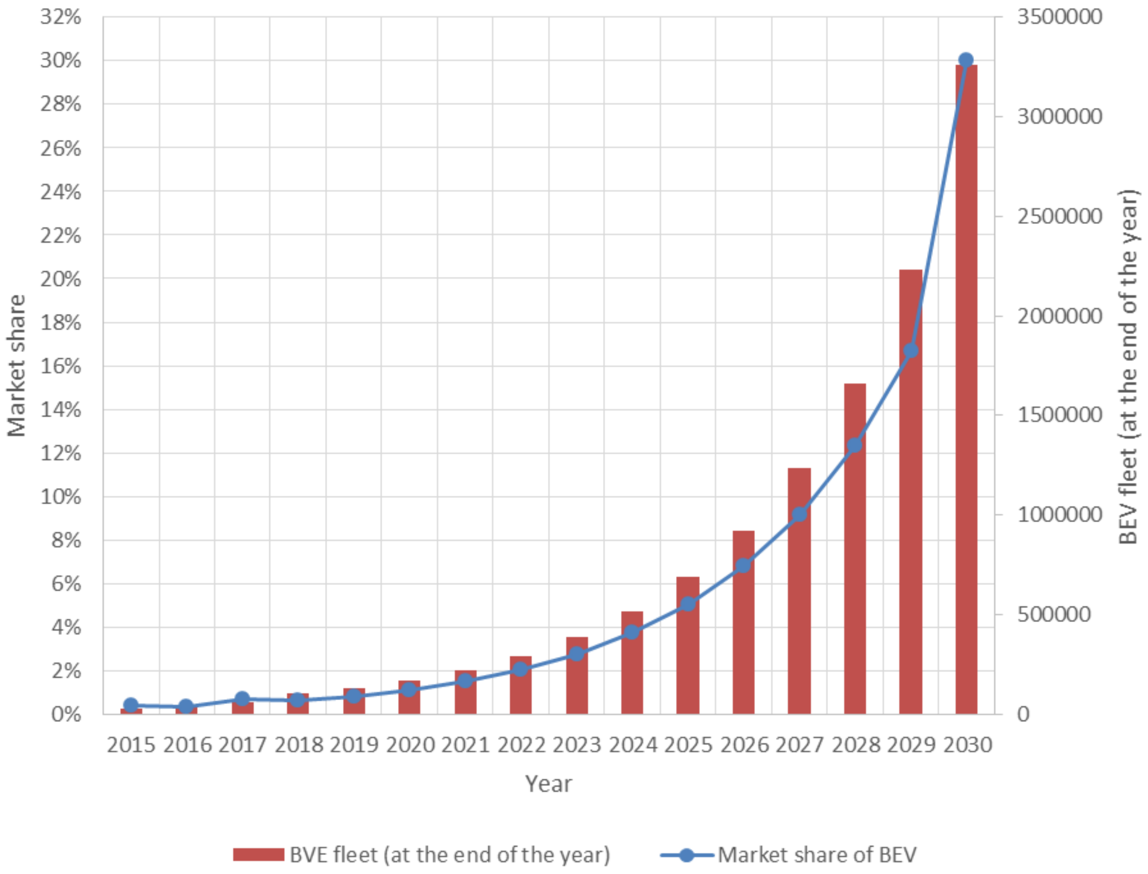

Figure 11: Prognosis of the BEV fleet in Germany until 2030

Table 4: Prognosis of the BEV fleet in Germany until 2030

Year	Registrations of new BEVs	Market share	BEV fleet (at the end of the year)
2016	11,696	0.34%	34,022
2017	24,424	0.71%	53,861
2018	21,153	0.61%	75,014
2019	28,553	0.83%	103,567
2020	38,543	1.12%	142,109
2021	52,027	1.51%	194,136
2022	70,229	2.04%	264,365
2023	94,799	2.76%	359,164
2024	127,966	3.72%	487,130

2025	172,736	5.02%	659,866
2026	233,169	6.78%	893,034
2027	314,745	9.15%	1,207,779
2028	424,861	12.35%	1,632,640
2029	573,502	16.67%	2,206,143
2030	1,032,000	**30.00%**	**3,238,143**

In the next step, the prognosis of the BEV fleet in Germany and the ratio of registered cars for Hamburg to whole Germany were used to calculate an estimation for Hamburg. In the year 2017, 45,803,560 passenger cars were registered in Germany and 771,573 in Hamburg (KBA 2019). Therefore, 1.685% of the estimated numbers of BEVs in Germany can be allocated in Hamburg. In addition, further data were used to distinguish the amount of BEVs in private and commercial sector. In Hamburg, 80.6% of the cars are used in the private sector and 19.4% in the commercial sector (which includes for simplicity cars for civil service and public administration) (KBA 2019). In the next step, the number of BEVs for Hamburg and the numbers of registered private passenger cars for both Hamburg and Bergedorf were used to calculate the amount of BEVs in Bergedorf. In 2017, 12,120 private passenger cars were registered in Bergedorf. Therefore, 1.924% of all private cars in Hamburg are registered (and assumed to be located as well) in Bergedorf. Table 5 shows the result of the calculations to estimate the amount of BEVs for Bergedorf until 2030. For the year 2030, around 1.300 BEVs are estimated in Hamburg Bergedorf.

Table 5: Prognosis of the BEV fleet in Bergedorf until 2030 (KBA 2019)

Year	Amount of BEVs in Hamburg (at the end of the year)		Amount of BEVs in the private sector in Bergedorf	Amount of BEVs in the commercial and public sector for Bergedorf
	Statistic	Estimated	Estimated	Estimated
2015	858	434	7	2
2016	956	695	11	3
2017	1,387	1,048	16	4
2018	-	1,523	24	6
2019	-	2,165	34	8
2020	-	3,031	47	11
2021	-	4,201	65	16
2022	-	5,780	90	22
2023	-	7,911	123	30
2024	-	10,788	168	40

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2025	-	14,671	228	55
2026	-	19,912	309	74
2027	-	26,988	419	101
2028	-	36,539	568	137
2029	-	49,432	768	185
2030	-	**67,007**	**1,041**	**251**

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4. Methodology for the simulation and modelling of the charging infrastructure

To assess the network based on the increase of the number of private charging stations, it depends on the population the respective community. The low voltage terminal charging stations are assigned on the basis of classes. For this scenario, multiple assignment is possible but should not exceed the number of vehicles expected (can be analysed with the help of the number of parking spaces), i.e. maximum of two charging stations for a household, for industrial or commercial space it is randomly distributed with multiple assignments [1].

