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Final Report

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LOAD MODELLING AND DISTRIBUTION PLANNING IN THE ERA OF ELECTRIC MOBILITY

Final Report

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Executive Summary

The era of electric mobility is going to happen. In this report, DSOs and academics, mostly coming from Europe, put their efforts together to give some rules for the distribution network planers.

In this report, DSOs and academics put their efforts together to analyze different charging use cases with the objective to define **individual load profiles** for each level of assets (primary substation, Medium Voltage[1] network, secondary substation and Low Voltage network), propose a method to integrate and combine the charging load to the network simulation. One of the main challenge was the great disparity of grid connection and operation standards.

The charging use cases can be summarized as follows:

- Home charging: This use case covers individual dwellings (houses with garage) and the cases of collective residential building as well.
- Public charging: We distinguished two types of public charging: street and highway. Regarding the street charging a distinction can be done for urban areas with high population density, there is a big demand for public charging infrastructure, or for rural areas where there is hardly any demand
- Employer charging: Various studies show that there is an increasing need for EV users to be able to charge at work. Due to the almost simultaneous arrival of the employers at work, a peak is generated in the morning hours. By the usage of a charging management system, this load peak could be reduced.
- Opportunity charging: By opportunity charging is meant the case, when charging the electric car is not the purpose of a visit of charging station, but only an alternative, which is used as a benefit of parking in the destination.
- Other specific use cases, for example battery swapping, are also covered in the document.

Considering network planning, different methods corresponding to the scope of the study need to be used.

At the primary substation, a stochastic method seems to fit the issue best. In this approach the model estimates the number of EVs in different categories: personal cars, corporate vehicles, car-sharing etc. for each substation in the studied area. It is assumed that vehicles assigned to a given substation are always charged by this substation, whether at home, in the street or at work. The model adds up the individual probabilistic load curve of each vehicle to estimate the total consumption due to EVs. The results could be used to review and assess the need for reinforcement at primary substation level

The impact of electric vehicles on the MV network has been relatively little studied. Indeed, at this level of planning, these impacts are combined with residential, industrial and decentralized production loads, but with less aggregation than at the level of the primary sub-station. The stochastic approach, which is

[1] Medium voltage refers to High voltage of 1st category with a voltage range higher than 1 000 V to 50 000 V as well as the high voltage of 2nd category operate by Distribution System Operator.

only valid on a large number of loads and time series than that the one by simultaneity factor, which de facto considers only a single peak moment, do not seem sufficient to correctly establish the maximum loading on these equipment. Nevertheless, we propose a hybrid method based on clustering the EV load on the MV feeder which mixes stochastic method and simultaneity factor.

For LV feeders and secondary substation, we propose two different approaches. The first one is a quick assessment method based on simultaneity factor without considering unbalance which can be easily used for secondary substation load. The second approach is a power flow application in excel that is more suitable for LV feeder analysis.

The document ends with some outlooks that can only be touched in the scope of this work. One of the most predominant open question is the relationship between the load flow and the energy and flexibility market. For the time being, conceptually, it is clear that the flexibility provided by the EV (e.g. V2G) is of a big interest for the balancing at the TSO level and that market price could also deeply impact the behavior and the simultaneity factor of the EV's users. However, these service products do not have enough maturity to be able to anticipate their real impact at the moment.

The ramp up of electric vehicles is only just beginning. Three different fields of action can be identified based on the observations of this working group:

- **Need for better data:** There is an extensive need for different kind of data that allows for better understanding what happens at the low voltage level of distribution grids. This is particularly important as current planning and operation principles are based on current mobility pattern of driving behavior, where traditional fuels are dominating the number of vehicles. As the charging requirements for electric vehicles differ in space and time from the requirements of combustion fuel vehicles, these changing requirements might also affect the driving behavior and subsequently grid utilization in a way that cannot be foreseen at the moment.
- **Execution of extensive academic research with focus on improved models:** While the data collection mainly needs to be executed by the distribution grid operators themselves, it is advised, that the collection and in particular the data analysis, is carried out in close corporation with research institutes.
- **Development of advanced planning tools that better reflect reality:** Although it is state-of-the-art in practice to use simultaneity factors for distribution grid planning purposes, several publications have been released in the past years indicating that in the long term, with more complex system participants in the low and medium voltage grid as well as expected smart grid and smart market mechanisms, simultaneity factors might not be suitable anymore for medium and long term distribution grid planning.

Contents

1 Introduction

1.1 Background

To limit CO2 emissions, many countries announced ambitious targets for the development of e-mobility (electric cars, buses, etc). The charging of these vehicles will create new loads with very specific characteristics and could have a significant impact on distribution networks if the loads are not carefully managed. Smart charging solutions will be designed to minimize network congestions and limit reinforcement costs.

Hence, charging of Electric Vehicles (EVs) in an efficient and economical way will present new challenges for Distribution Grid Planning.

1.2 Objectives and scope

Considering that this document is addressed to the planning of the public distribution network, only vehicles traveling on public streets and highways are in the scope. Railway vehicles (trains, trams), watercraft (ships, boats) and other special purpose vehicles (golf cars, off-road motorcycles, etc.) are therefore excluded. For the sake of simplicity and given their low energy requirements, electric bicycles and motorbikes are not covered.

This document covers:

- How to forecast EV load profiles and charging stations load profiles (EV charging at home, in public areas, in collective residential building car parks, in office building car parks, etc.) for network planning purposes.
- How to assess the demand of a "smart house/building" (e.g. one with Photo-Voltaic generation on the roof, local storage, an EV and a home/building energy manager) and the total load of a group of such houses/buildings (Load diversity, impact of PV shading).
- How urban planning and traffic models can influence load profiles of fast and public charging stations.
- Which EV load profiles could impact positively the distribution network, and in which cases.
- How smart charging systems that limit charging demand in case of network can be used.
- Which new methods and tools will be needed by Distribution Grid Planning.

The objectives consist in two fold. The first one is to give a common understanding amongst Distribution Grid Planning agent about the challenges raised by charging infrastructure for EV. The second objective is to provide them with methods and tools bundle as a framework to facilitate a holistic approach to network impact.

However, the scope of this document does not cover the following topics:

- EVs participation to Flexibility (neither at local or system level)
- Mechanical design of the charging facilities (e.g. hanging device for supporting the weight of EV charging cable, suitably protected from ingress of dust and water, etc.)

About flexibility, there is growing interest in using the flexibility of electric vehicles (EVs) to actively manage the demand on the distribution system and rationalize the need for new investments on behalf of customers. The benefits of a smart charging approach are two fold:

1. Mitigation of localised distribution network demand exceedances created by EV chargers. This could have a significant impact in the long-term by reducing the LV-network investment needs by up to 60%.
2. Additionally, there is a potential benefit at system level as EVs could, by means of the energy stored in their batteries, provide ancillary services to the national and European electrical system, such as frequency regulation (R1 (FCR) or R3 (mFRR)). This opportunity is still at research stage and several techniques are the subject of in-depth analysis. Two main directions seem to emerge[2].

Besides the necessity to create clear business model to engage clients to adopt this flexibility, there are also some technical issues.

On one hand, decentralized control (without central control) is recommended because of its reliability and much lower communication requirements. For example, a linear service delivery based only on local measurement (linear function of the frequency) is commonly used in the various projects but leads to low efficiencies (efficiency defined as the ratio MW flexibility offered to the service / number of participating EVs).

On the other hand, while controllers with 3 modes (idle load, full charge, full discharge) lead to better efficiency, it is found that this also leads to large errors in calculating the reserve available when the aggregation is small. Indeed, knowing the exact number of EV and their state of charge is an essential information for this type of operation, which is only possible with some sorts of charging infrastructure (e.g. CHADEMO).

In addition, the efficiency of the inverters / chargers is not symmetrical in charge / discharge as shown in next Figure (taken from [1]).

[2] *Response Accuracy and Tracking Errors with Decentralized Control of Commercial V2G Chargers* Charalampos Ziras; Antonio Zecchino; Mattia Marinelli (Technical University of Denmark, Denmark) (2018)

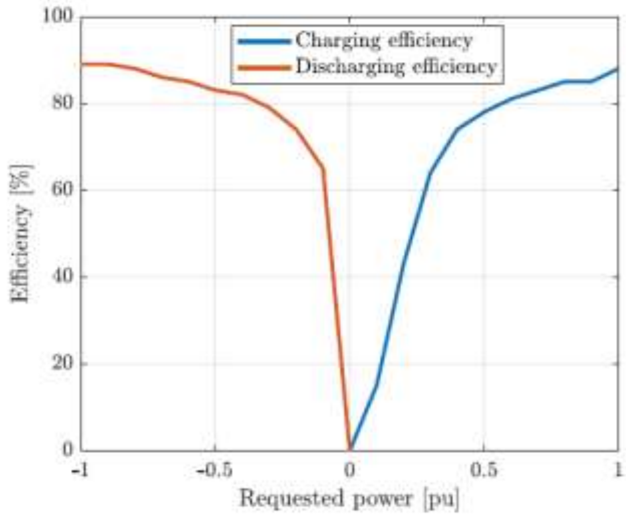


Figure 1: efficiency charging/discharging

It is extremely difficult at this stage to predict how this particular market will be designed, and how often it will be used (a.k.a. reserve activation).

For these reasons, we have not retained the impact of flexibility in the consumption profile of Electric Vehicles in the context of this paper. However, careful monitoring of technological, regulatory and electric tariff developments must be maintained.

2 Definitions and classification

The goal of this chapter is to provide definitions and explanations to help the understanding of the framework proposed in this document.

2.1 Definitions

Terms	*Definition*
Distribution network	means the transport and distribution of electricity on high voltage, medium-voltage and low-voltage distribution systems with a view to its delivery to customers, but does not include supply (ref directive 2009/72/CE)
Distribution system operator (DSO)	means a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity;(ref directive 2009/72/CE)
Electric Vehicle (EV)	is a vehicle which uses one or more electric motors for propulsion. The different types of EVs are presented in the next chapter.
Motorcycles	a self-propelled road two (or three)-wheels vehicle designed to carry passengers
Passenger cars	a self-propelled road four wheels vehicle designed to carry passengers. This notion included the automobile classification in appendix 1.
Bus	a large self-propelled road vehicle designed to carry passengers (≥ 10) between stopping places along a regular route (public transport bus services)
Utility vehicles	a self-propelled road vehicle with four wheels designed to carry loads with weight is less or equal to 3.5 T
Truck-lorry	a large motor vehicle designed to carry loads with weight higher than 3,5 T

2.2 Classification

2.2.1 Type of Electric Vehicle

Each vehicle type defined in the previous section can be propelled by electric motor(s). The following table shows the classification of the way the electricity is used.

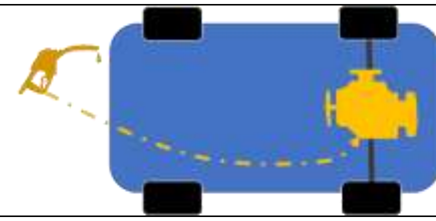
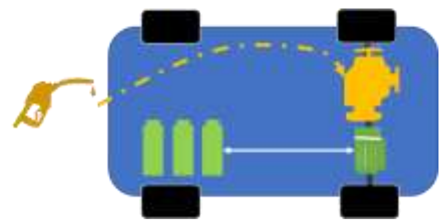
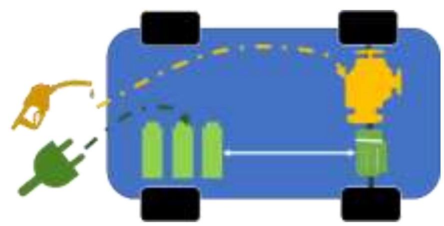
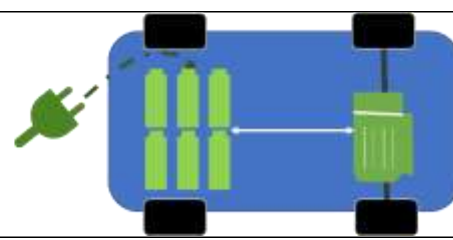
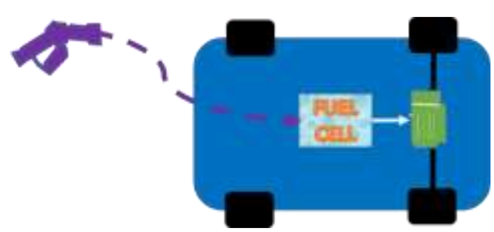
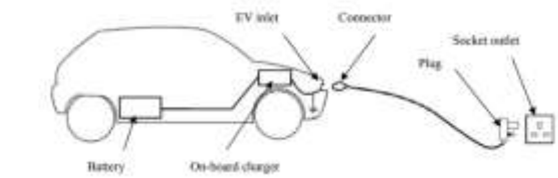
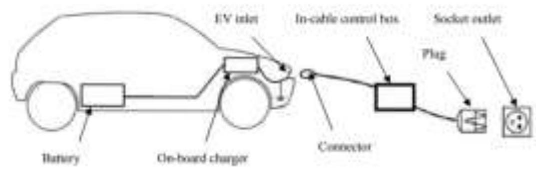
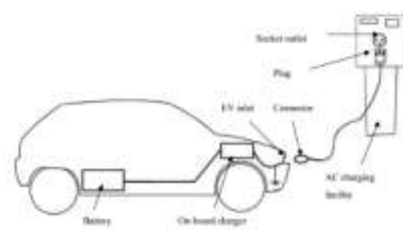
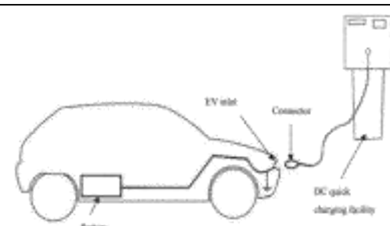
Type	Description	Scheme
Internal combustion (pro memory)	is propelled only by internal combustion engine (ICE) using some kind of fuel (e.g., diesel, gas, or petrol)	
Non Plug-in Hybrid	combines a conventional ICE system with an electric propulsion system (incl. batteries and electric motor). This vehicle can run only on a combustion engine, only on an electric motor, or on a combination of both. Batteries are only charged by the ICE and by regenerative breaking	
Plug-in Hybrid (PiHEV)	combines a conventional ICE system with an electric propulsion system (incl. batteries and electric motor). This vehicle can run only on a combustion engine, only on an electric motor, or a combination of both. Batteries can be charged by the ICE, by regenerative breaking, or an external source of electricity	
Battery Electric (BEV)	is propelled only by electric propulsion system. Batteries can be charged by regenerative breaking and an external source of electricity.	
Fuel Cell Vehicle	is equipped with a fuel cell to power its on-board electric motor. This fuel cell is an electrochemical cell that converts the chemical energy of a fuel (often hydrogen) and an oxidizing agent (often oxygen) into electricity through a pair of redox reactions.	

Table 1 EV classification

Regarding the scope of this document, this report will focus on BEV and PHEV.

2.2.2 Type of charging facilities[3]

Mode /Type	Charging Capacity (kW)	Type of current	Data exchange	Scheme /Illustration[4]
Mode 1	3.7	AC	None	
Mode 2	11	AC	None or with specific equipment	
Mode 3	22	AC	• Vehicle detected • maximum allowable charging current • control charging begin/end	
Mode 4	125 (Tesla)	AC or DC	Unknown	
	60 (ChAdeMO)	DC		
	170 (CCS)	DC	HomePlug Green PHY	

[3] In the scope of this document, electric vehicle charging facilities are fixed electrical installations that include, but not limited to, switchboards, distribution boards, cabling, conduits, trucking's, socket outlets and EV supply equipment.

[4] Illustration from EMSD (Hong-Kong China) https://www.emsd.gov.hk/filemanager/en/content_444/Charging_Facilities_Electric_Vehicles.pdf

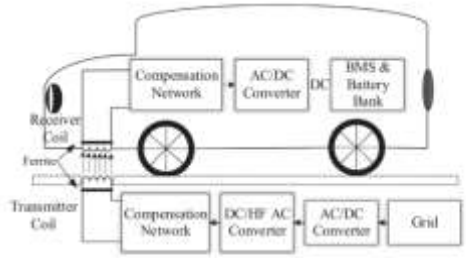
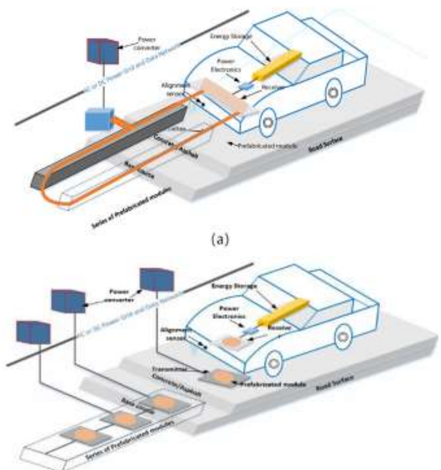
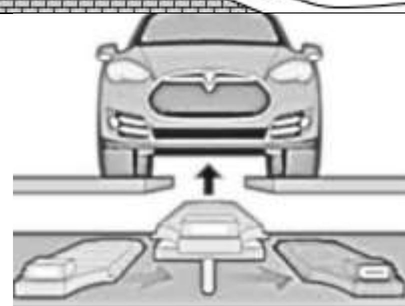
Static Wireless charging (or inductive charging)[5]	3.6 (up to 22 kW with new J2954 standards	AC (but kHz)	Unknown	
Dynamic wireless electric vehicle charging system (also called 'roadway powered') (only experimental[6])	30 (outlet power)	AC (but kHz)	Unknown	
Flash charging (e.g. pantograph for Buses)	600 (15 sec)	DC	Unknown	
Battery swap [7]	Charging time at swap station 100 kWh / 3 minutes	AC	Yes, with battery swap station	

Table 2: Charging technologies

[5] Image from Review of static and dynamic wireless electric vehicle charging system, Chirag Panchal en al. Griffith School of Engineering, Griffith University, Nathan Campus, Brisbane 4111, Australia Engineering Science and Technology, an International Journal,
[6] e.g. https://cities-today.com/tel-aviv-pilots-electric-road-to-charge-buses/
[7] Information from NIOs EV8 (China) https://www.nio.com/es8

Thus, the two following modes were defined in the EN 68151-1:2019 standard[8]:

- Mode 1: Connection of the EV to a standard AC household or industrial socket with a maximum of 480 V three phase voltage and a charging current of maximum 16 A. (Power between 3.7kW-11kW) No communication takes place between EV and socket.
- Mode 2: Connection of the EV to a standard AC household or industrial socket with a maximum of 480 V three phase voltage and a charging current of maximum 32 A (Power between 3,7kW-22kW) including communication and protection devices between socket and vehicle. This Mode is mostly realised using charging cables, which include an in-cable control and protection device. It should be noted that regarding the power, DSO could impose the type of connection (see figure 4). In some countries, e.g. Austria [9]and Germany[10] fix mounted wall boxes must be reported to the DSO or approved by the DSO. The threshold between a notification and an approval depends on the charging power and can differ from country to country. For example, in Germany if the total charging power in a detached house is below 12 kVA (three phase) it is necessary to report the wall box to the DSO. Due to safety reasons the fix mounted wall boxes have to be connected and checked regularly by a certified electrician. We have to note that at the global level, the lack of standardization of the systems of charging of the electric vehicles forces the automobile manufacturers to develop their own system and infrastructure for charging, and / or to adapt to the various regions of the world.