The substation reserves are to be analysed in this case for the region Bergdorf. The studies indicate that the expansion for the considered region is expected between 2025 and 2030. Scenario analysis has to be carried out with respect to minimum and maximum conditions with an expected forecast of around 100,000 EV’s by 2030 from 17,020 in 2020. Based on the existing of vehicles, they are distributed to the respective substation reserves sector wise. The additional load due to electromobility in the stepwise process below [8][9].

Flow chart for a methodology to determine the additional load on a certain substation can be followed by the steps wise analysis of the process in the flowchart below. Either implementation of a smart charging infrastructure or by reinforcement of the overloaded section the negative impact of the EV charging on the grid can be avoided [8][9].

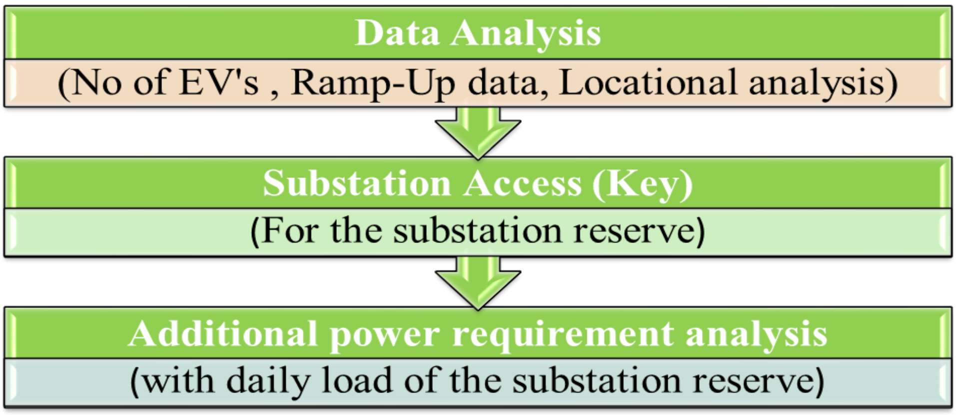

Figure 12: Methodology to determine additional load of substations [9]

Now, here, the list of considered scenarios are listed below

- 0% of households with a 22kW charger times 0.75 (simultaneity factor)
- 50% of households have 22kW charger times 0.75 (simultaneity factor)
- 70% of households have 22kW charger times 0.75 (simultaneity factor)

- 90% of households have 22kW charger times 0.75 (simultaneity factor)

The simultaneity factor is 0.75 for electrical drive applications and is simulated with the grid defined in the next section [10].

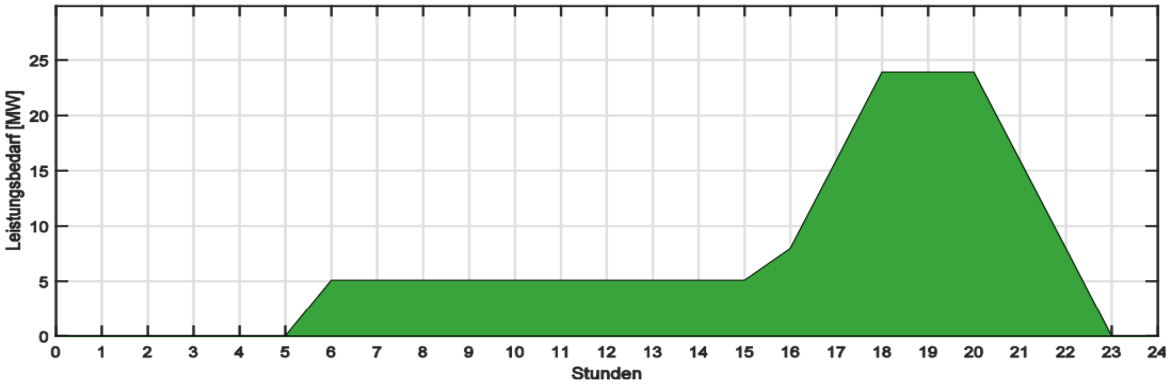

Figure 13: Daily expected load profile of private vehicles Hamburg 'META'2030 [9]

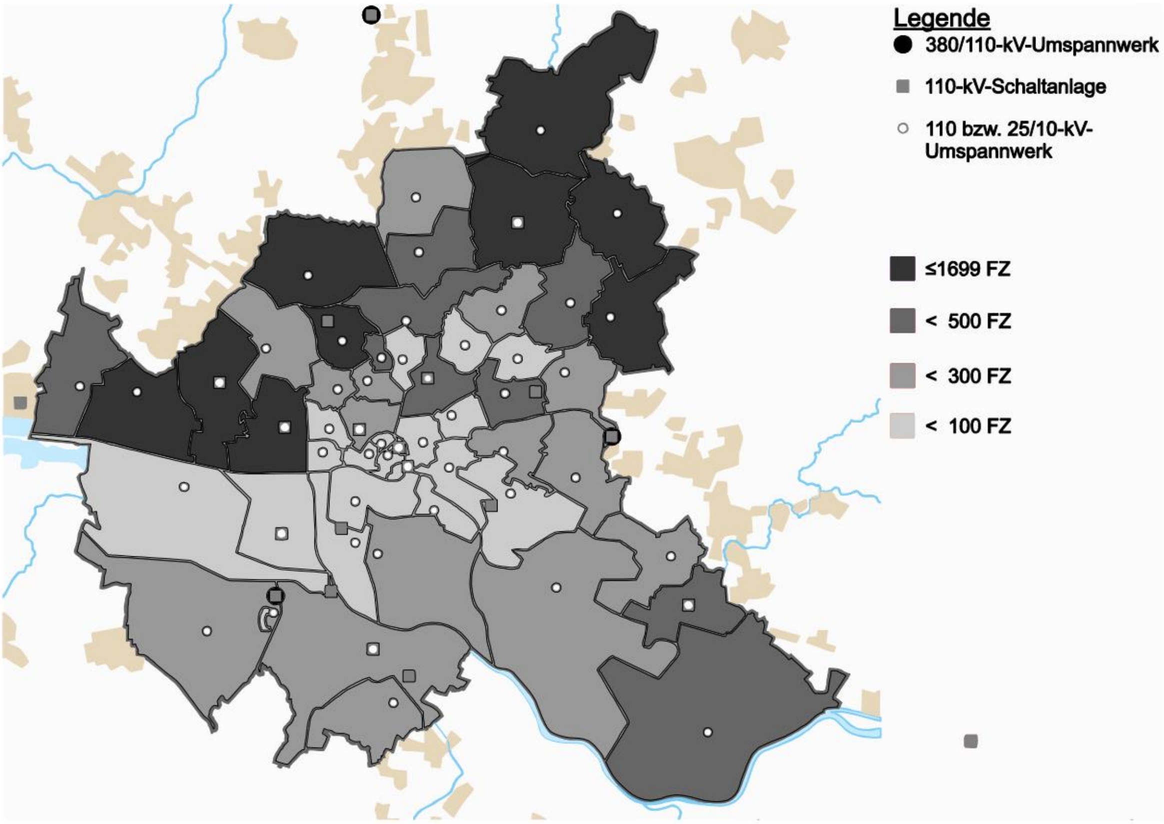

Figure 14: Distribution of private EV's in substation areas, "META" 2030 [9]

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Table 6: Distribution of private EV’s in substation areas, "META" 2030 [9]

Colour coding	Scope of electrification	Percentage
⬛	Very High Electrification	55%
▓	High Electrification	25%
🟩	Medium Electrification	10%
░	Less Electrification	7%
	Very Less Electrification	3%

Smart Charging, with automated control signals reacting to the market values via communication layer and information layer in a smart grid, helps shifting some charging cycles and compensating power. This also helps in optimizing the process with distribution constraints. This can support to overcome the void with respect to the local grid overload and ultimately contributing to a system level. The loads are always measured on 0.4 kV cables. An emphasis on the communication needs to be focused upon [11].

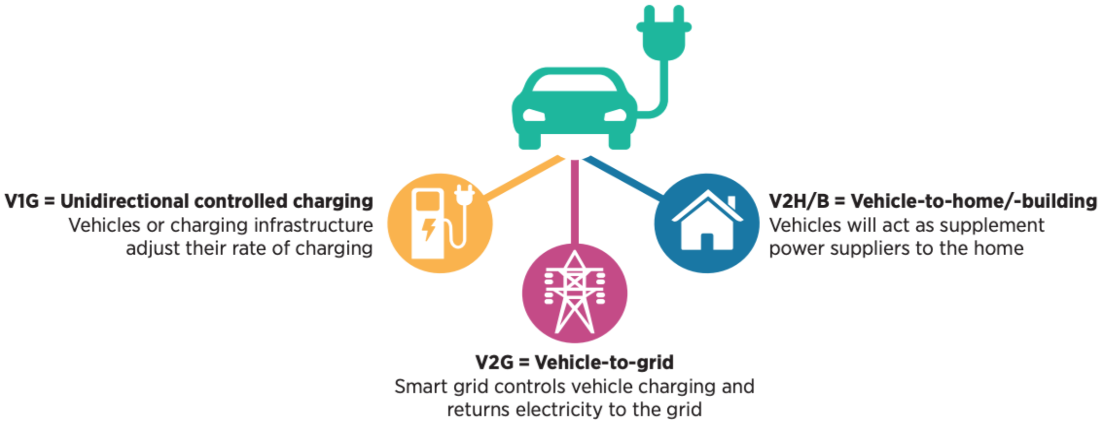

Figure 15: Scenario of Smart Charging [11]

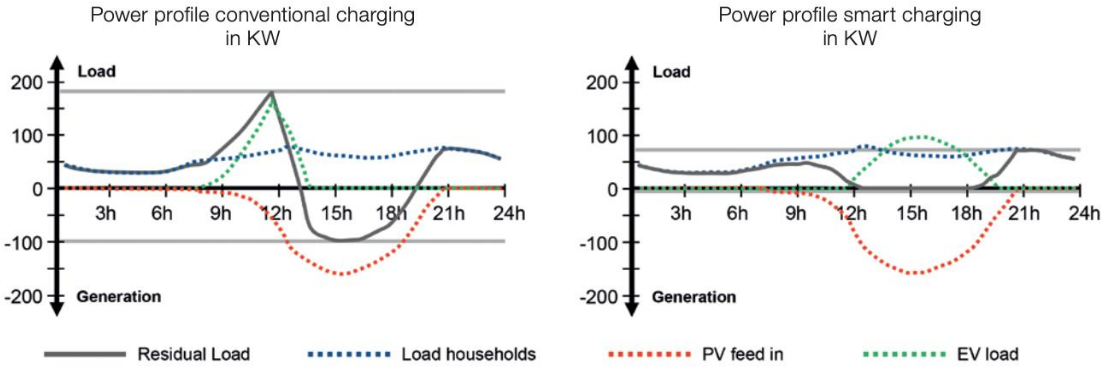

Figure 16: Power profile of Smart Charging [12]

The grey lines in Figure 13 indicate the threshold without smart charging and with smart charging. With large EV in number there is a lesser negative impact on the grid and subsequent decrease in load with smart charging [12].

From the above depiction in Figure 14, it is expected that there would be an increase of substations by 2050. The indicated figure below is the expected scenario of the substation in the years to come from 2020, 2025 and subsequently 2030. There is expected to be a severe increase in the less than 10 MVA substations from the prognoses below. Subsequently, these substations might correspond to the increasing charging stations with followed by the expected demand. In such a scenario, smart charging techniques can be proven worth based on the power profiles in Figure 16, the grey lines here define the new threshold limit and indicate a lesser impact on the grid. This can avoid grid congestions and fluctuations with increase charge of EV's. Also, Figure 15 is self-explanatory of the current smart charging scenario.