First, only at the level of the connection (plug) at the vehicle level, we can distinguish four types of plug (see next Figure).

[8] European Committee for Electrotechnical Standardisation European, Standard EN IEC 61851-1:2019: Electric vehicle conductive charging system – Part 1: General requirements (IEC 61851-1:2017), July 2019, Brussels
[9] TOR D1: Technische und Organisatorische Regeln für Betreiber und Benutzer von Netzen (TOR) - Netzrückwirkungsrelevante elektrische Betriebsmittel, E-Control, Austria, Vienna, 2004
[10] VDE-AR-N 4100 Anwendungsregel - Technische Regeln für den Anschluss von Kundenanlagen an das Niederspannungsnetz und deren Betrieb, VDE, Frankfurt, Germany, 2019

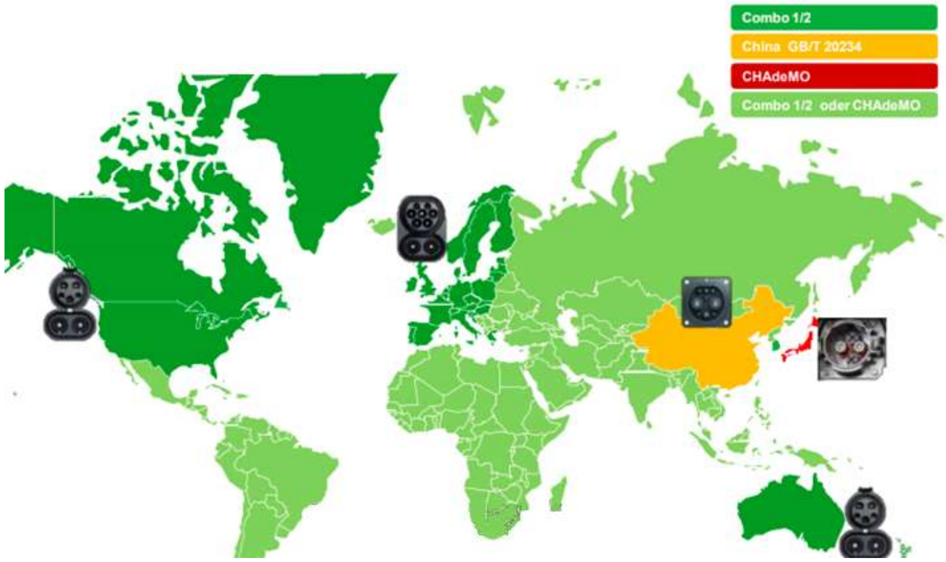


Figure 2: EV plug's world standard (courtesy of Audi Brussels S.A.)

Secondary, as the next figure illustrates the normal household network capacity and the recommended charging capacity (recommended by car manufacturer) can differ slightly from countries to countries.

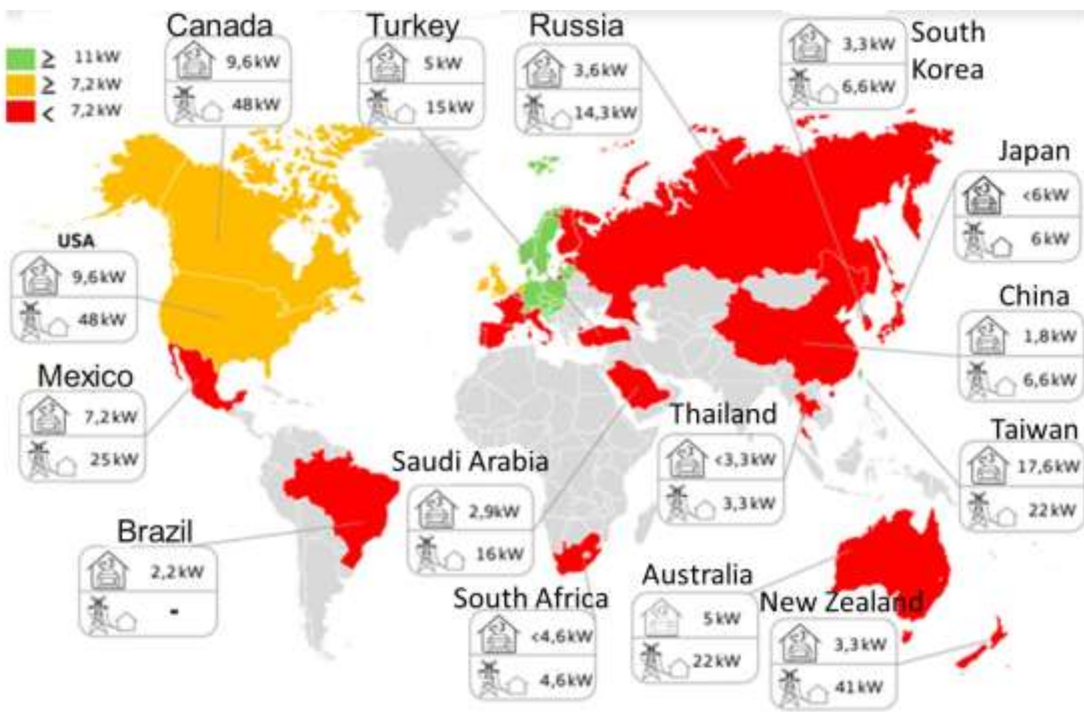


Figure 3 Normal electric network connection vs. normal charging capacity (courtesy of Audi Brussels S.A.)

3 Method overview

In the domain of electricity network planning, as it is for many other topics, it is always very hard to predict the future behavior of loads when the technology is disruptive and the user profile is unknown.

It is certainly the case with electric vehicle and in particular for passenger cars. To infer the possible future, DSO planner has to rely on deeply transparent assumptions about certain characteristics of the Electric Vehicle Passenger Car (EV PC) population and the behavior of their owners/drivers.

There are different ways to cope with these issues.
In this technical guide, we will consider the different charging use cases and analyze the impacts of these on the network. This method has the advantage that it starts from customer's requests to DSO and to provide a better understanding of the phenomena that DSO could/would be facing.

The power is the most relevant variable to be considered by planners. We will not scope here the energy side (adequacy issue) of EV integration.

4 Types of EVs and their evolution

4.1 Electric passenger cars

From the last report of the IEA Global EV Outlook,2019[11], the next figure shows the evolution of the market share of EV (BEV & PHEV).

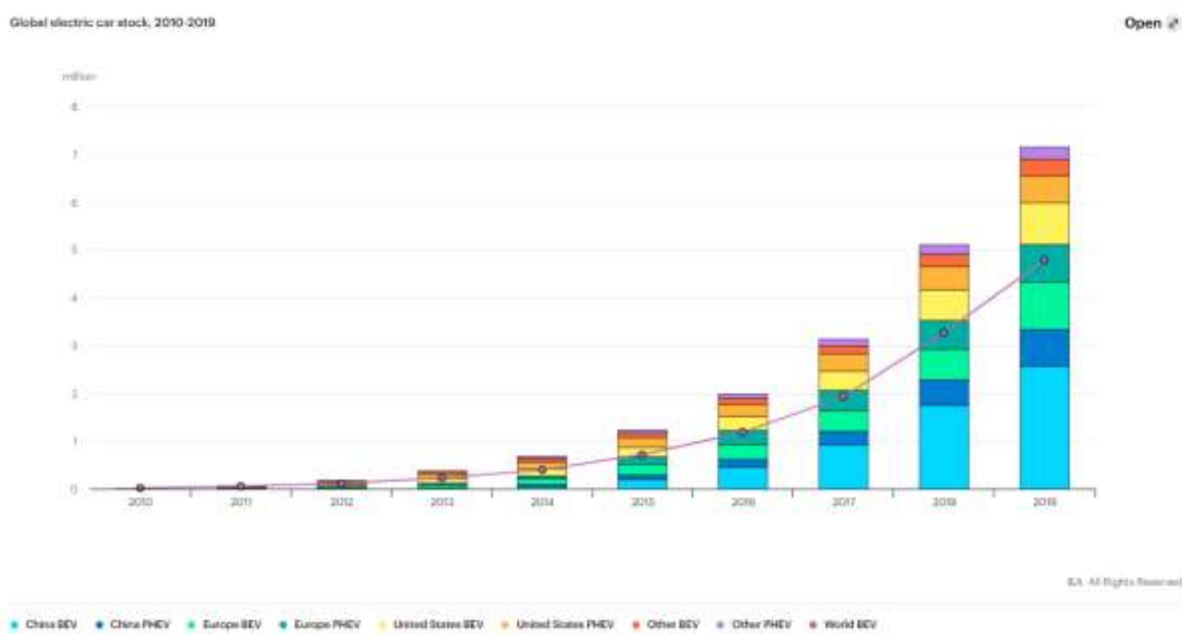


Figure 4: general evolution of EV market share

The rate of EV uptake is accelerating year by year: Since 2015 the number of electric cars has grown by a factor of 5. The mid-term objective for Spain is set by the National Integrated Energy and Climate Plan which aims for 5 million electric vehicles on the road by 2030, out of which over 3 million will be electric passenger cars. This target for the next decade translates into an increase of the current electric car population by a factor of 80 which the distribution network will have to accommodate.

Generally speaking, the market share of EVPC is to turn around 25% to 50% at the horizon of 2030[12].

Where and when:

[11] From the same source, you can consider the „Eletric car share in the Sustainable Development Scenario 2000 - 2030

[12] Bloomberg has conducted an online survey of those who read this report. The consensus that emerges is that over 83% of respondents believe that the percentage of EVs will be at least 25% in 2030 (21% raising the bar above 50%). This is purely indicative, this online survey is not scientifically representative. There is a strong presumption that those who read this study are already convinced of the arrival of EVs.

We have noticed in support of academic studies[13] that the speed of progression of new technologies and associated markets (first PV, now electric vehicles) could be estimated from the socio-economic profile of customers, in starting with the better-off profiles (i.e. those in the upper median income). They then propagate to other profiles. This is notably what is found under the term "theory of diffusion of innovation" (DOI).[14]

If the statistics are known, it is then possible to cluster the different statistical zone where the most adequate profile occurs. For instance, the definition of the cluster can be driven by:

Cluster N°	Population density (inhabitant / km²)	Capital income / inhabitant
1	Less than quartile 1 (Q1)	Less than third quartile
2		Higher than third quartile
3	Between Q1 and Q3	Less than third quartile
4		Higher than third quartile
5	Between Q3 and percentile P95	Less than third quartile
6		Higher than third quartile
7	Higher than P95	Less than third quartile
8		Higher than third quartile

Table 3: example of clustering population profile

[13] Sovacool, B. K., Axsen, J., & Kempton, W. (2017). The future promise of vehicle-to-grid (V2G) integration: a sociotechnical review and research agenda. *Annual Review of Environment and Resources*, *42*, 377-406.
(11 continued) Sierzchula, W., Bakker, S., Maat, K., & Van Wee, B. (2014). The influence of financial incentives and other socio-economic factors on electric vehicle adoption. *Energy Policy*, *68*, 183-194.
Li, W., Long, R., Chen, H., & Geng, J. (2017). A review of factors influencing consumer intentions to adopt battery electric vehicles. *Renewable and Sustainable Energy Reviews*, *78*, 318-328.
[14] See on this subject Rogers, E. M. (2010). Diffusion of innovations. Simon and Schuster

4.2 Buses

As of today, in Europe there are around 4,000 electric buses running (in the definition are included not only battery electric buses but also plugin hybrids, trolleybus IMC and fuel cell buses). A small part of the global circulating of 400,000 units of electric bus (the figure is taken from the Electric Vehicle Outlook 2020 by Bloomberg New Energy Finance). 85% of all new buses in European Union in 2019 were diesel-fueled, with electric vehicles making up 4.0% of total new bus registrations. The figures coming from ACEA (European Automobile Manufacturers Association) take into consideration all bus registration for buses over 3.5 tons. Although the 4 % share of electric drives could look like a marginal piece of the puzzle, it is worth considering that electric bus registration in the EU increased by 170.5% from 594 units in 2018 to 1,607 buses sold in 2019.

The year 2019 will be remembered as the year when the electric bus sales volumes ramp up. While in 2018 the European electric bus market increased 48 per cent compared to 2017, the year 2019 saw a tripling in the number of electric bus registration in Western Europe. And a first insight from year 2020, focused on the first three quarters, gives the following results: slightly over 1.200 battery-electric buses registered in Western European countries (with the addition of Poland). The size of the electric bus market at the end of the year could reach nearly 2,000 units (compared to 1,600 last year), as there are up to 800 e-buses in delivery in Q4.

Within the scope of this paper, we will focus on Battery buses.

The public transport sector can set Europe on a course to become climate-neutral. Transport represents almost a quarter of Europe's greenhouse gas emissions and is one of the main causes of air pollution in cities. The transport sector has not seen the same gradual decline in emissions as other sectors, with individual car usage and short distance flights being some of the problems. The fastest and most cost-efficient way to decarbonise people’s daily mobility and reduce the carbon footprint of their mobility choices is to promote the use of public transport, walking and cycling.

Where and when

With the support of the EU Green Deal, the public transport sector can achieve net-zero greenhouse gas emissions at the latest by 2050 in a cost-efficient manner. At the center of this will be further efforts to decarbonize the public transport fleet. The future EU Green Deal will have to stay compatible with other economic and social priorities, also meaning that the impact of future climate actions will have to be mitigated for the most vulnerable citizens.

Smart mobility: busses will not drive without any of the optimizations:

- Bus’s route and km travelled per day or month must be included in simulations of the route optimization.
- Buses’ size, beside the path is also relevant for the economic optimization.
- Recharging station power and recharging time optimization:

- The charging can take place with a capacity of 30 kW to 450 kW, with a difference between slow and fast charging. In general busses are equipped with a Combo2 charging plug for a charging power of 50 kW. For higher capacities, roof and infrastructure mounted pantograph options are available. With a pantograph, a capacity of up to 450 kW can be obtained. The roof and infrastructure mounted pantograph can also be used for depot charging.
- Time: time of a charging can be estimated on the basis of the combination of battery energy capacity and maximum power . Here is an example of buses:
  - Standard cooling batteries system (e.g. air): energy capacity between 216 kWh and 288 kWh combined with a roof or pantograph system having a maximum charging power equal to 430 kW.
  - Advance cooling batteries system (e.g. liquid based): energy capacity between 315 kWh and 420 kWh, the maximum power can be up to 330 kW.

4.3 Fleet and Utility vehicles

In order to reduce traffic emissions, it is not sufficient to consider only passenger cars. According to data from the European Environment Agency, 12% of all EU-wide emissions come from cars, but 2.5% also come from vans and 6% from trucks. Due to an EU Parliament regulation, truck manufacturers must reduce the emissions of their new vehicles by 15% from 2025 and by 30% by 2030 compared to 2019. One possibility is the incentive mechanism created for this purpose, which gives greater weight to zero-emission and thus electric vehicles in the fleet emissions balance sheet.

Figure 5 shows the current development of the battery-electric truck population and the amount of battery-electric vans in the EU using data from the *European Alternative Fuels Observatory*. PHEVs are not included in the figures, as their share among the electric trucks in the data set is 0 % and among the electric vans in 2020 0.4 %. Although a growing stock of electric trucks and vans is already visible, their total volume is still very small compared to the conventional vehicle stock. Only 0.8% of all newly registered vans in the EU are electrically powered.

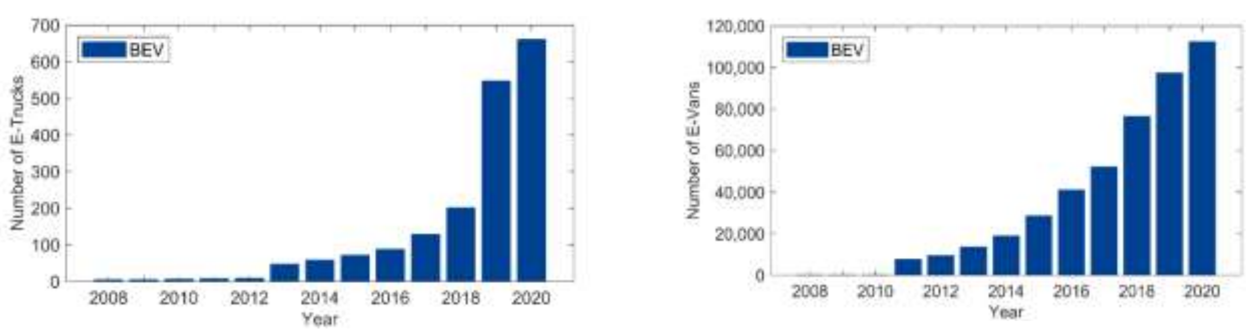


Figure 5: Total number of battery-electric heavy-duty vehicles in EU, and Total number of battery-electric light commercial vehicles in EU.

More and more manufacturers are testing electric trucks and vans. Their fuel consumption and battery capacities differ significantly from those of electric cars.

Where and when

The charging point for heavy-duty vehicles would be placed at the depot and at the delivery points and therefore more than likely connected to MV. For the moment, it is very hard to forecast the pace of proliferation of these heavy-duty vehicles as their commercialization is not yet happening.

The light commercial vehicles (for both the charging point and their market share pace) can be assimilated with private car charging at work. Nevertheless, heavy-duty has a very well predefined routes. So, should be easy for Trans-European Transport Network (TEN-T) to establish policies to engage the penetration of electric heavy-duty vehicles with charging points framework.

5 Charging use cases

The aim of this chapter is to provide load profiles for the main Charging Use Cases:

- Home Charging
- Public Charging
- Employer charging
- Opportunity or Sub-public charging
- TEN-T strategic charging for electric heavy-duty vehicles

The profiles are the input for Chapter 6, in which we describe simultaneity factors and expand planning aspects. Furthermore, we describe some other specific use cases in this chapter.

5.1 General overview

The distribution of the charging infrastructure depends on the settlement structure. Figure 6 illustrates the expected distribution of the charging stations, about their location of installation, classified as public, sub-public, private areas and work places on the example of Greece. Same as in other countries in rural and sub-urban areas private parking and charging is predominant. Due to the higher proportion of rental apartments - where retrofitting of private charging stations can be problematic - and the smaller number of private parking spaces, the installation of private charging stations in urban areas is significantly lower than in suburban and rural areas. Although urban grids are used to be more robust because of higher load density, charging hotspots in areas with high density of employers might become challenging from the network planning perspective. Islands are expected to have higher shares of public and sub-public charging stations compared to the previously mentioned areas, because tourists and a smaller portion by permanent residents are expected to use a high share of EVs.