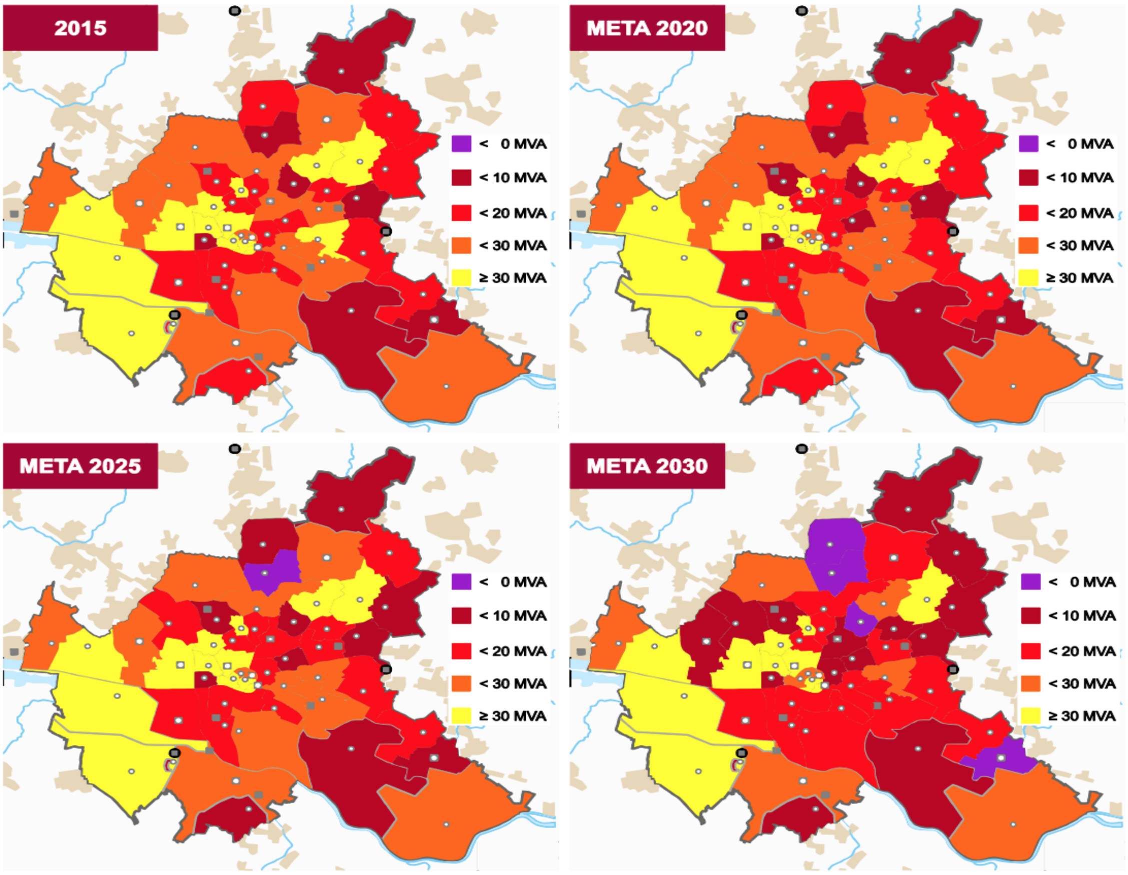

Figure 17: Development of available substations reserves with 'META' scenario for 2015, 2020, 2025 and 2030 [11]

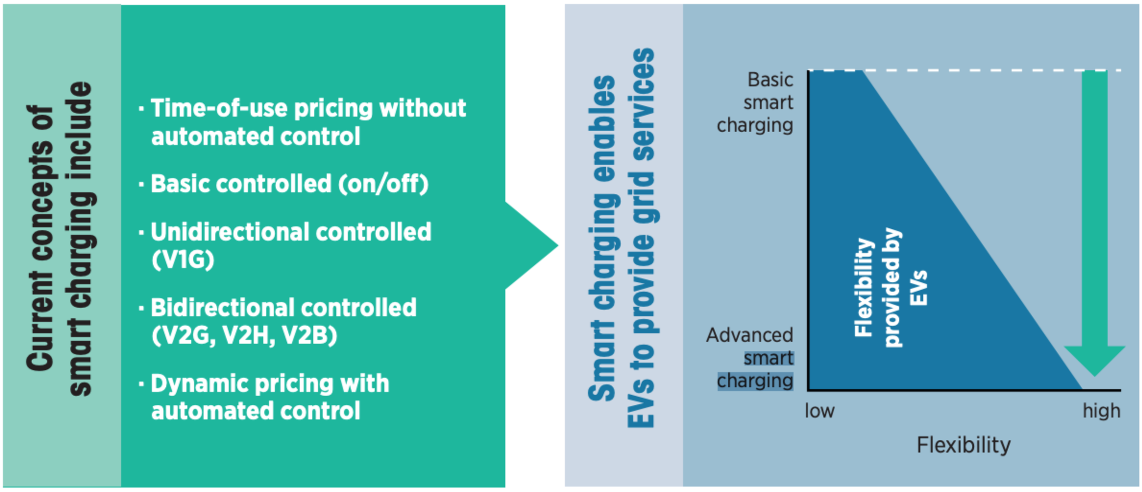

Figure 18: Smart Charging Analysis [11]

4.1 Data basis for the performed simulations

Table 7 is an expected consumption for different sectors. However, they might vary depending on the number of people in the households and subsequently the businesses based on the scale.

Table 7: Sector-wise consumption [2][4][13][14]

Sector	Consumption per year
House Holds	3,500 kWh
Small Scale Business	5,000 kWh
Medium Scale Business	15,000 kWh
Large Scale Business	62,500 kWh

The peak loads are considered for the periods October to December expecting the maximum consumption due to winter on an hourly basis. The peak loads vary based on the number of households as the conversion factor plays a key role in defining it which is explained below and can be understood better with the formula. However, these values are variable with variable data.

Table 8: Peak load SLP for the households [14]

Node	Households	Period	Peak load (kW)	Date	Time
1	170	Oct – Dec	159.66	31/12/2019	19:15
2	0	Oct – Dec	0.00	31/12/2019	19:15
3	109	Oct – Dec	102.37	31/12/2019	19:15
4	107	Oct – Dec	100.50	31/12/2019	19:15

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5	132	Oct - Dec	123.97	31/12/2019	19:15
6	190	Oct - Dec	178.45	31/12/2019	19:15

Table 9: Peak load SLP for businesses [14]

Node	Households	Period	Peak load (kW)	Date	Time
1	18	Oct - Dec	63.52	01/11/2019	19:15
2	10	Oct - Dec	60.52	01/11/2019	19:15
3	2	Oct - Dec	29.96	01/11/2019	19:15
4	3	Oct - Dec	19.78	01/11/2019	19:15
5	8	Oct - Dec	55.73	01/11/2019	19:15
6	3	Oct - Dec	17.38	01/11/2019	19:15

The data chosen for the peak load calculation is the SLP data from Stromnetz Hamburg for the year 2019. The data is in excel format with the SLP value in kWh for every 15 minutes. The values listed in Table 8 and Table 9 have the same peak date and time for all the households and all the businesses as the same data is considered for all the nodes. It might differ in the real scenario. Several considerations from Table 7 and assumptions on the scale of the business have been made for the calculation of the conversion factor [14].

$$Conversion\ factor\ = \frac{Annual\ Consumption}{(No\ of\ Households\ or\ Businesses\ ) * Relevant\ Consumption}$$

For the analysis, a Level 2 charger is selected, for charging point loads with 22 kW AC power as our upper limit is 22 kW (the description and scope is given below for this) considering the current scenario with slow charging of the EV.

Table 10: European standards of Power charging [11]

Type of charger	Wattage	Scope
Level 1 Charger	AC ≤ 3.7 kW	Private Households, no scope of EV's
Level 2 Charger	AC > 3.7 kW and ≤22 kW	Public or private places
Level 3 Charger	AC or DC > 22 kW	On highways generally

Table 11: European standards for mode of charging [11]

Mode of charging	Phase connection	Connected to	Scope
Mode 1	16 amperes per phase	Standard socket	Very low current, EV application not possible
Mode 2	32 amperes per phase	Standard socket of cable with control pilot	Limited to lower currents , EV application not applicable
Mode 3	63 amperes per phase	AC EV supply permanently connected to AC supply network, extends from the AC EV supply equipment to the EV	Secure AC charging solution
Mode 4	Extended DC supply equipment, at least on CCS connector	AC or DC supply network utilising DC EV supply equipment. Control pilot function extends from the DC EV supply equipment to the EV.	Priority charging technology

4.2 Modelling the electricity grid

As seen in the picture below, the model has the below mentioned parts

- External grid (static) – A condition where there is a transfer of a level of AC electrical voltage to another level. Generally, power at low voltages is transferred to voltages at higher level, ultimately resulting in low currents and lesser transmission losses. This is done with the help of a transformer.
- External grid (dynamic) – A condition where a constant speed and constant power applications achieved by means of controllers. It is more or less a steady state condition [15].
- Nodes N1 to N12, 6 loads, 6 transformers and the distances between the busses as D1 to D2, cables. Each one of these is defined in Table 12, Table 13, Table 14 and Table 15 below.

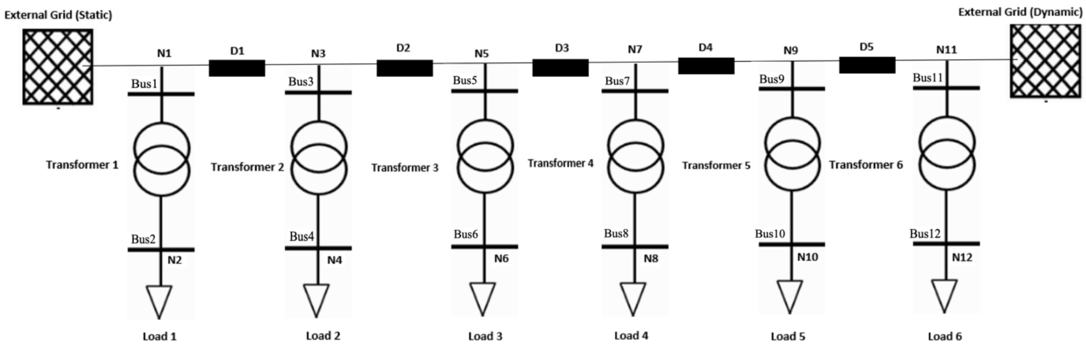

Figure 19: Grid model with transformers, nodes, loads, distances between busses and grids

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Nodes act as integration of several busses (in our case 2) and are connected by transmission lines. The power is induced at the generation node and withdrawn at the load node, indicating a power flow from source to sink.

Buses act as a power supply point to many output circuits. The applications range from switchboards to distribution networks. Generally semi-enclosed structures for proper cooling via air vents. The rated power for each node can be seen below in the Table 12 [20].

Table 12: Bus numbers with corresponding nodes and ratings

Bus	Node	Rated power
Bus1	N1	10 kv bar
Bus2	N2	0.4 kv bar
Bus3	N3	10 kv bar
Bus4	N4	0.4 kv bar
Bus5	N5	10 kv bar
Bus6	N6	0.4 kv bar
Bus7	N7	10 kv bar
Bus8	N8	0.4 kv bar
Bus9	N9	10 kv bar
Bus10	N10	0.4 kv bar
Bus11	N11	10 kv bar
Bus12	N12	0.4 kv bar

Transformers: Induced with a magnetic field. The transformers work with a principle of more the current flow (AC), stronger is the magnetic field. In this process a mutual induction takes place with the voltage in the wire. An ideal transformer has same primary power and load power. The energy transferred is in the form of a magnetic coupling. Current generation transformers focus on ‘’ impedance match’’ which means the resistance at the source and at the load needs to match for a maximum power transfer.