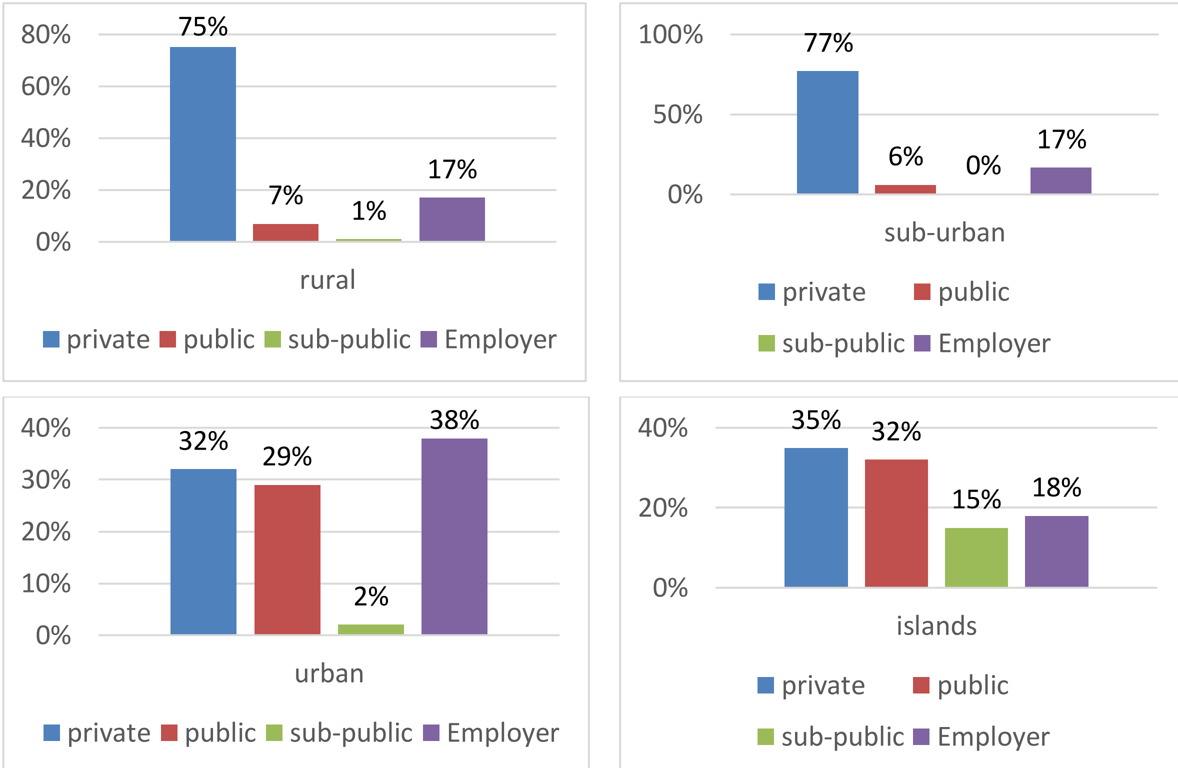


Figure 6: Distribution of utilized charging infrastructure (from review or survey see [1], [2], [3])

To assess the energy demand that is used at different charging stations, it is important to know where vehicles are parked the longest. Figure 7 shows the results of a survey that has been conducted during the project MERGE[15] regarding the location of a survey responders' vehicles in which they are parked for the longest period of time in a given day. 56 % of vehicles are parked either in a garage or on a driveway on weekdays, rising to 72% on weekends. If cars parked on the street directly outside the owner's house are included, which would require providing an extension cable to the vehicle, the proportions rise to 73% on weekdays and 92% on weekends. The data in Germany [16] confirm also that 92 % of EV are parking at home in a garage or private parking space. Therefore, for network planning, private charging is most challenging because there is a risk that the charging event occurs at the peak hours (see also Figure 58 - Figure 59 in Appendix).

[15] mobile energy resources in grids of electricity, deliverable d1.1 ,specifications for ev-grid interfacing, communication and smart metering technologies, including traffic patterns and human behaviour descriptions, 24 august 2010

[16] http://www.mobilitaet-in-deutschland.de/publikationen2017.html

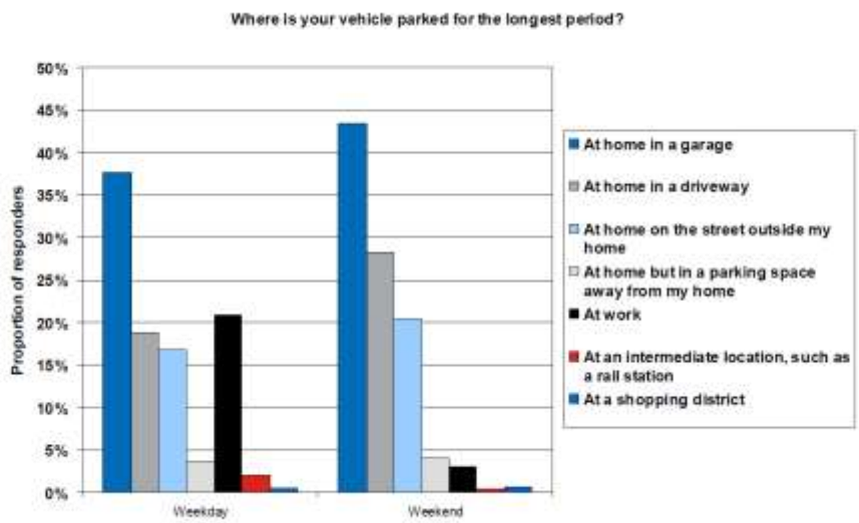


Figure 7 Location of vehicle for longest period of inactivity [14]

Figure 8 shows the results of availability of a standard domestic electricity socket to the place where respondent's is parked for the longest period of the day. 57 % of drivers reported that they could provide a supply of electricity to their car where it is parked for the longest period on weekdays, rising to 65% at weekends. These numbers are similar to the proportions reporting that their cars are kept in a garage or on a driveway. But they may suggest that the option of providing an extension cable to a car parked on the street directly outside the owner's house is either undesirable from a convenience, security or safety perspective or possibly just not known to be available option.

Figure 8 shows also, that a high share of over 70 % would need an extension cable or has no access to electricity at the normal parking place. To increase acceptance for e-mobility for this group development of technical solutions to connect charging infrastructure to the grid in private as well as in public areas as simple as possible is strongly required. Otherwise, alternative (public) charging solutions should be a real alternative to the costly installation of charging infrastructure in residential areas.

Nevertheless, it is emerging that home charging will be predominant, so we will focus on that in the following chapter.

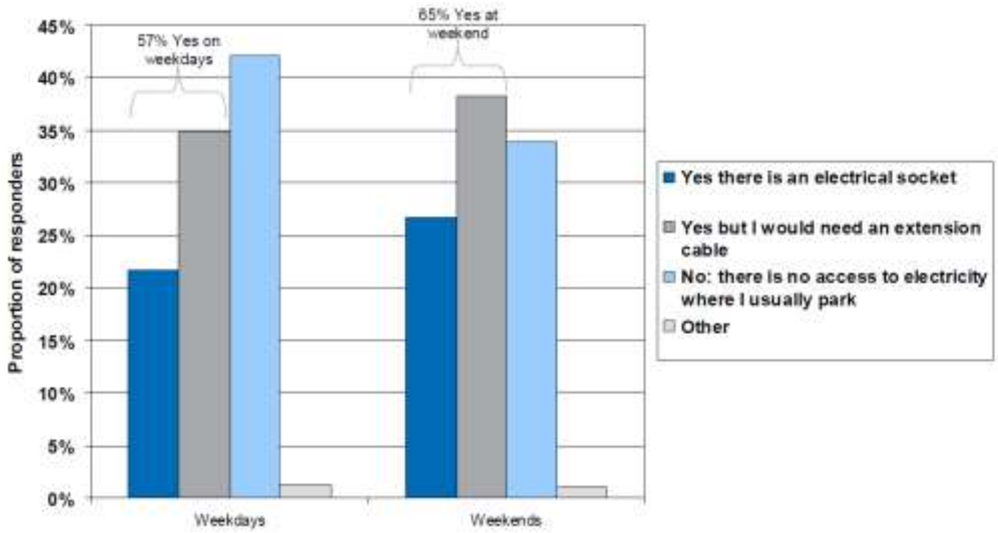


Figure 8. Access to electricity at parking space [14]

Considering the impact on the network of the power due to charging event in AC, it is to note that the individual load profile depends on the model of the car, state of charge the car has arrived at the charging point, the model of charging and the length of the stay. The charging is usually at the beginning with a constant power (constant electric current phase A) up to distinct state of charge, when the charging power starts to drop exponentially (constant voltage phase B). The maximum power of charging is the lower of maximum charging power of the car and the maximum capacity of the charging point. In the following Figure 9 various charging profiles of different electric vehicles are shown

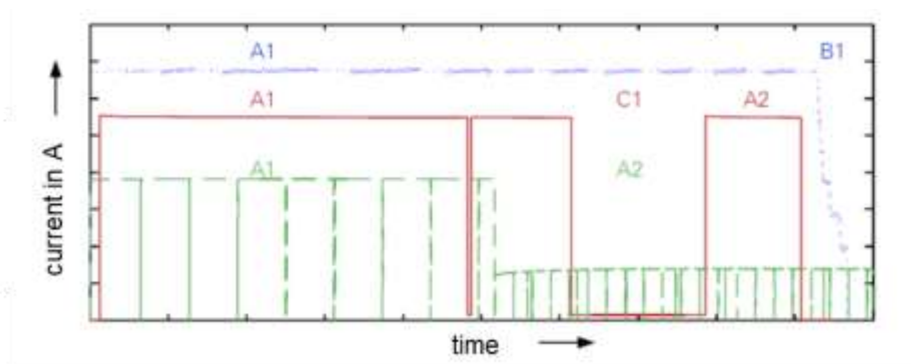


Figure 9 various charging profiles of electric vehicles[17]

The different charging modes can be described as follows:

- Phase A (1-2) - constant electric current phase (with different fixed currents possible)
- Phase B (1) – constant voltage phase

[17] TU Dresden Auswirkungen einer zunehmenden Durchdringung von Elektrofahrzeugen auf die Elektroenergiequalität in öffentlichen Niederspannungsnetzen. Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit. 2017

- Phase C (1) – no charging phase

As it can be seen in the Figure 9 the electric vehicles have different charging modes. The following Table lists the various combinations of the analysed electric vehicles (EV model in 2012)

Type	Combination of charging modes	Number of EV Type
1	A1 + B1	15
2	A1 + C1 + A2	1
3	A1 + A2	2
4	A1+ C1 + A2 + B1	1

Table 4: Depiction of the analyzed combination of the charging modes from the electric vehicles[16]

The most common charging mode is the combination between A1 and B1. It will be additionally mentioned that the Type 3 charging mode (A1 and A2) both were a prototype of electric vehicles.

High power DC charging mostly depends on the state of the battery (i.e. temperature). Although theoretically it should be with a constant power, the real-life measurements show, that charging with the maximum power only appears at the beginning of the charging session and then fluctuates somewhere in between.

In the next section, these different charging modes are aggregated to be used in the planification processes.

5.2 Home charging

The term "Home" has to be understood in a broad sense. This chapter covers individual dwellings (houses with garage) and the cases of collective residential building as well. Even if the differentiation is necessary from grid planning point of view, typical EV load profiles resulting from user behavior are not expected to differ between settlements of individual dwellings and collective residential buildings.

In **individual domestic garages** EV users are expected to charge their vehicles overnight regularly (generally speaking daily or at least two times per week). Therefore, they want to make use of cheap off-peak electricity prices. Some EV users in **shared domestic garages** may not have access to their own personal garage but may share one with other residents (e.g. a shared garage for a large block of flats or public resident car parks). Especially in bigger cities new buildings usually have a parking space for each flat. The integration of charging infrastructure is very challenging for distribution system operators. Indeed, for efficient distribution network planning purposes, it is important to have visibility of the demand trends, which are particularly challenging in the case of home charging as a significant proportion of the charging points will be installed behind the meter of each flat or a special meter for the charging infrastructure in the garage. The degree of visibility will dictate the viability of smart charging to alleviate distribution network constraints. Especially from the point of grid connection costs, we see a huge potential for smart charging applications. However, the practicability also depends on the metering and the accounting concept. For instance, in France, ENEDIS propose different schemes for equipping collective buildings in order to cover different market and technical situation[18].

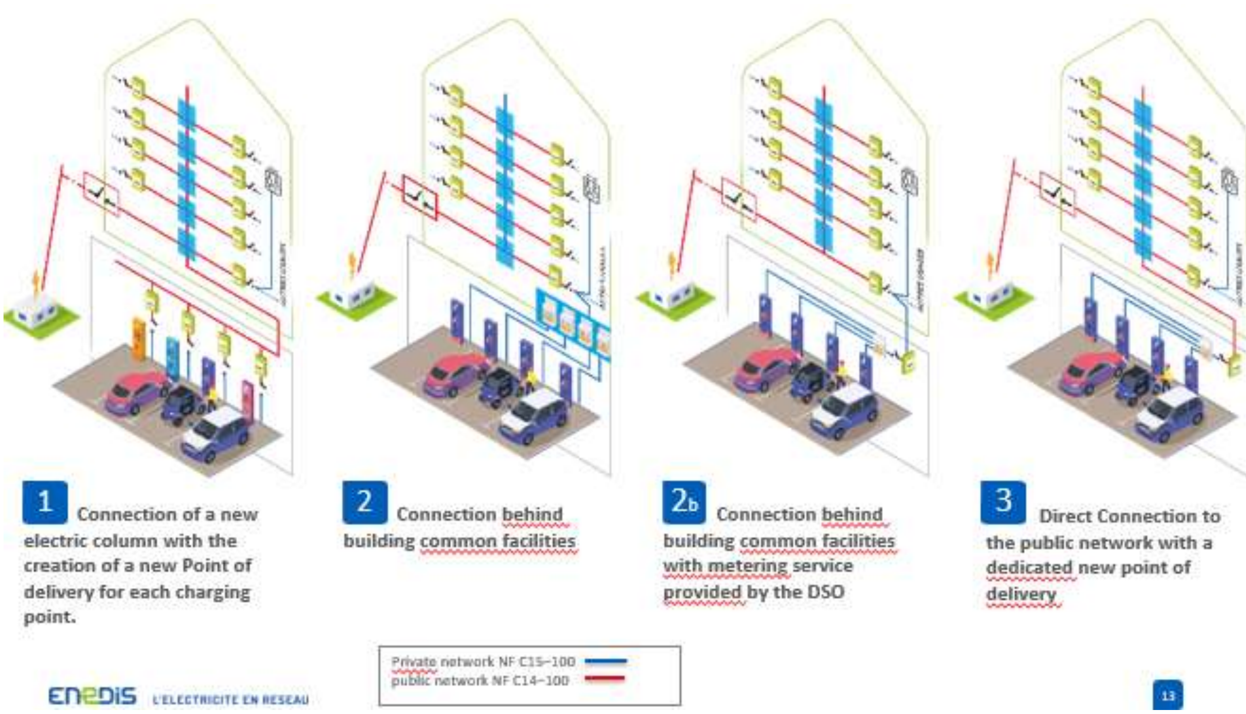


Figure 10: Electrical schemes for collective building - Enedis presentation – Lyon EVS 32 – April 2019

As described on the figure above the distribution network can be extended into the car park to pre equip all parking places up to the meter. It will be up to each owner to arrange for their charger installation whenever they like. This allows residents to be independent in choosing their electricity provider and pay for their own charging consumption. Another choice would be to equip some charging points for those who are buying that service (to a CPO for instance). The connection could be either directly from common services or through a dedicated delivery point.

The demonstration project "Urcharge" in Austria investigates the charging behavior of BEV in multi-apartment buildings with 106 households and 51 charging points (11 kW for each charging point). The BEVs were made available during the demonstration phase (6 months) for the residences of the 51 households. The results of this research project show that an efficient static load management system for electric charging stations significantly reduce the overall required system charging power without any loss

[18] http://www.avere-france.org/Uploads/Documents/161848754620450870f6eef474d2fa0a5065e75f36-AVERE_GUIDE_INTERACTIF_15042021.pdf

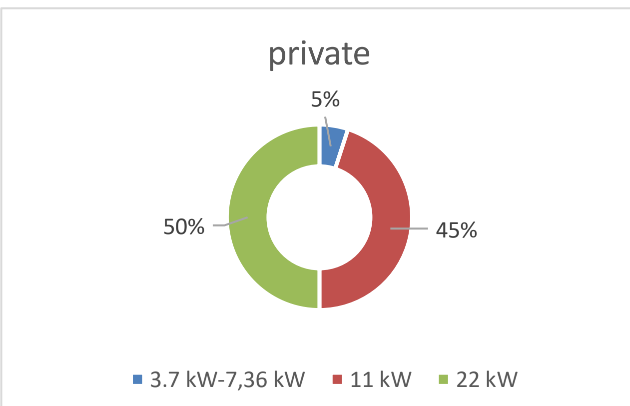
of comfort for the users. The charging power for each BEV results in 1,3 kW/BEV[19]. With respect to include also the winter season and the in future expected higher battery capacities, the effective charging power would be around ~2 kW/BEV[20]. From grid planner point of view the maximum power of the load management for electric charging stations together with the power of the residential households could be considered.

5.2.1 Share of different types of charging points

Single-phase charging points (Mode 1) were very common at the beginning of e-mobility. Single-phase charging in various European countries is limited to 3.7 kW through the grid connection guidelines[21]. Although, as depicted in Figure 2, there are a lot of different standards, generally speaking the single-phase house connections are limited to a maximum current between 35 A to 50 A (e.g. 40 A in Belgium). Thus, with simultaneous use of other devices, overloads can easily occur. With perspective to 2030 it is assumed that single phase charging will be used to a limited extent only.

11 kW and 22 kW charging points are 3-phase coupled to the grid. 11kW charging points currently are the most commonly used charging power for new private charging stations in various countries. With the perspective of 2030, higher charging powers are hardly expected in the private sector.

Based on the evaluation of various studies, it is assumed that the distribution of home charging as depicted in Figure 11**Error! Reference source not found.**.