Step-up Transformer – Secondary voltage is greater than primary voltage.

Step-down Transformer – Secondary voltage is less than the primary voltage.

Although this is the basic principle of the transformer, there a several types of transformers based on the usage application. The transformer 1 and 3 is rated 0.315 MVA 10/0.4 (kV), while the rest are 0.4 MVA 10/0.4 (kV) [22].

Table 13: Transformers and corresponding values

Transformer	Type	High Voltage bus	Low Voltage bus	Corresponding rated power
Transformer 1	0.315 MVA 10/0.4 kV	1	2	0.315 kVA
Transformer 2	0.4 MVA 10/0.4 kV	3	4	0.4 kVA
Transformer 3	0.315 MVA 10/0.4 kV	5	6	0.315 kVA
Transformer 4	0.4 MVA 10/0.4 kV	7	8	0.4 kVA
Transformer 5	0.4 MVA 10/0.4 kV	9	10	0.4 kVA
Transformer 6	0.4 MVA 10/0.4 kV	11	12	0.4 kVA

Table 14: Cable type and corresponding description [16]

Cable type	line capacitance in nF per km	line resistance in ohm per km	line reactance in ohm per km	maximum thermal current in kA	type of line	Cable type	line capacitance in nF per km
149-AL1/24-ST1A 10.0	11.25	0.194	0.315	0.47	ol (Overhead line)	149	0.00403
94-AL1/15-ST1A 10.0	10.75	0.306	0.33	0.35	ol (Overhead line)	94	0.00403

The distance calculation between the busses is calculated by the coordinates based on the formula:

$$d = \sqrt{(x1 - x2)^2 + (y1 - y2)^2}$$

Where d is the distance between coordinates,

(x1, x2) and (y1, y2) are the considered coordinates for each corresponding distance

Table 15: Distance between busses

Nomenclature	D1	D2	D3	D4	D5
Distance	0,24 km	0,12 km	0,14 km	0,26 km	0,54 km
Busses	Bus1 – Bus3	Bus3 – Bus5	Bus5 – Bus7	Bus7 – Bus9	Bus9 – Bus11

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5. Impacts of e-mobility on the electricity grid

E-mobility creates an additional electricity demand. The electricity grid and especially the contribution network have to handle the requirements of e-mobility charging with a greater quantity of charging stations. To discover how the contribution network could cover the electricity demand, calculations need both, the characteristics of the local segment of the network and the expected growth scenarios of charging infrastructure.

Based on data about one segment of the contribution network in Bergedorf provided by Stromnetz Hamburg (SNH), the segment was examined in simulations, using PandaPower, a free and open source simulation tool. It contains largely detached houses where a large growth rate of private charging stations is expected.

The simulation has been carried out for three test cases as enumerated in the tables below:

Table 16: Case overview

Case	% of Households with Chargers	Diversity Factor
Case_1	3.00%	0.75
Case_2	5.00%	0.75
Case_3	7.00%	0.75

As can be seen from the above Table 16, a diversity factor of 0.75 has been assumed to start with, including varying percentages of the households possessing charging stations, whereas the charging stations are rated at 22 KW each. Additionally, the total loads, owing to the chargers for each of the three cases, have been calculated based on the above assumptions above (see results below).

Table 17: Total and Charger Loads for each case

Case	Diversity Factor	Existing load (MW)	Total Load incl. Charging stations
Case 1	0.72	0.35	1.08
Case 2	0.72	0.58	1.31
Case 3	0.72	0.82	1.54

Further, the total loads owing at each of the transformers for each of the three cases has been summarized in the table below.

Table 18: Transformer loads in MWh

Case	Transformer Load (MW)					
	Tfo-1	Tfo-2	Tfo-3	Tfo-4	Tfo-5	Tfo-6
Case 1	0.24	0.06	0.16	0.15	0.19	0.27
Case 2	0.30	0.06	0.19	0.19	0.23	0.33
Case 3	0.36	0.06	0.23	0.22	0.28	0.40