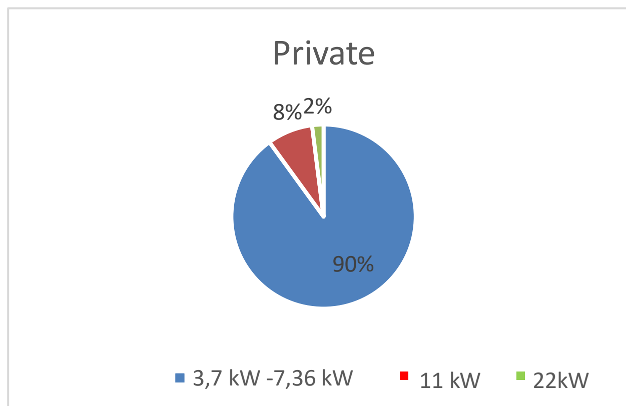


Figure 11: Expected installed power distribution of the home charging stations in 2030 (Hellenic Electricity Distribution Network Operator S.A at the left side / ENEDIS and ORES self-assessment at the right side)

Nevertheless, there are also reasons, to expect another distribution of charging powers at home:

[19] J. Ramsebner, A. Hiesl, R. Haas: “Efficient load management for BEV charging infrastructure in multi-apartment buildings”, Energies 13, No. 22, 2020

[20] G. Mayrhofer: “Intelligente Ladeinfrastruktur für den großflächigen Einsatz im großen Wohnbau”, E-Mobilitätstage, Wien, 2020

[21] the status quo in Greece allows charging up to 32 A

- In Austria in 2030 the forecast share of electric passenger cars will be about 27 %[22] based on the actual number of passenger cars. For home charging the following distribution of charging powers will be expected: 24 % (3,6 kW), 50 % (11 kW) and 26 % (22 kW)[23]. From the total expected number of charging points 29 % are planned for public charging infrastructure and 71 % for home charging infrastructure. In general, the electric charging stations in Austria are a power quality relevant equipment, which must be notified or approved (depending on the connection power) due the technical and organizational rules (TOR[24]) by the DSO.
- In Belgium (Wallonia)[25]: Considering the average daily travel pattern (less than 50 km taking account the additional measures to incentivize the use of public transportation) and the average consumption 20 kWh/100 km, the needed energy per day is around 10 kWh. It is believed that 3,7 – 7 kW chargers will remain the main standard as the vehicle can be charged during the night.
- In France, the charging power for residentials is assumed to be at 3,7 - 7kW with a trend towards the 7kW charger. A recent survey (over about 800 EV drivers) shows further behavior regarding charging habits[26]:
    - The subscribed power of most of the household is 9kW.
    - The majority of electric vehicle users charge their vehicle at a conventional electrical outlet. (58%)
    - 43% of the domestic sockets where electric vehicles are charged already existed and were not dedicated to this use.
    - 87% of respondents did not increase their electricity power subscription (contract supplier) in order to recharge their electric vehicle.
    - 42% of respondents do not know the power of the charging point, and 60% of respondents do not know the charging power of the vehicle.
    - Most of the main charging is done at home, while charging on the road and at work remains marginal.
    - 70% of respondents never use public charging points ; 2/3 of those who do use them charge in supermarket car parks.
    - A main recharge does not necessarily take place every day. For 64% it is even once or twice a week.
    - Of all respondents, users with a recharge control system are in the minority (37%).
    - 42% of those who charge at home start charging between midnight and 7am.
    - The majority of respondents are willing to delay recharging their vehicles to avoid peak consumption

[22] AustriaTech: “Elektro-Autos zuhause laden - Bedarf an und Maßnahmen für Heimladestationen in Wohnanlagen”, Mobility Explored, Vienna, Austria, 2019

[23] VCÖ: „Mobilitätsfaktoren Wohnen und Siedlungsentwicklung“, Mobilität mit Zukunft, Vienna, Austria, 2020

[24] TOR D1: Technische und Organisatorische Regeln für Betreiber und Benutzer von Netzen (TOR) - Netzrückwirkungsrelevante elektrische Betriebsmittel, E-Control, Vienna, Austria, 2004

[25] Synergrid (Belgium) Les gestionnaires de réseaux belges se préparent aux défis de la mobilité (http://www.synergrid.be/index.cfm?PageID=20914)

[26] https://www.enedis.fr/actualites/resultats-de-lenquete-bva-aupres-des-possesseurs-de-vehicules-electriques)

- In Germany the installation of charging facilities starting from 0 kVA have to be declared according to network Connection Ordinance. Charging facilities with a total rated power of 12 kVA are subject of approval and further needs to be prepared for remote control by the DSO. From technical effort and economical point of view charging with mode 2 (11 kW) is expected to be predominant for home charging.
- In Slovenia, the appliances connected behind the utility electric meter, which may also be an EV charging station, are not limited by the current legislation and no specific requirements or limits are settled. Namely, the electricity distribution companies are only authorized for approving the applied active power of a household connection, what is in reality installed is not a matter of the distribution company. Exception is only for the customers possessing a production unit, in this case the utility has the right to be informed. Summarizing this fact, in Slovenia behind the utility meter, a household can install even an EV charger of a 22 kW of nominal active power, but the main connection power, the main fuses, are in case of a household connection limited up to 14 kW. Nowadays, more and more households apply for the connections higher than 14 kW. This is a bit specific for Slovenia and is a consequence of installations of more and more heating pumps. But it is expected, that in next 3 years in Slovenia, the EVs owners would install EV stations with the nominal power at least of 3,7 kW, 1 phase, in some cases, where the needs of the owners would be different, e.g. having not only one vehicle, in these cases the local DSOs expect the installations of higher nominal powers, even 22 kW, but most probably the investors would respect the load guard features of the modern smart charging stations. As an example, the Slovenian company Etrel d.o., produces the smart rechargers, with an option of a smart feature of a load guard. Interactive charging the Etrel's INCH Home charger, it can remember and predict EV charging habits and charge the vehicle in the time of the lowest possible tariff. When the Load Guard sensor is coupled to the station, the charger can adjust charging power according to other consumers to prevent overloads, if a local power generation is present, than the charger enables eco-friendly fast charging.
- In Spain the installation of 3,7 – 7 kW chargers is expected in the domestic sector[27]. In general, as long as the EV can be fully charged overnight there is no customer drive for higher recharging powers. This implies that the contracted electric power at home can also be lower, with subsequent positive impact on customer bills. Besides, if smart charging is enabled the actual charging power is likely to be managed below the rated power of the charging point, in line with identified distribution network constraints.

Due to the high cost and complexity of DC equipment, home use is generally limited to Modes 1 and 2 for unidirectional charging. Nevertheless, DC equipment will find its way also in private charging infrastructure

[27] Monitor Deloitte, Los retos y las necesidades de las redes para el despliegue eficiente de la infraestructura de recarga del vehículo eléctrico, 3 December 2018

when electric vehicles are able to discharge[28] . The converter for feeding back from the EV battery will be placed in the charging infrastructure outside of the vehicle.

Installing an electric vehicle charging station at home has ecological, technical and economic advantages:

- at the ecological level: the charge time with a domestic terminal mode 2 is reduced to less than 6 hours (against up to 10 hours with a conventional mode 1 plug). If you have photovoltaic panels, it gives you the opportunity to use renewable energy to recharge your car. Of course, the share depends strongly on the driving behavior and attendance time at home.
- at the economic level: electricity at home costs generally less than public or shared terminals. If you have photovoltaic panel and it is possible to charge your EV with this energy, it is more than likely the cheapest way. Though, the cost of the installation is still high (between 300 € to 1000 € investment cost per charging point)
- at the technical level: the charging station can be equipped with interesting "smart" features. It can for example automatically reduce its power if other large devices are in use or delay charging at the most convenient times. It can also manage the automatic transfer of recharging data via the Internet or the flow of energy between the electrical network and the electrical installation. Such system could be used in coordination with smart charging equipment.

5.2.2 Typical individual load profile

Load profiles are the basis to derive grid-dimensioning parameters for Distribution Grid Planning. For an individual household the load profile depends on the arrival and departure time (or the time in which the EV is plugged in), the charging power and the energy demand. The energy demand of course depends on the distance driven. Results of a German survey[29] show that

- ~64 % of vehicles drive less than 10 km per day,
- ~95 % of vehicles drive less than 50 km per day, and
- ~ 1 % of vehicles drive more than 100 km per day.

The arrival time depends strongly on the user group (commuters, pensioners). Therefore Figure 12**Error! Reference source not found.** illustrates a European average of the survey results conducted in[30] weighted by the number of vehicles in each country. It shows that there is a regular pattern to the times that drivers return from their last journeys of the day, with the vast majority returning between 17:00 and 21:00 and

[28] https://www.ffe.de/en/topics-and-methods/mobility/933-bidirectional-charge-management-bdl-intelligent-interaction-of-electric-vehicles-charging-infrastructure-and-energy-system

[29] http://www.mobilitaet-in-deutschland.de/publikationen2017.html

[30] mobile energy resources in grids of electricity, deliverable d1.1 ,specifications for ev-grid interfacing, communication and smart metering technologies, including traffic patterns and human behaviour descriptions, 24 august 2010

a significant peak every day at 18:00 and another at 20:00. Many studies [31] demonstrated this effect, so it seems to be applicable for the vast majority of countries.

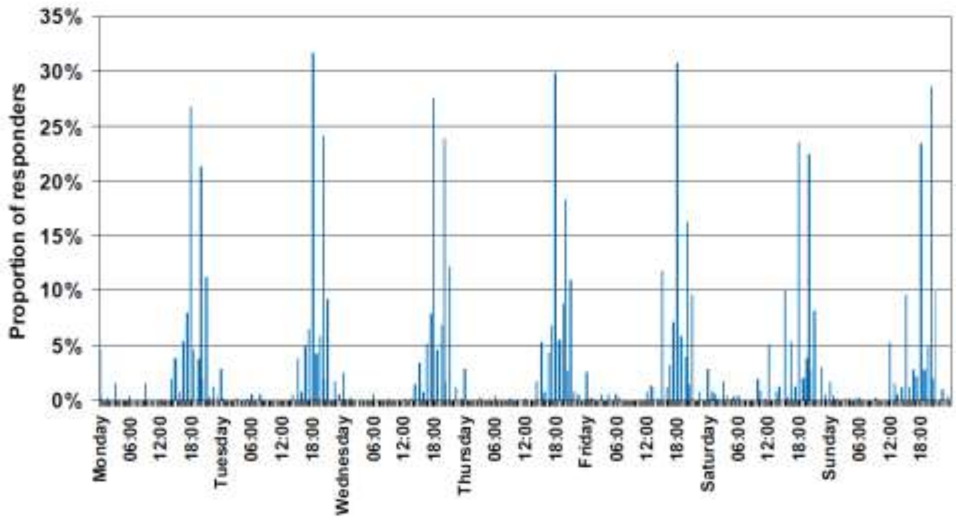


Figure 12. Profile of time of return from last journey of the day, European average

Predominant arrival times in the evening are leading to charging profiles with a load peak between 6:00 pm and 10:00 pm in case of uncontrolled charging (Figure 13; Figure 60 - Figure 65). Figure 13**Error! Reference source not found.** indicates the fully diversified EV load profile using a 3,7 kW rated charger. It can be observed that the addition of an EV typically will approximately double the peak demand of a domestic customer, because both load profiles are correlated to the time the customer returns home. While a diversified profile is valid for assessments with a sufficient number of customers (e.g. secondary substation level) a more granular analysis requires consideration of less diversified demand profiles.

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[31] http://www.mobilitaet-in-deutschland.de/publikationen2017.html; EA Technology, The University of Manchester, Western Power Distribution: My Electric Avenue: November 2015 and Skotland C. H., Eggum E., Hva betyr elbiler for strømnettet? NVE Rapport nr. 74-2016. September 2016, Oslo (in Norwegian)

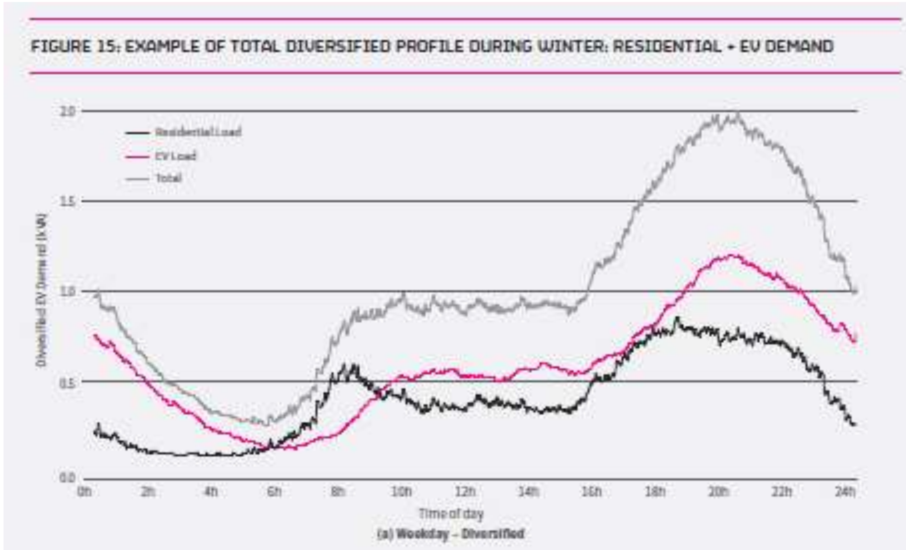

Figure 13: Example of total diversified load profile during winter (average diversified winter residential demand of 1000 households). Residential + EV demand[32]

One particular situation where EV load is fully decoupled from other forms of demand is where an independent point of supply is utilized for domestic charging. For example, this can happen in cities when the building where the parking space is located is different from the building where the home is located. A DSO in Spain, i-DE, has undertaken an analysis of the demand patterns on this type of EV-dedicated supply points based on a small sample of real smart-meter gathered data. The figure below shows the results of this assessment where the aggregated EV demand across these supply points is divided by the number of supply points. The impact of more economic overnight tariffs is clearly observed.

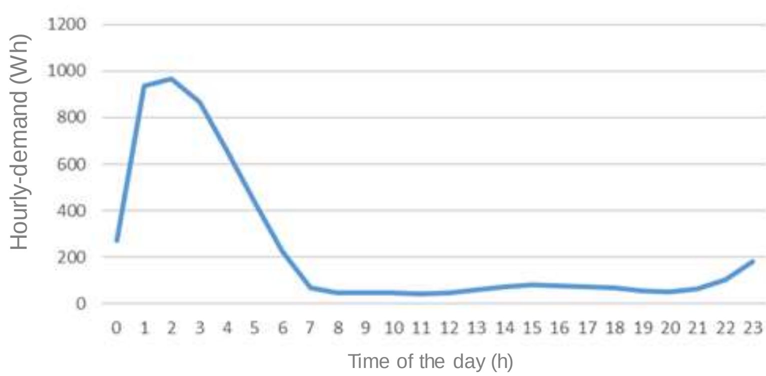

Figure 14bis: Average EV demand per EV-dedicated supply point.

[32] EA Technology, The University of Manchester, Western Power Distribution: My Electric Avenue: November 2015

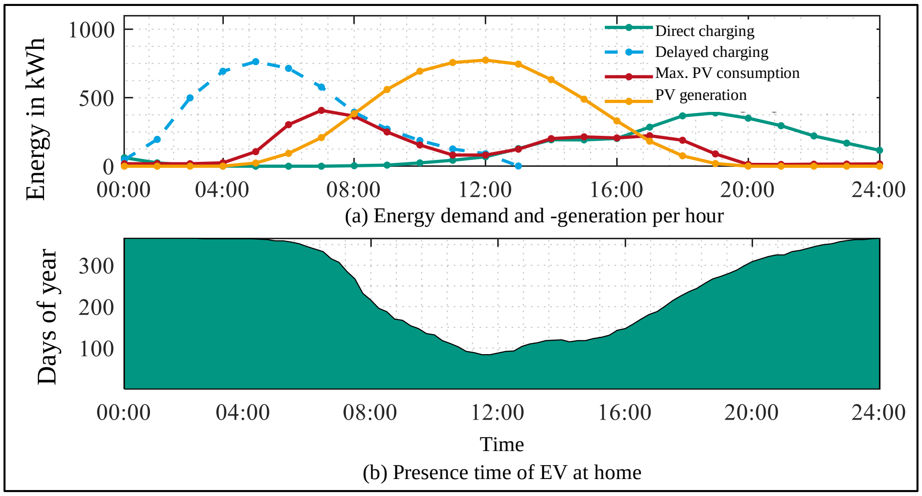

Figure 15: Load profiles (cumulated energy over one year) with different charging strategies (a) and presence time at home (b) [33]

Figure 15 indicates the potential of PV own consumption and the load shift potential for the use case of home charging[34]. The results come from a simulation model of a household with PV generation and an EV with 3,7 kW charging power. The EV charges about 52 % of the energy demand between 18:00 and 06:00 (green), whereas the PV-system produces only 2,3 % of the overall energy in the same period of time (yellow). The red curve shows the load profile with maximized PV own consumption. In this best-case optimization the autarchy rate increases from 15 % to 25 % and the self-consumption increases from 8 % to 13 %. It can clearly be seen, that neither the PV peak nor the EV peak can be compensated (without the use of a stationary battery storage). Otherwise user groups who can charge their EV during the day could increase own consumption significantly (Pensioners, parents in parental leave, employees in home office).

Beside the arrival time, also the charging power has impact on the overlapping of the load peaks of the EV and the conventional residential load (Figure 16). Increasing the charging power from 3.7 kW to 11 kW leads to a two times higher load peak on average, when charging habits do not differ except for the charging power. Increasing the power to 22 kW only leads to slightly higher load peak on average. Of course, for dimensioning the domestic junction box / fuses the installed charging power is the planning parameter. However, for dimensioning the grid infrastructure beyond the domestic junction box, power values in the range of 1-2 kW per household instead of 11 or 22 kW are sufficient. Nevertheless, the overall load peak per household increases from ~1 kW to over 3 kW. Chapter 6.4.2 will state on the peak values and simultaneity factors in detail.

[33] Uhrig, M., Aspekte zur Integration stationärer und mobiler Batteriespeicher in die Verteilnetze, Dissertation, 2017, Karlsruhe (Germany)

[34] the time between 24:00 and 06:00 is relatively short to guarantee a recharged battery but giving the fact that the average journey is short (see survey in Germany at the beginning of this chapter), there is plenty time to charge

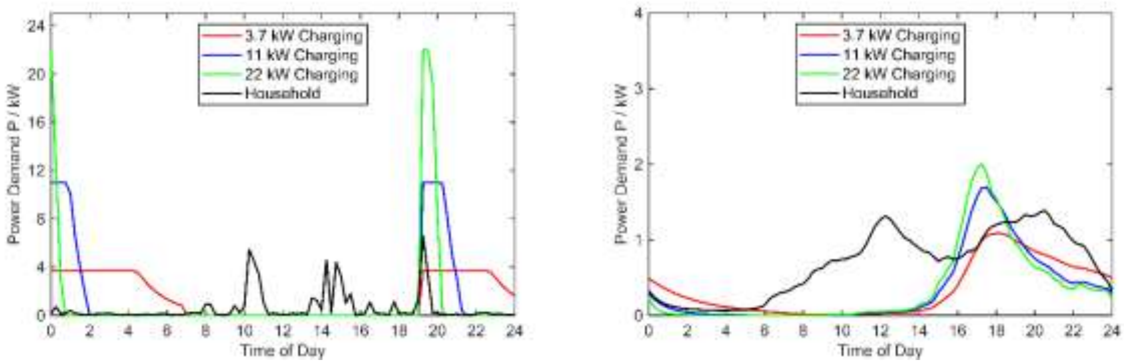

Figure 16: Impact of the charging power on the load peak[35] compared to the household load profile (real consumption left and secondary station level view on single household right)

Another important aspect and a big planning uncertainty are the charging habits of the EV owners. How frequently and where will they plug in and charge their EV? To give a first answer in this question Figure 17 shows the percentage of owners charging in different time intervals. The aforementioned peak in the evening is confirmed by the evaluation in Norway. Nevertheless, the fear that "every owner will charge the EV every day the same time" cannot be confirmed, although, theoretically speaking, a market-oriented charging model together with a high penetration of EVs can lead to a high simultaneity factor.