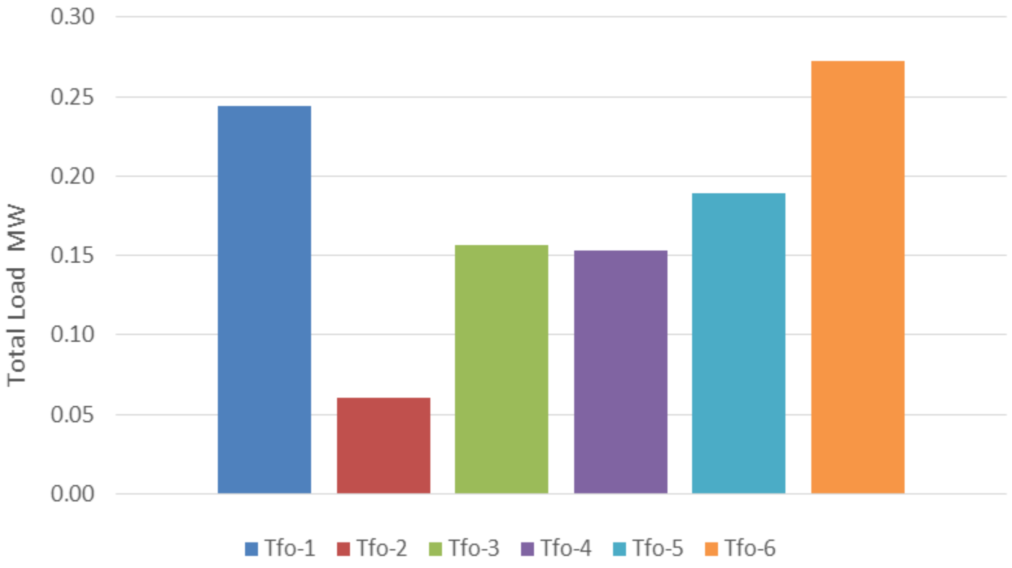

Figure 20: Transformer loads Case 1

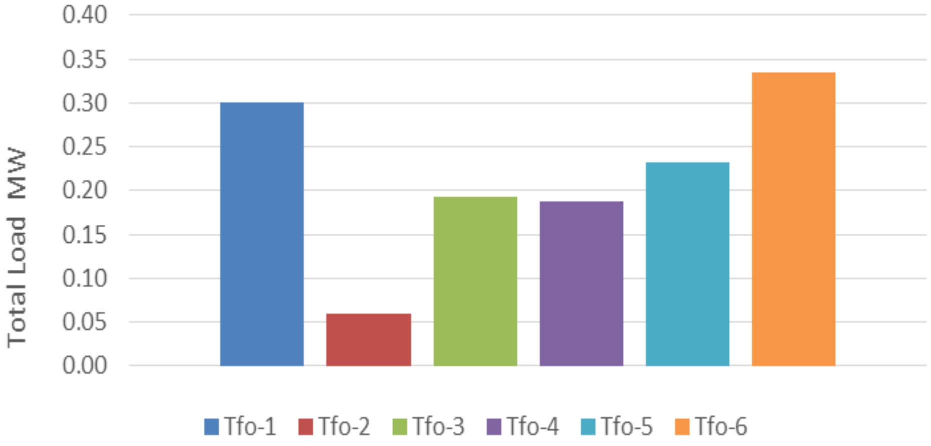

Figure 21: Transformer loads Case 2

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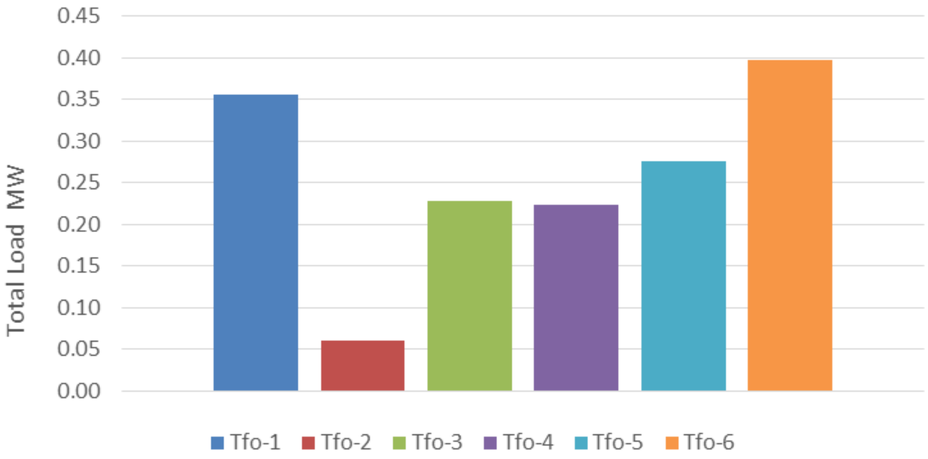

Figure 22: Transformer loads Case 3

On performing the simulation, the extent to which the transformers are loaded due to the inclusion of the charging stations for each of the three test cases are presented in the table below

Table 19: Transformer loads in %

Case	Transformer Load (MW)					
	Tfo-1	Tfo-2	Tfo-3	Tfo-4	Tfo-5	Tfo-6
Case 1	78.66	15.40	50.29	38.69	60.93	68.90
Case 2	96.92	15.40	61.90	47.63	75.03	84.92
Case 3	115.29	15.40	73.54	56.59	89.20	101.02

The above-mentioned loadings on the individual transformers corresponding to each test case are graphically represented below

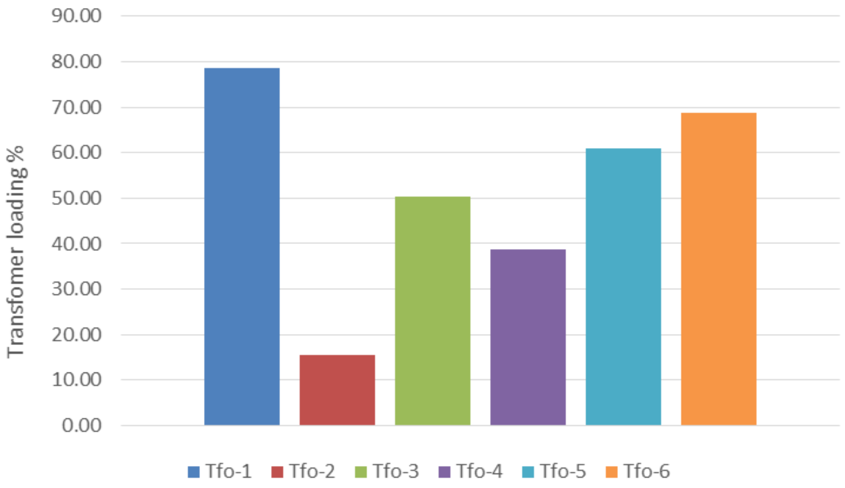

Figure 23: Transformer load Case 1

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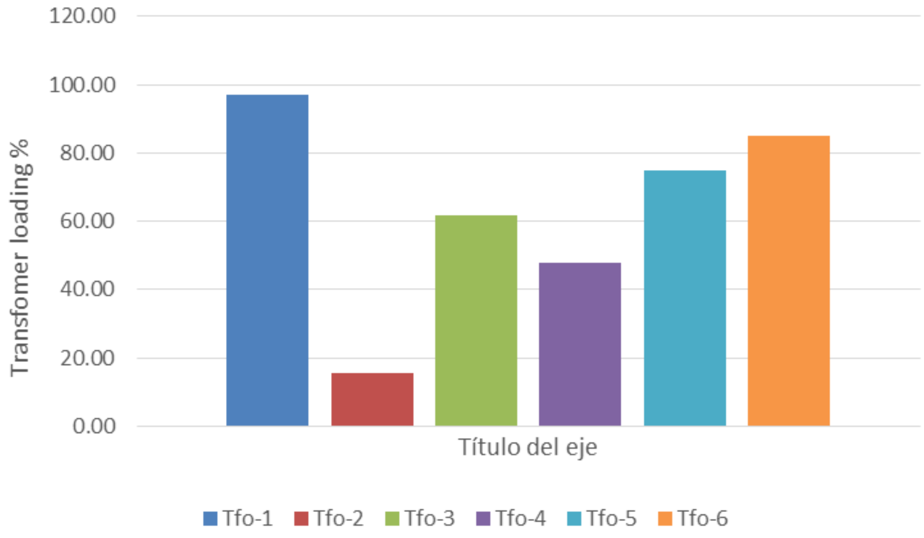