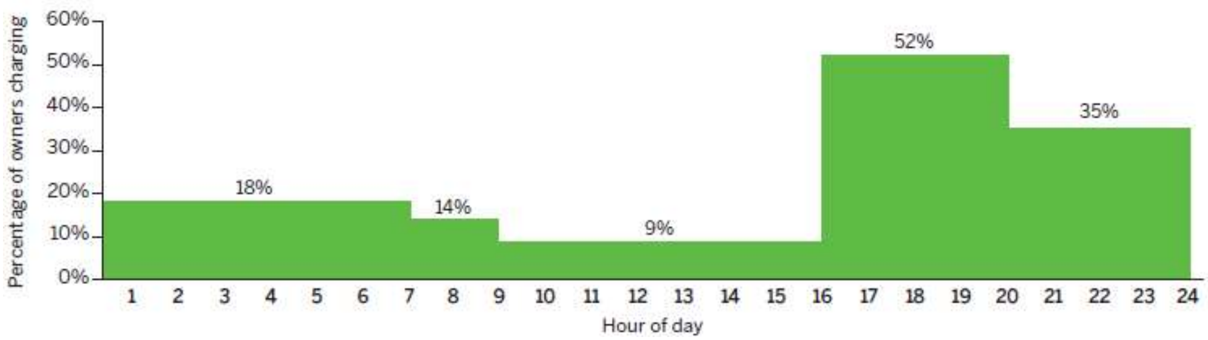

Figure 17: Home charging habits of EV owners in Norway [36]

5.3 Public charging

Especially in urban areas with high population density, there is a big demand for public charging infrastructure. The assessment of charging infrastructure usage in rural areas in Germany ("mayor charging station") confirm that there is hardly any demand. This might change with new business cases for mobility in rural areas, like car sharing in future. Nevertheless, main use cases for public charging are street charging in the city and fast charging especially on highways or service stations in the city.

[35] P. Wiest und D. R. K. Groß, „Probabilistische Verteilnetzplanung zur Analyse der Gleichzeitigkeit von Elektromobilität," in Zukünftige Stromnetze für erneuerbare Energien 2018, Berlin, 2018.
[36] Skotland C. H., Eggum E., Hva betyr elbiler for strømnettet? NVE Rapport nr. 74-2016. September 2016, Oslo (in Norwegian). It is to note that the sum is higher than 100% because some vehicle are charged at every stop at home

Figure 18 shows the power distribution of public charging powers. Charging powers of up to 22 kW sum up to 79 %. Those charging points are expected for street charging und usually can be integrated in the LV grid as long as their number stays relatively low (e.g. 2 or 3 per LV circuit).

Fast charging stations with charging power > 50 kW might in some cases be integrated in LV grids. But especially on roadhouses at highways in the past there was no demand to dimension grid infrastructure for high power peaks. Therefore, in most cases installation of fast charging infrastructure implies grid reinforcement in terms of installation of substations and/or additional line capacities. Nevertheless, the dimensioning issue is based on the power peaks of charging profiles.

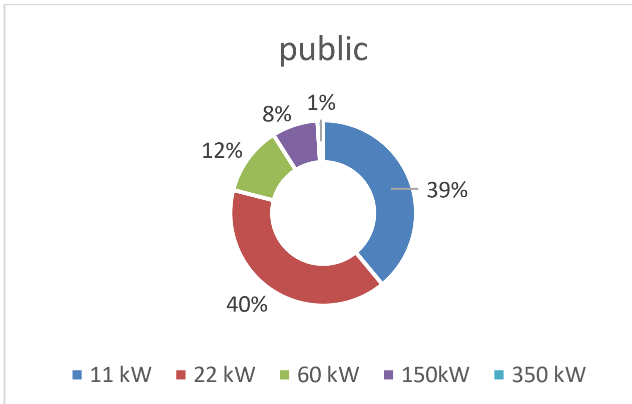

Figure 18: Expected *installed power distribution of public charging stations in 2030* [37] *and HEDNO Hellenic Electricity Distribution Network Operator S.A)*

5.3.1 Street

Cities worldwide were observing the EV run-up in the past years. In several planning issues, facts can more and more substitute estimations. E. g. the city of Hamburg has seen a significant increase in using public charging infrastructure in recent years. This is the result of the increasing number of electric vehicles on the streets. Both, the increasing number of electric vehicles and the more than 1000 public charging points in use, were a crucial reason for the resident distribution network operator and at the same time also the charge point operator of most of the public charging infrastructure to analyze the use of the public charging infrastructure. The evaluation is based on data from approx. 125,000 charging events at 872 charging points with a total charged energy of almost 1.4 GWh and a maximum power output of 746 kW in the period from December 2017 to November 2018. The charging points can be combined in 810 AC and 62 DC charging points. Almost every of the AC-charging points are with 22 kW charging power, only a few with 11 kW. The DC charging points enable a power output of 50 kW on the DC side and 11 kW power

[37] For example Maier U., Ropenus S., Jahn A., Jörling K., Knapp J., Nabe C., Steinbacher K., Tiedemann S., Greve M., Tretschock M., Kippelt S., Burges K., Verteilnetzausbau für die Energiewende Elektromobilität im Fokus, Navigant, RAP, Agora Energiewende, Agora Verkehrswende, August 2019, Berlin and Vennegeerts H., Tran J., Rudolph F., Pfeifer P., Metastudie Forschungsüberblick Netzintegration Elektromobilität, FGH e.V., Dezember 2018, Aachen

output on the AC side. The installed charging infrastructure power sums up to almost 21 MW[38] . So, the maximum power can be interpreted as a simultaneity factor of about 0.04. To get a first understanding on in which season and day of time load peaks might occur, Figure 19 shows the development of the number of charging events in this period by month and Figure 20 the cumulated charging events broken down to the time of a day. Additionally **Error! Reference source not found.**Figure 21 shows the number of charging processes per charging station.

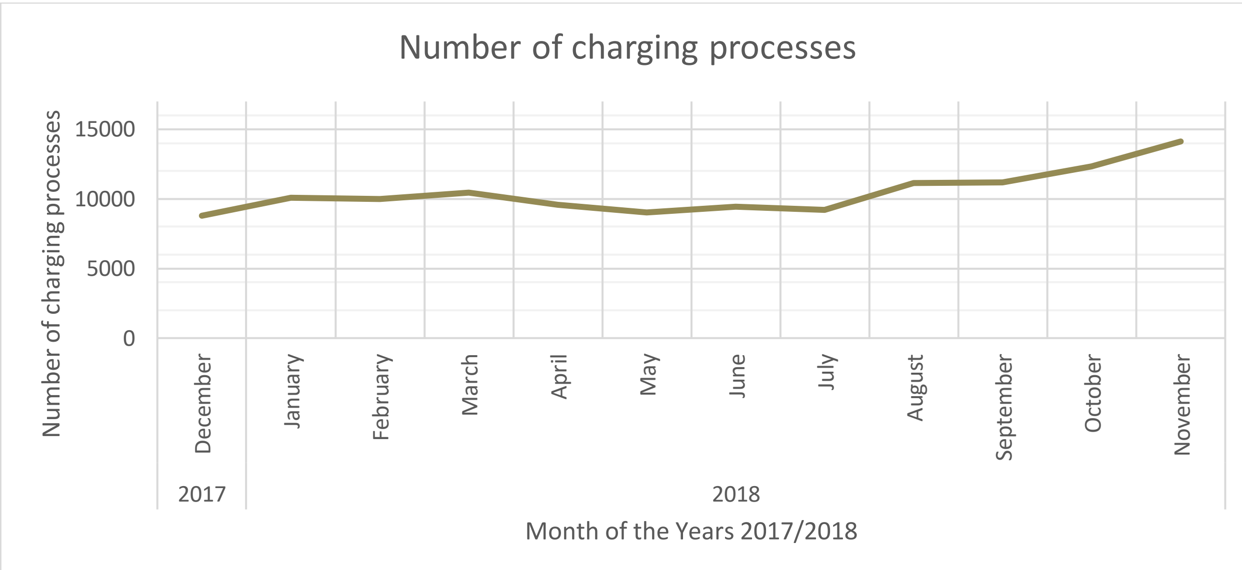

Figure 19: Number or charging processes in the period Dec. 17 - Nov. 18

[38] Roughly 22kW*810+62*50kW, and Greece, FGH Report, 2019-0541-FGH, October 2019

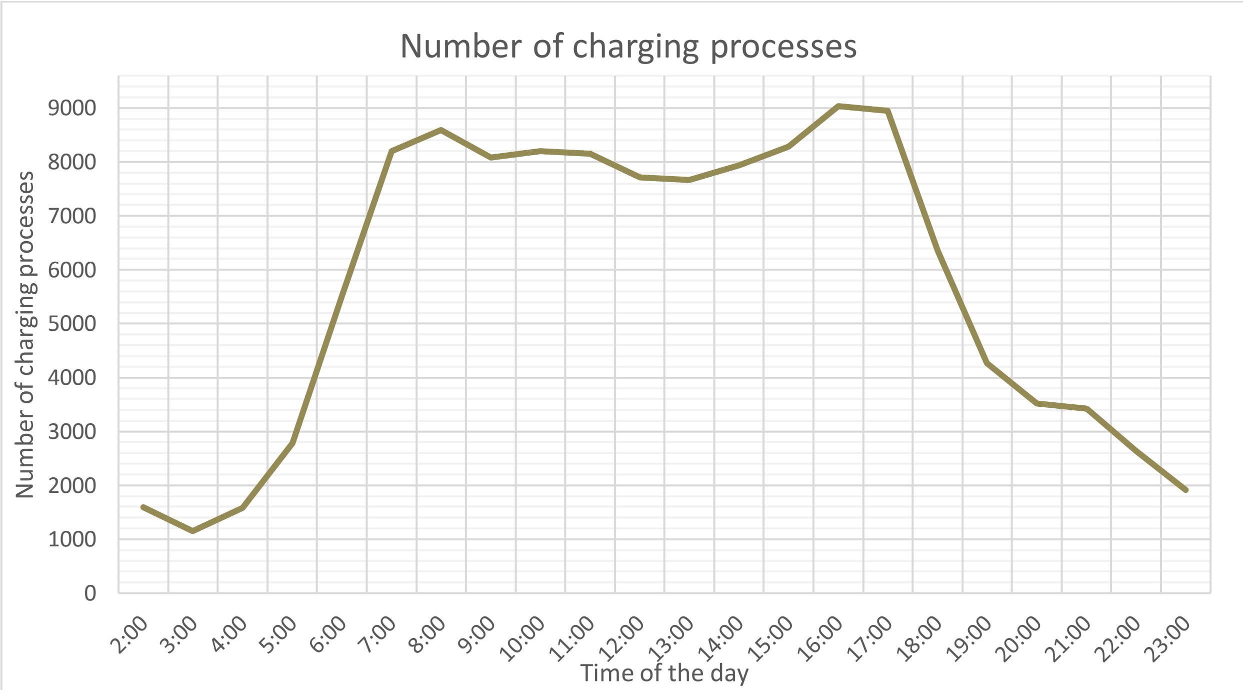

Figure 20: Number of charging processes in the period of Dec. 17 to Nov. 18 broken down on the time of a day[39]

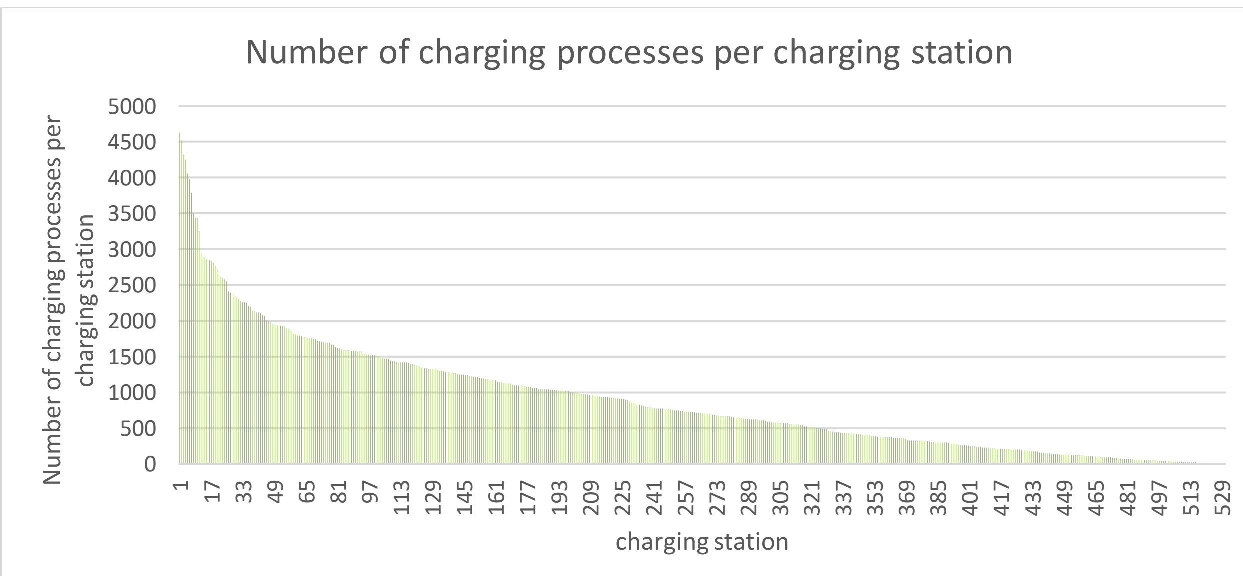

Figure 21: Number of charging processes per charging station

[39] profile also similar in T. Wieland: Eine neuartige probabilistische Methode zur Betriebsmitteldimensionierung in aktiven urbanen Niederspannungsnetzen, Dissertation, TU Graz, 2017

Based on the clustering of the charging events using the connection time and the available total charged energy per charging event (see methodology in technical appendix 2), an evaluation of the cumulative average power demand for one day is also possible. This is shown in Figure 22

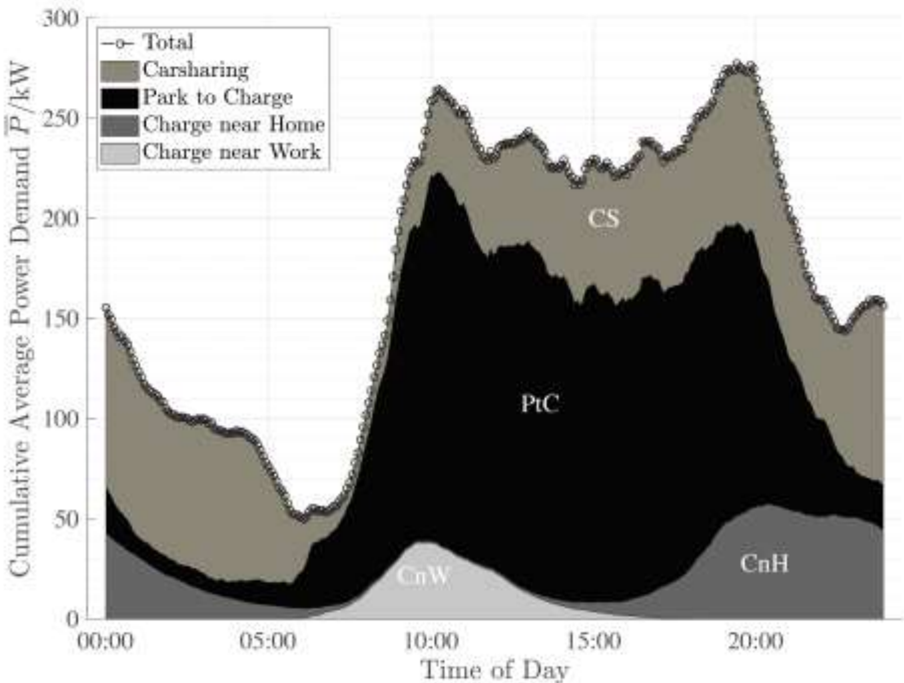

Figure 22: Average load profile grouped by classification of charging events

The rising number of EVs caused an increasing number of charging points and a rising power consumption. The rising power consumption needs to be considered in network planning by the DSO. For instance, the increasing use of public charging infrastructure In Hamburg (Germany) is shown in Figure 23

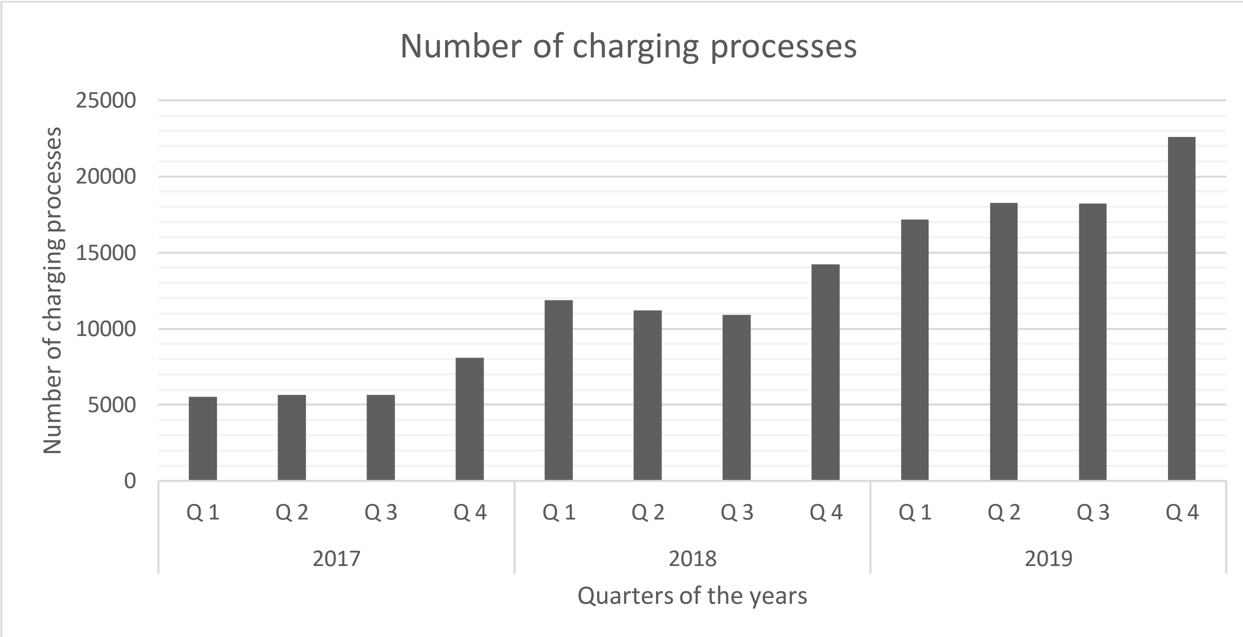

Figure 23: number of charging events in the period of Q1 17 to Q4 19

5.3.2 Highways

Although most charging events are taking place at home or at work, 40 % of the annual distance is driven on trips > 50 km; and 25 % on trips > 100 km. This indicates, that there is a demand of charging infrastructure nationwide to allow drivers to travel beyond the range of their vehicles. Of course, this fast charging infrastructures needs to be placed in corridors around highways.