Figure 24: Transformer load Case 2

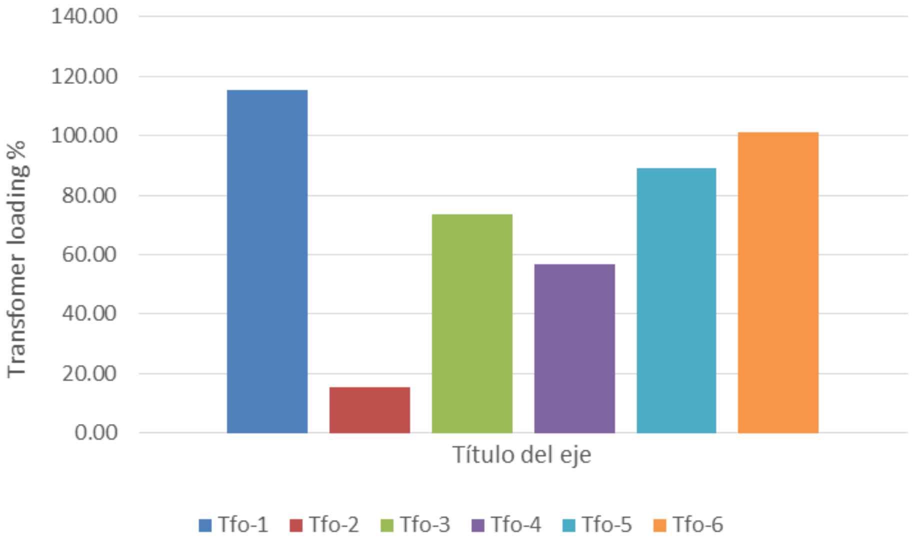

Figure 25: Transformer loading Case 3

6. Conclusions

The impact of the charging station on the simplified representation of the distribution grid, or better said, the individual substations comprising the transformers for each of the aforementioned test cases can be summed up graphically as shown below.

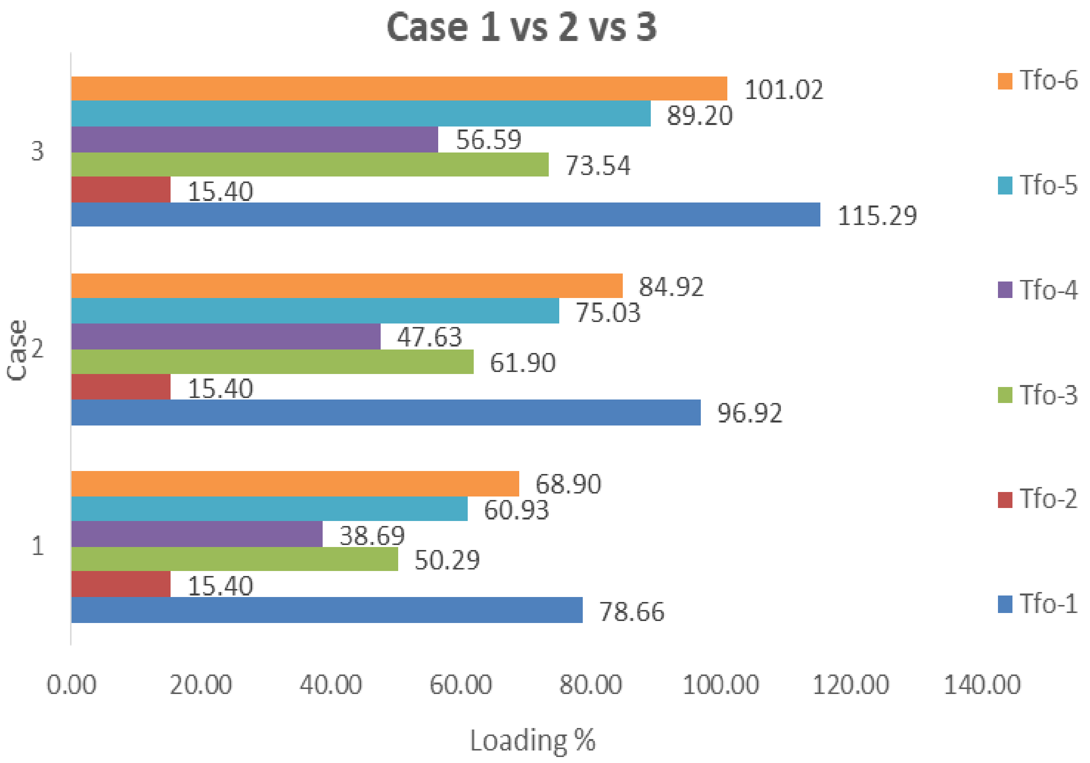

Figure 26: Transformer loading Case Summary

As observed from the chart above, while for case 1 the all the transformers are to be loaded within acceptable limits, case 2 reveals that the transformers 1 and 6 approach their limits, showing a loading of about 97% and 85% respectively.

Case 3, i.e. when the number of households possessing charging stations is taken to be 7%, as expected, the load on the transformers exceeds their capacities, with transformer 1 being slightly over 100% and with transformer 6 markedly higher at over 15% of its rated capacity.

It must however be born in mind, that the simulation represents a generalized depiction of the distribution network with respect to the network topology, for the purpose of a preliminary estimation.

Taking the results into account, further deliberations would need to be made if the charging stations are to be accommodated within the existing network.

These may involve, but not restricted to, expansion of the existing network infrastructure, by means of upgrading the transformers to ones with higher rated capacities use of variable voltage transformers etc.

In the simulations it has been assumed that e-Cars are charged as soon as they are connected to the charging station. This causes the load from the households to overlap with that from charging the vehicles. Charge management, as also described in D3.8 for various applications, has the potential to avoid overload. This can reduce or eliminate the need for network expansion.

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