Figure 24: Existing EU fast Charging Network (c) Transport-environment.org (2018)

At the end of 2019, in Europe, a total number of around 8074 CCS (Mode 4) charging points were installed. These stations (with an average of 2 CCS chargers) are placed every 60 km on EU motorways on an average (spread across about 76,500 km)[40]. Such chargers are mostly rated at ~50kW, enabling a full charge of a standard vehicle in approximately one hour. Ultra-fast charging facility aims to replenish for up to 400 km of range in only 15 minutes. The ultra-fast charging network is currently being developed and is considered essential for time efficient en-route charging along the main large capacity corridors. There are several initiatives such as "The Electric Circuit", an initiative of Hydro-Québec, or FastCharge Project, Ionity, Ultra-e, and Mega-e in the European Union. In these initiatives, high-speed charging stations (DCUFC) with capacities ranging from 150 kW to 350 kW are often considered (mode 4).

From Distribution Grid Planning point of view the density of fast charging infrastructure is an important aspect. Especially in regions with high renewable energy sources penetration, energy demand and generation might compensate, which lead to a reduction of power peaks. From grid planning prospective it is necessary to dimension the electric components (transformers, cables and overhead lines) to the maximum demand. Decentralized generation units e.g. PV units can decrease the power peaks from the demand, but the electric grid must fulfil its job also when there is no infeed from decentral generation units during the whole year. Nevertheless, highway service areas usually do not have high power demand and therefore can have a weak grid connection point in low voltage grid tails. Therefore, the connection of the fast charging infrastructure is exclusively on the MV network.

As illustration of these fast charging infrastructures, we take the example of TEN-T that supported Electric Vehicle infrastructure projects: 9 projects, representing more than 1.000 fast charging stations and 36 projects (2014-2016).

In Slovenia, the TEN-T call for The Central European Green Corridors Consortium- CEGC has well-deserved for setting up 26 fast charging stations for electric vehicles, in 2015. The owner of these stations is the DSO, the company SODO, d.o.o., who together with Ministry of Infrastructure of the Republic of Slovenia implemented the project. In accordance with the Energy Act, SODO is responsible for developing the basic public infrastructure for fast charging stations for electric vehicles on the motorways across the Republic of Slovenia. Based on this experience, the figure 24 present the repartition of the charging activities in these fast charging facilities.

[40] CCS Charge Map Europe, January 2020, CCS Charging Map – CharIN and Gnann, T. et al., The load shift potential of plug-in electric vehicles with different amounts of charging infrastructure, Journal of Power Sources 2018

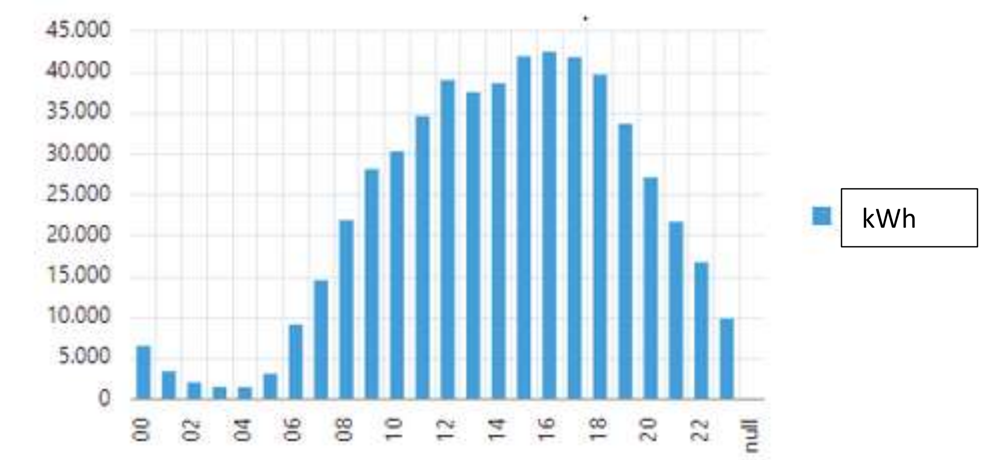

Figure 25 consumption of energy on a daily level in Slovenia

The following Figure 26 shows an example of a load profile of a public charging station (fast charging) near the highway for one week (Monday to Sunday) in a time step resolution of 15 minutes. Each electric charging station has a connection power >100 kVA.

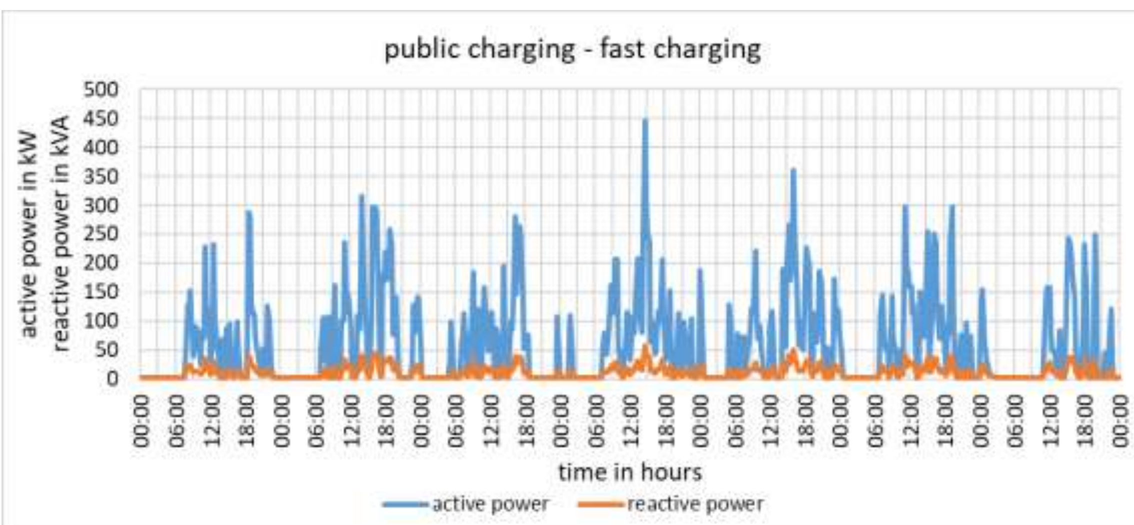

Figure 26: Example of a load profile of a public fast charging station (Monday to Sunday)[41]

[41] T. Wieland: „Praxisbeispiele Elektromobilität – reale Umsetzungen, E-Mobilitätstage, Österreichs Energie, 2019

As it can be seen in Figure 26 this charging station has a power factor λ = 0.99 and needs reactive power for their power electronics. A in depth analysis of the load profiles for each day of one year, depicted in Figure 266, shows that the maximum peaks occur in the morning until the late evening. In comparison, a lower peak load is reached in the hours after midnight (> 00:00) until the morning.

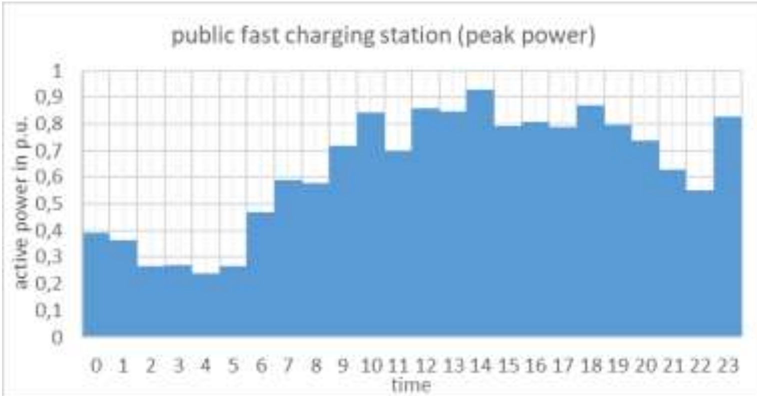

Figure 27: Illustration of the maximum load (active power) for each hour for a public fast charging station during one year[40]

For a future orientated grid planning in the medium voltage network the installed charging power for one public charging stations with a dedicated MV/LV transformer station a diversity factor of one (g=1) has to be considered.

Based on measurements done on a fast charging station in Prague, it can be seen that the charging power may fluctuate rapidly.

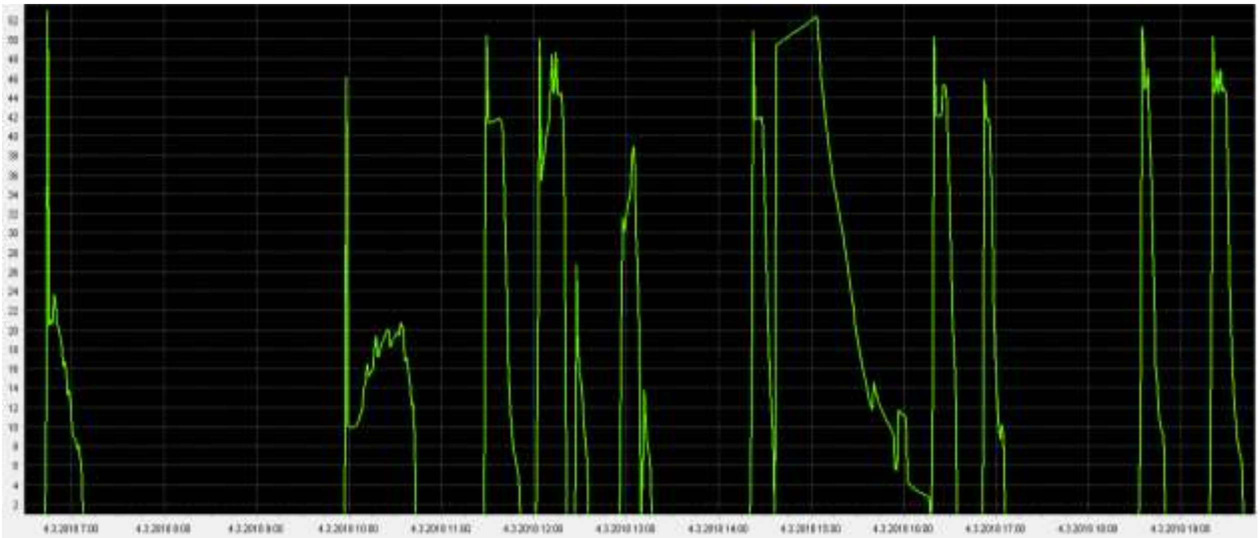

Figure 28: Measurements of fast charging station in Prague (2018)

On the next figure the individual charging profile (as explained in section 5.2 General Overview Table 4, constant current followed by constant voltage charging phase) can be clearly observable.

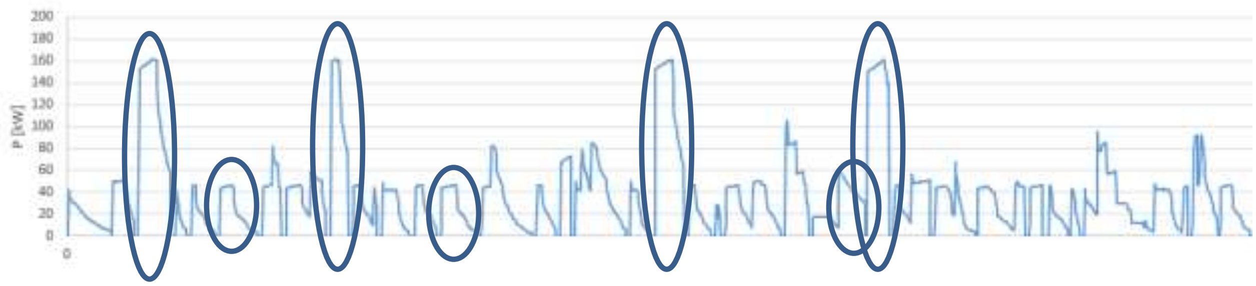

Figure 29: Measurements of fast charging station in Prague (focus on some day) (2018)

5.4 Employer charging

Various studies[42] ,show that there is an increasing need for EV users to be able to charge at work. Due to the almost simultaneous arrival of the employers at work, a peak is generated in the morning hours. The clustered charging profile is shown in Figure 30**Error! Reference source not found.**.

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[42] E.g. https://www.enedis.fr/sites/default/files/Report_on_the_integration_of_electric_mobility.pdf and A. Bouallaga, B. Doumbia, «Stochastic Electric Vehicle Load Modeling for HV/MV Substation Constraint Assessment,» CIRED - *25th International Conference on Electricity Distribution*, Madrid, 2019.

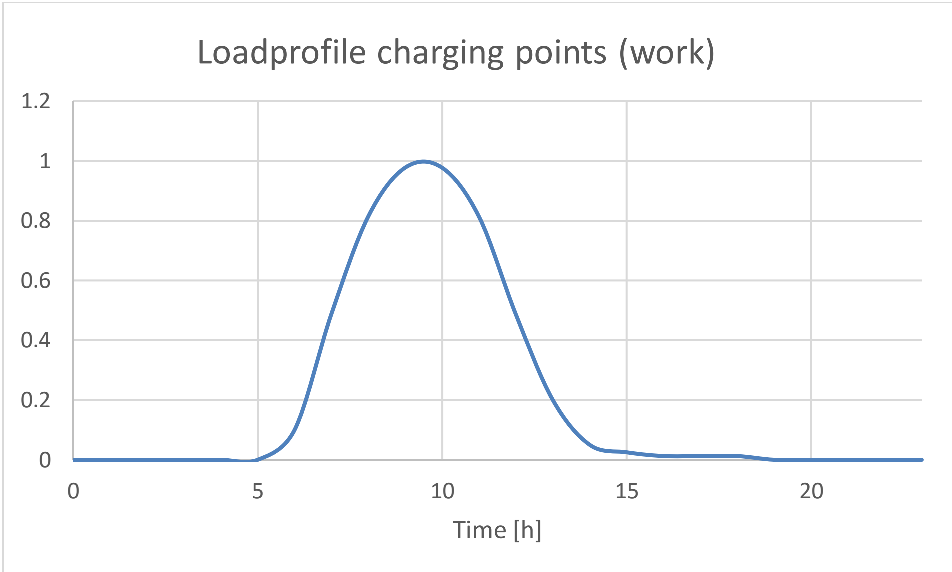

Figure 30: Load profile of charging points (work) (Hellenic Electricity Distribution Network Operator S.A)[43]

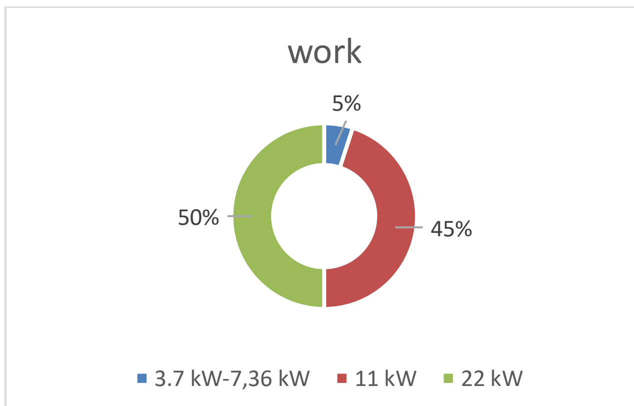

Figure 31: Expected share of charging power for charging at work (Hellenic Electricity Distribution Network Operator S.A)

[43] The Y axis is a normalized values (1 = peak). This chart is an image of the probability to encounter the peak.

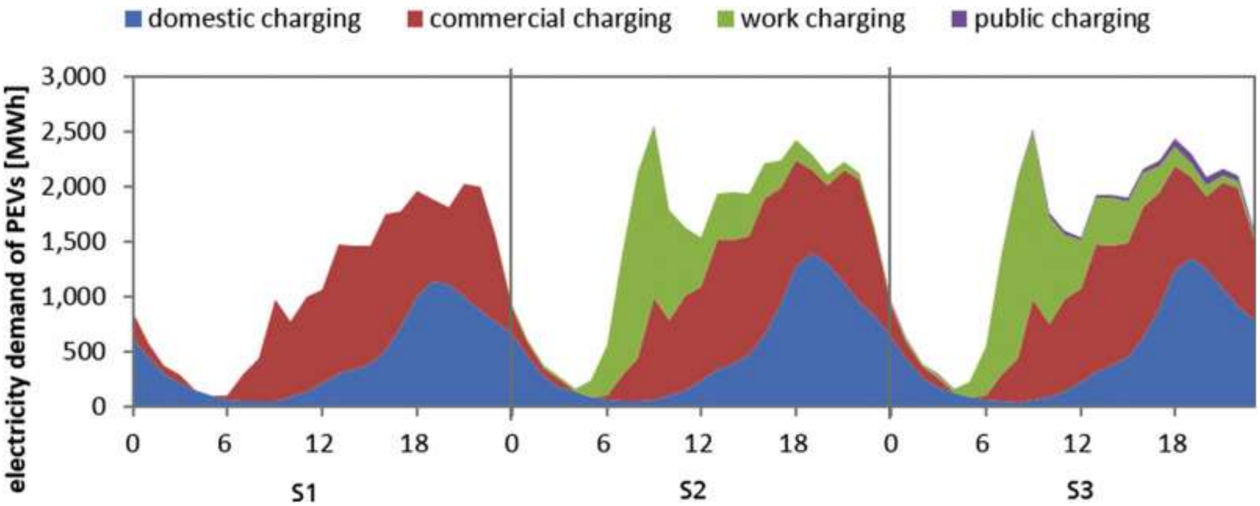

Figure 32: Simulated scenario dependent electricity demand of PEVs without DR on a Tuesday[44]

5.5 Opportunity charging

By opportunity charging is meant the case, when charging the electric car is not the purpose of a visit of charging station, but only an alternative, which is used as a benefit of parking in the destination. While fast charging stations usually assume a similar use to a filling station for conventional fuels, charging stations with an installed power of 11 kW and up to 22 kW usually have longer charging durations. Some publications[30] show that Public parking is used slightly over 15 % of the whole day and they assume a correlation between the use of public charging stations and the use of public parking spaces. Therefore, a cumulative charging profile for public charging stations up to 22 kW as shown in Figure 33 is used in the following analysis.

[44] Schaeuble J., Kaschub T., Ensslen A., Jochem P., Fichtner W., Generating electric vehicle load profiles from empirical data of three EV fleets in Southwest Germany, Journal of Cleaner Production, May 2017

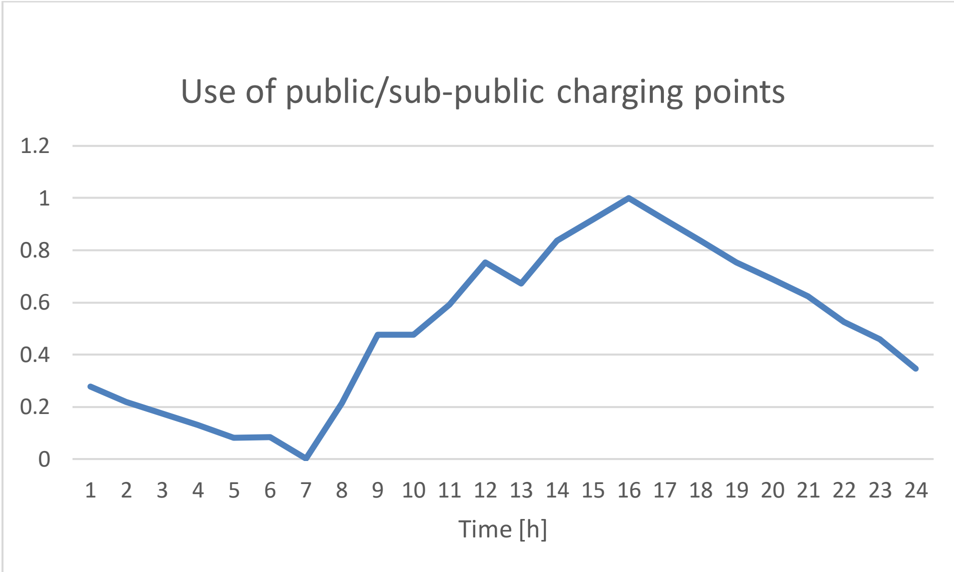

Figure 33: Charging profile for public/sub-public charging stations up to 22 kW[45] (Hellenic Electricity Distribution Network Operator S.A)

Sub-public charging points are only accessible at certain times for the public or only for a specific group of customers. Examples of sub-public charging stations are parking places at shops, shopping malls, restaurants or parking garages. In the context of this study, the same cumulative charging behavior as for public charging stations is assumed for sub-public charging stations.

Regarding the individual charging point, the expected installed power is depicted on Figure 34.

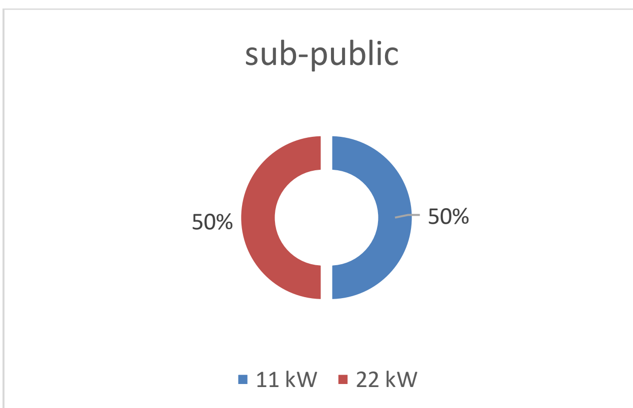

Figure 34: Expected share of type of charging power of sub-public charging stations (Hellenic Electricity Distribution Network Operator S.A)

In the next section, different use cases of public charging will be addressed.

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[45] The Y axis is a normalized values (1 = peak). This chart is an image of the probability to encounter the peak. Source Support for the integration of electric vehicle charging stations into the distribution network in Greece, FGH Report, 2019-0541-FGH, October 2019

5.5.1 Commercial area / Mall

Commercial areas and malls offer the possibility of charging to its customers as a benefit to attract them. Most of the charging stations in commercial areas are mode 3 and 4. Charging power is usually between 11 and 22 kW (and in some cases 50 kW), usually AC with the DC for higher capacity. It should be also noted, that bigger commercial areas are usually supplied from medium voltage grid. Thus, the connection point of the charging station is usually in the installation of the customer. This also allows to use available load management systems to diminish the impact on the peak demand. Location of the commercial area/mall and its opening hours has a significant influence on the charging. It should be also considered, that parking lots of shopping areas may be used by local residents, if they are located reasonably close to their homes. Another important factor is the tariff of charging.

Following figures are based on the data from the Czech Republic. Data were gathered from 54 charging points located at parking lots of malls from the period of January to June 2019.

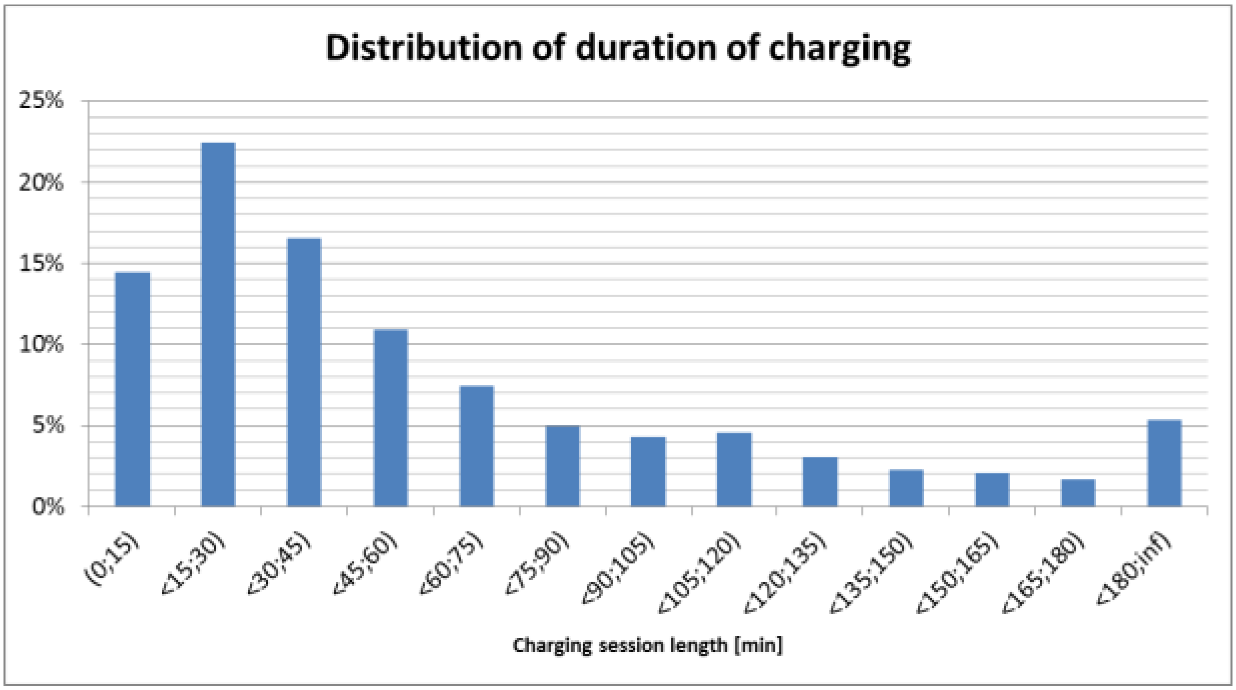

Figure 35 Plug time distribution of charging at malls (Prague, 1H 2019)

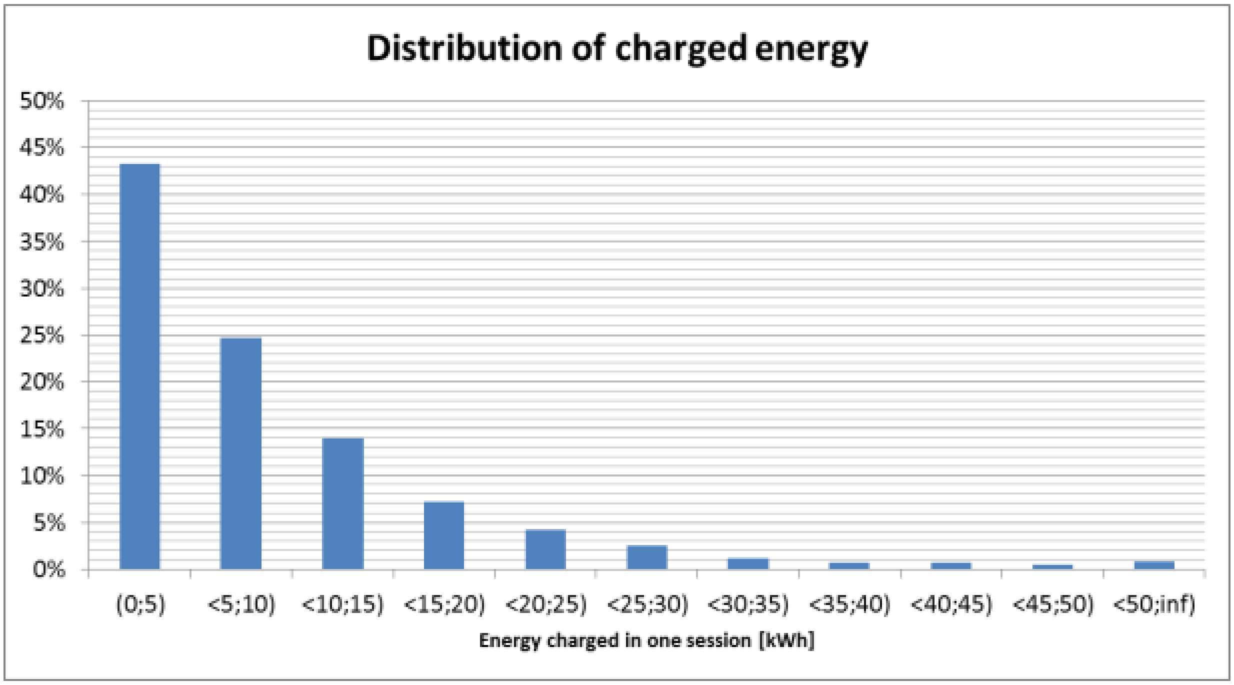

Figure 36 Distribution of charged energy (Prague, 1H 2019)

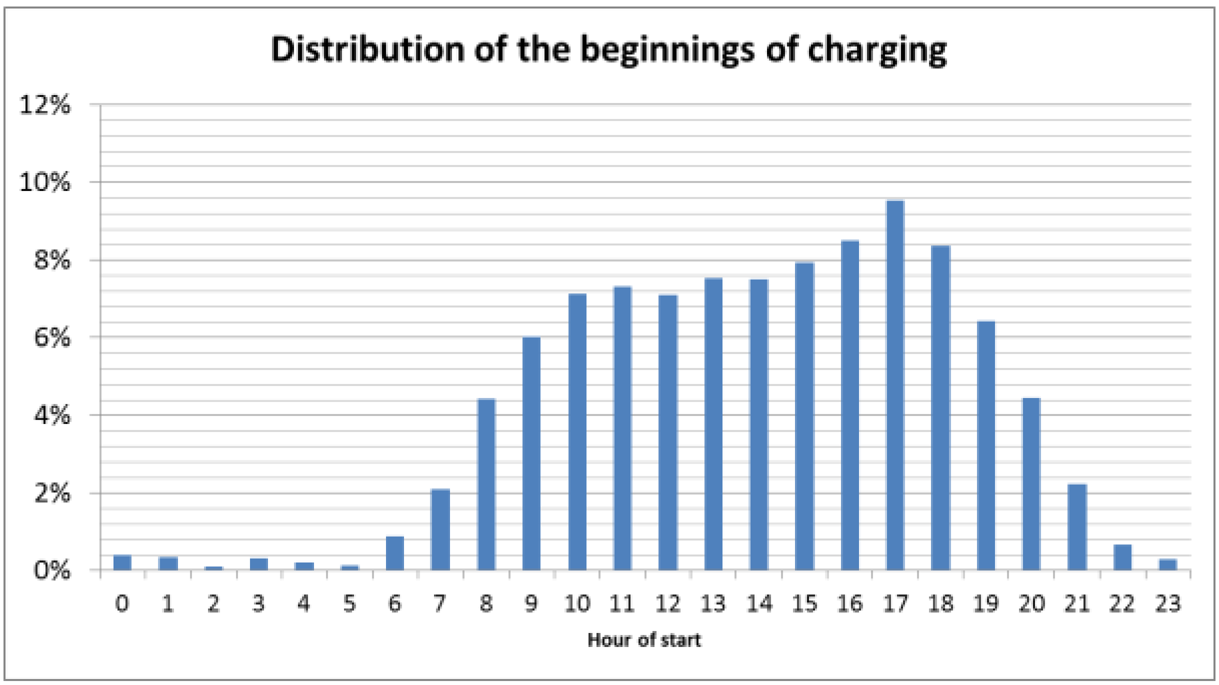

Figure 37 Distribution of the beginnings of charging (Prague, 1H 2019)

Based on these data it is possible to compute a simultaneity factor as shown in Figure 38.

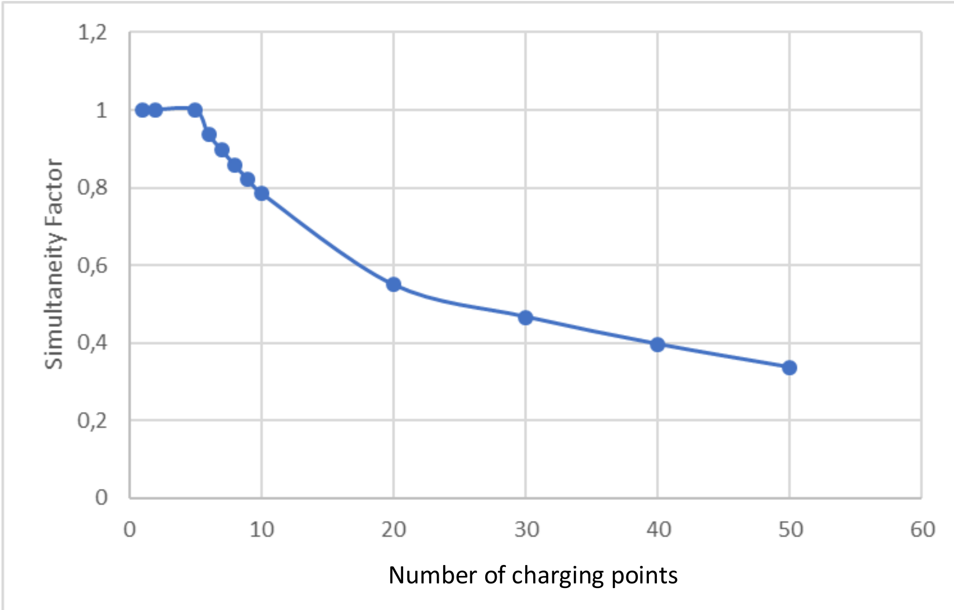

Figure 38 Simultaneity factor based on the week profiles

5.5.2 Car parks

There are three crucial phases of the parking policy development in Europe. The first phase is characterized by a parking lot[46] in a form that is most often available today. Trivially, the parking lot is equipped with parking spots, which have the sole purpose of providing the parking service for a certain price per hour. Historically speaking, those parking spots have been most often occupied by internal combustion vehicles (ICVs).

In the second phase, the parking lot, now called the EVenabled Parking lot (EVPL), introduces parking spots with installed chargers, i.e., EV spots. Such parking spots are transformed from non-EV spots by investments in charging infrastructure. As such, EV spots are used to offer the charging service for a certain premium price per hour where an EV can be charged. It is obvious that the DEFAULT policy is no longer appropriate since, for example, EVs should have the highest priority for parking in EV spots. This leads to the conclusion that new parking policies need to be developed.

Finally, the third phase marks the successful transition of the EVPL into the smart EV-enabled parking lot (S-EVPL). The emphasis in this phase is placed on the smart management of parking spots thanks to the introduction of advanced IT infrastructure.

As mentioned for the commercial mall, the connection point of the parking lot is generally in the MV network. Therefore, EV smart charging management can also be used to reduce the impact on the peak.

It is to note that, nowadays, the hereabove mentioned third phase of parking lots is not enough deployed to have measurements and/or conclusion.

The next figure represents the parking profiles (arrival and departure times) of a typical phase 2 park lot. The energy demand and charging profiles are simulated. Resolution of simulation is 1 Min. The threshold (charging event) was given by the carpark operator. The figure shows that in times of high parking volume also load peaks of charging EVs might occur. Further the potential of smart charging for the integration of a higher number of EVs can be derived. In this case smart charging enables to increase the number of charging vehicles by factor 3 in compliance with the power limitation of the car park.

[46] See also Babic, J., Carvalho, A., Ketter, W., & Podobnik, V. (2017). Evaluating policies for parking lots handling electric vehicles. *IEEE access*, *6*, 944-961.

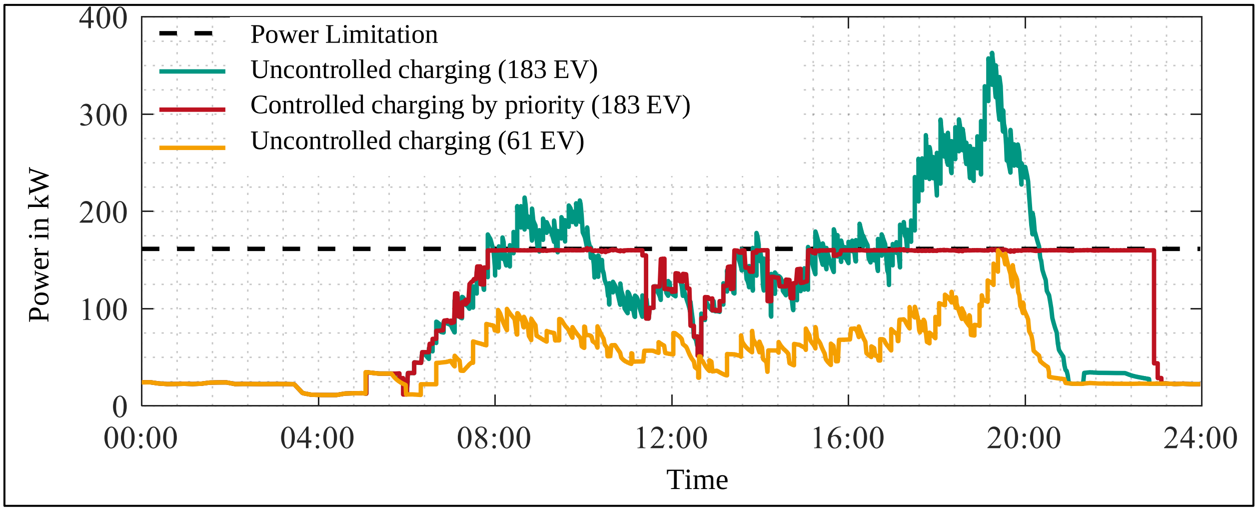

Figure 39: Overall charging profile of car park in inner city (Simulation)[47]

5.6 Specific use cases

5.6.1 Batteries swapping charging facilities

Obviously, a single EV bike or scooter battery is not enough energy nor power to be considered in the planning stage. Nevertheless, recent development (e.g. Yamaha and Taiwanese scooter company Gogoro Global) indicates that battery swap station could have enough capacity to be considered as a specific connection. There is until now too few technical data to evaluate this opportunity.

[47] The parking profiles (arrival and departure times) are real data. The energy demand and charging profiles are simulated. Resolution of simulation is 1 Min. The threshold was given by the carpark operator. Uhrig, M., Aspekte zur Integration stationärer und mobiler Batteriespeicher in die Verteilnetze, Dissertation, 2017, Karlsruhe (Germany)

Figure 40: Example of Battery Swapping station for motorcycle in Thailand

EV batteries have complex cooling systems, are large, heavy, and operate at dangerously high voltages. The battery swap operation requires an automated platform that not only replaces the power source but also takes into account the cooling system.

For example, NIO, a Chinese manufacturer of electric vehicles, completed its 500,000th battery exchange in 2020.

We can summarize the procedure as follows: A worker places the car on a specific location, the battery support bolts are unscrewed, the battery is removed, a new one is placed in the vehicle and everything is reassembled using laser guided tools.

Regarding connection to grid, these swapping stations can be considered as a static storage devices that could be used for different ancillaries' services.

5.6.2 Public Buses

5.6.2.1 Typical individual load profile

Of course, loading operations at bus stops are directly linked to their timetables. An exchange of information on these timetables between public transport companies and DSOs can be extremely useful for network planning. Regarding the load at the depot, the entry and exit times can also be useful information. In any case, the number of buses which are present simultaneously in the depot allows the DSO to have a very good approximation of the type of profile with which the network will be confronted.

The two figures bellow show the typical load profile of the bus station and a bus pantograph.

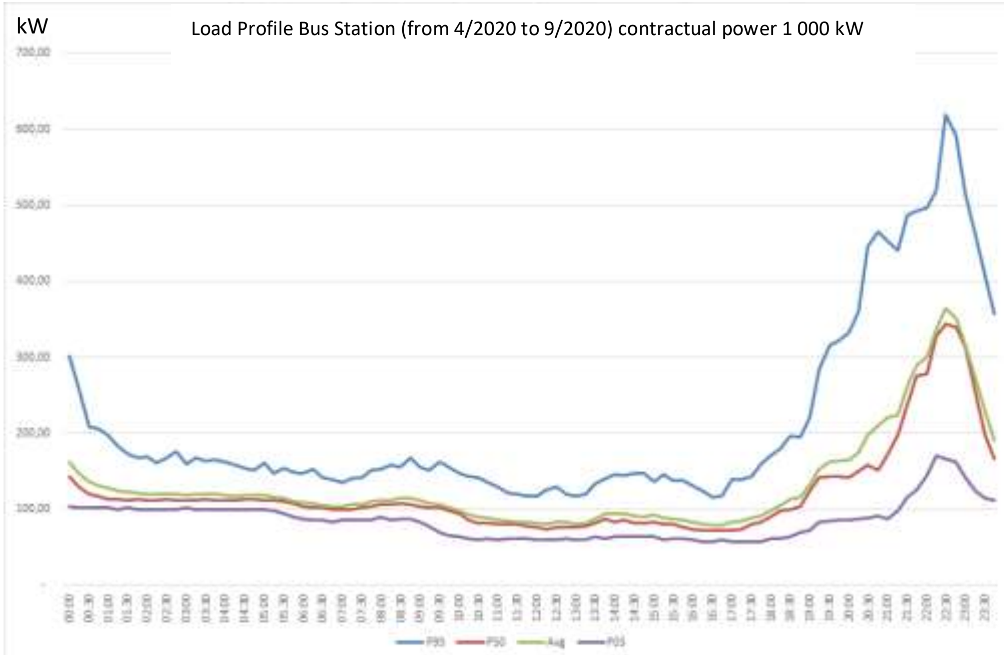

Figure 41 Load profile Bus station

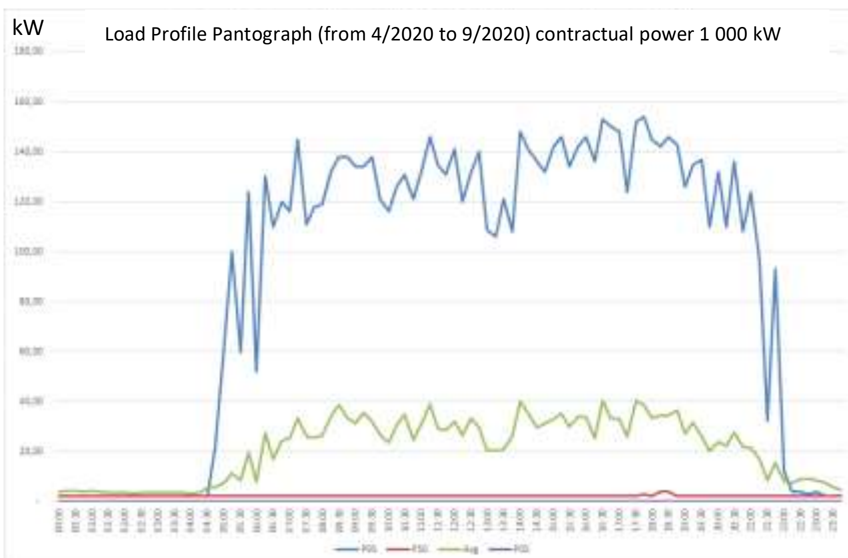

Figure 42: Load profile pantograph

6 Perspective for the network planner

In this chapter, we will firstly introduce the issue that network planners have to take into account. Then, in order to give them tools to assess the different issues, for each planning level, we will propose which use cases (from the previous chapter) need to be integrated in their studies (with a scale that represents the importance of the use case (from "+" low importance to "+++" very important) and some best practices.

An essential part of the planning process for electrical grids is the dimensioning of electrical components like transformers, cables and overhead lines. The dimensioning of this electrical equipment is based on the concurrent maximal power consumption for each usage like residential households, agriculture, office, small-scaled industry and industry. Due to the fact that electrical components of LV grids like transformers, cable and overhead lines do have a lifetime span of more than several decades. Therefore, it is very important to assess the actual maximum power consumption as well as to estimate the maximum power consumption in the next 10 years, under huge uncertainties. It will be mentioned that the digging work for cables is an important cost driver. In urban regions the digging costs are much higher than the costs in rural areas due to the nature of the soil.

The conventional approach to dimension electrical equipment is to use a nominal power together with a simultaneity factor for each usage. This simultaneity factors are normally based on real measurements as well as on longstanding experience values from grid planners.

The simultaneity factor regarding home charging for EVs can be determined probabilistically based on e.g. on statistical arrival data. Actually, here are a lot of uncertainties like the real charging behavior of EV users (everyday charging, energy consumption, charging at home/at work/at public, future energy tariffs, …) which strongly affects the simultaneity factor.

A big uncertainty for the DSOs in the future is the coordinated, automatic start of the charging processes, which can be triggered by a market signal. This would lead to a very high simultaneity factor in the low voltage grid. The simultaneous power consumption in a low voltage grid at peak times can lead to overloading of the electrical components and can affect the voltage level in the LV grid as well.

As the electrification of both transport and heat accelerate, the planner will need to asses the combined impact of EV and heat pumps on the distribution network. In this sense two reference studies have been identified:

1) Slovenia

A study carried out by the national Electric Power Systems Institute in Slovenia[48] (2018) tried to identify the influence of the heating pumps and EV recharging, on the LV level. If the grid will not be rebuilt (reinforced) or enhanced with new connections and larger cables. It considers the usage of heat pumps during the winter (at least 6 months usage), smart houses, high energy efficiency apartments' blocks,

[48] Author: Leon Valenčič, MSc, EIMV, 2018, www.eimv.si

(home) e-recharging of passenger cars and all other EVs, incentives for the implementation of more and more RES- e.g. local micro PV. The main issues: how to plan the LV to fit the new requirements. The study has shown the influence of mass electrification of personal transport and heating on the development of the distribution network. Because distribution network was not built for such purposes, a rapid re-electrification should start immediately due to the high load increase expected. Firstly, most of the LV network should be re-built, which would be followed by an intensive construction of a stronger MV network, the transformation of 110/20 kV and the 110 kV power supply network. Investments in the distribution network should be at least doubled in order to be able to comply with the requirements of modern energy policy with the network.

2) Spain

In Spain i-DE has carried out an analysis of the LV network and MV/LV transformers combining the effects of EV and heat pump clustering based on socio-demographic data, network and smart metering data into a power flow simulation model. The analysis enabled identification of relevant network constraints. It has been identified that in the medium term approximately 2% of the secondary transformers and 1% of the LV network will require reinforcement.

6.1 Issues to take into account

6.1.1 Thermal effect

Simple computation can demonstrate that there is a low probability that the thermal limit of the cables will be reached.

The most common types of cables used as LV feeders have a section of 150 mm² or 240 mm² aluminum and 95 mm² aluminum for overhead lines. The cable with a section of 150 mm² has a thermal capacity of 300 A (255 A if using underground pipes) and with a section of 240 mm² the thermal capacity is 363 A (308 A using underground pipes) respectively. Protection elements like NH-fuses for low voltage feeders - located at the secondary substation (MV/LV) or at public distribution panels - are used as an overload and short circuit protection for the electrical equipment like underground cables and overhead lines. Being the single point of contact between the LV and the MV grid, the MV/LV transformer can become a bottleneck as well. Depending on its existing preloading the risk of congestion or thermal overload at the coupling point might increase with an increasing share of EVs.

6.1.2 Voltage issue

With a high penetration of EVs and the charging of these electric vehicles in a LV grid for several hours a day substantially increases the risk of under-voltage situations, given the increase in network demand levels. Additionally, the introduction of self-consumption installations adds an additional degree of complexity as they introduce a risk for over-voltage during the central hours of the day. Voltage wise networks are expected to experience an unprecedented range of voltage variations.

An increase on concurrent charging process of EVs might also affect the voltage level at medium voltage grids. Especially when the automatic start of this charging process is triggered by a market signal, this can lead to a very high simultaneity factor. Due to the lack of measurements available for now, the real impact can only be estimated. Based on the estimations available, it would make sense to analyze existing substation and grid coupling points in regard to their range until they violate the EN 50160 criterion. Furthermore, to address possible violations, (automatic) tap changing transformers might be considered as a short term alternative to conventional grid extensions to resolve voltage band issues

6.1.3 Power Quality issue

The EU directive 85/374 concerning the standardization of the product liability laws in the European Union declared electricity as a product. The European Standard EN 50160 contains the limit values of the different power quality parameters. As a result, at each point of common coupling (between DSO and costumer) the power quality of supply corresponds – under normal operating conditions – to the power quality regarding in EN 50160.

The following situations during the charging process of the EVs can affect the power quality in the LV grid:

- Inrush currents at the beginning of the charging process (relative voltage drop < 4 % according to EN 61000-3-3 at a reference impedance (IEC 60725))
- Harmonics (≤ 2 kHz) from the AC/DC-Converter (exceeding the harmonic limit values according to EN 61000-3-2 or EN 61000-3-11)
- Unbalance (electrical charging infrastructure does not prevent single-phase charging with a current of e.g. 32 A (7,4 kW))
- Reactive power consumption (under excited operation mode) and reactive power injection (over excited operation mode) that violates the allowed rated voltage
- Higher harmonics (>2 kHz, limits regarding IEC 61815-21-2); Actual measurements show that during the charging processes partially grid perturbation in the range of 30 kHz to 60 kHz can occur.

In the future at high penetration of decentralized generation units together with the charging infrastructure of electric vehicles this can lead to inferences at higher current harmonics (>2 kHz). The high harmonic current between EVs during the charging process as well as between decentralized generation units and electric vehicles can lead to interferences, thermal stress (faster component aging), malfunctions etc. Practical measurements[49] in a LV grid performed during the charging process of two identical EVs showed the fundamental current superimposed with a high harmonic current shown in Figure 43.

[49] TU Dresden Auswirkungen einer zunehmenden Durchdringung von Elektrofahrzeugen auf die Elektroenergiequalität in öffentlichen Niederspannungsnetzen. Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit. 2017

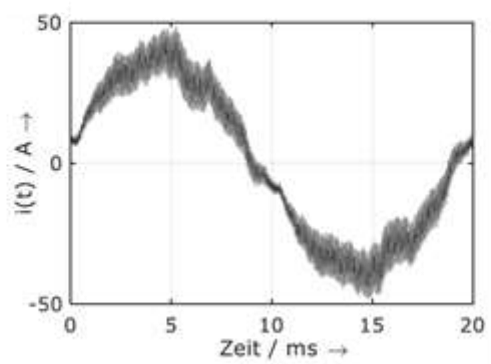

Figure 43: Fundamental current superimposed with the high harmonic current while the charging process of two EVs [50]

This high harmonic current may occur because of small switching frequency differences by the result of small component differences between the EV chargers. Similar effects have been observed with PV inverters.

The following Figure 44 depicts the high harmonic currents (@10 kHz) for a different number of charged EVs.

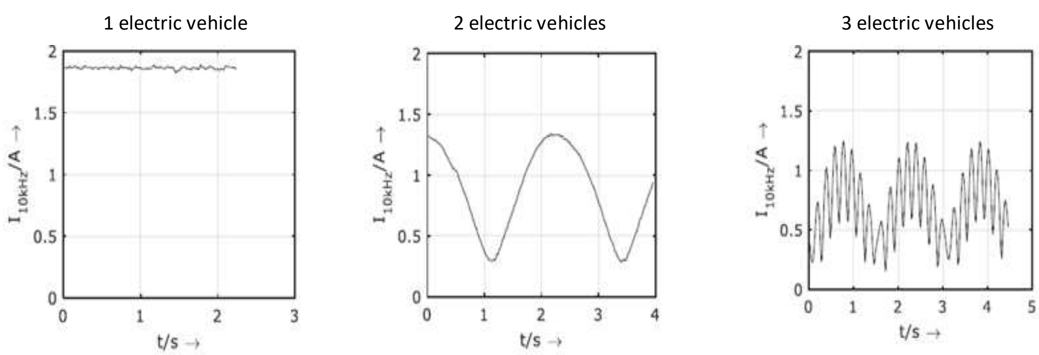

Figure 44: High harmonic current (10 kHz) between a different numbers of EVs [51]

Another aspect, which has to be investigated in detail is, if the charging process of the electric vehicle can affect the smart-meter-data communication between the data concentrator (location secondary substation) and the smart meter (customer side). When the smart-meter-data communication standard the Cenelec-A Band (9 - 95 kHz) or the standard G3-PLC (FCC-1 (150 - 500 kHz) is used.

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[50] A. M. Blanco: "Einfluss von Elektromobilität und Photovoltaik auf die Strom- und Spannungsqualität in Niederspannungsnetzen - Ergebnisse aus verschiedenen Pilotprojekten in Deutschland und Österreich", TU Dresden, 2018

[51] A. M. Blanco: "Einfluss von Elektromobilität und Photovoltaik auf die Strom- und Spannungsqualität in Niederspannungsnetzen - Ergebnisse aus verschiedenen Pilotprojekten in Deutschland und Österreich", TU Dresden, 2018

With the following measures, it is possible to integrate more EV charging infrastructure into the LV grid and to keep the power quality parameters regarding EN 50160 within the limits:

a) Public low voltage grid (DSO):
  - Force symmetrical 3-phase charging even with low charging power
  - Limitation of the maximum 1-phase current (e.g. maximum current 16 A, 3,6 kW)
  - Symmetrical and cyclical distribution of EV with single phase chargers
  - Possible external conductor assignment at the beginning for single phase EV chargers (improvement of quality parameters in the electrical LV grid)

From the DSO point of view, symmetrical charging of the EV reduces the power quality influences on other customers and avoids unnecessary grid measures to fulfil power quality limits. Another point to charge the EV with low power results on the one hand in a longer charging time for the costumer but on the other hand, it prevents grid measures in the low voltage level.

Actually, in some countries like Germany and Austria the electricity tariffs at low voltage level for residential customers are based on the energy consumption. In future, the electricity tariffs for low voltage customers could also include a stronger power component. If residential customers like to use a relatively high charging power (e.g. 22 kVA) compared to the normal power consumption of residential customers, it could be a more expensive for them because this higher charging power could trigger some grid reinforcement for the DSO[52]. Relatively symmetrical low power charging could reduce the grid measures in the low and the medium voltage level.

b) Central charging infrastructure (e.g. separate Transformer or LV voltage feeder for e.g. public charging)
  - Equal and cyclical distribution of the "L1" conductor for the charging station to all three phases of the grid
  - Symmetrical loading (also with charge control)

For a public charging infrastructure with a separate Transformer or an own LV voltage feeder the short circuit power is relatively high which results in a very low probability for power quality violations.

If properly managed and supplied with bi-directional charging capabilities, EVs can provide useful services to the power system operator such as fast active-power injection which serves to improve the system frequency response (SFR) after a disturbance. With the growth in the number of charging stations equipped to provide bi- directional charging, the potential for the provision of fast active power injection during frequency violations is expanding rapidly. As more power is handled by the charging stations, the chance that poorly set controllers or long delays in measurement produce negative effects on the system’s frequency by overcompensating increases.

[52] E-Control: “Tarife 2.1 - Weiterentwicklung der Netzentgeltstruktur für den Stromnetzbereich, 2020

6.1.4 Phase unbalance

Voltage imbalance is a significant problem as it results in less efficient system operation and loss of EV charger capacity. The imbalance has often been not on the focus of the distribution system operators due to the lack of monitoring data in the low voltage (LV) network. However, the massive deployment of smart meters in recent years in many countries provides very valuable information to detect unbalance. In addition, in the current context of the growing presence of single-phase distributed energy resources connected to LV networks, such as electric vehicle (EV) chargers, there is a risk that the voltage imbalance issue will increase.

6.2 HV/MV sourcing (primary) substation impact

6.2.1 Use cases to be considered

The following table summarizes the use case a primary substation planner needs to consider.

Use case	To be considered
Home charging	+++
Street	++
Highways	+++
Employer charging	+
Commercial area / Mall	++
Car parks	+
Batteries swapping charging facilities	+
Public Buses	++

Table 5: Summary use cases for HV/MV network

6.2.2 Best Practices and tool for the planner

HV/MV primary substations make the link between the transmission and distribution grids. A single primary substation (typically one to three power transformers) feeds electricity to ten to thirty thousand people depending to the local population density (urban or rural areas), and up to hundred thousand people in largest urban cities. HV/MV transformers feed a MV busbar that connect up to ten feeders and fifteen thousand people in average. MV distribution grids are also sized to enable a safe n-1 configuration. Typically, the peak power of a substation transformer must be kept lower enough from the maximum value to enable the n-1 operation scheme.

HV transmission grids are planned and operated taking the n-1-criterion into account. If a failure occurs at a certain point in the electrical grid e.g. at the regulating transformer or a transmission line the grid should be able to operate under the forecast conditions anyway. As a result, the voltage in the electrical grid has to remain within the permitted voltage limits and overloading of the electrical equipment (Transformer, cables and lines) has to be prevented.

MV distribution grids can be planned and operated as n-1-configuration. To fulfil this condition after a failure in the electrical grid switching operations have to be performed to provide electrical power to the customers using connection points and lines to other medium voltage feeders from the same primary substation or from other primary substations. In urban areas the electrical medium voltage grid has normally more switching options compared the electrical grid in rural areas (radial networks).

6.2.2.1 Cars: Impact of charging behavior (systematic or not)

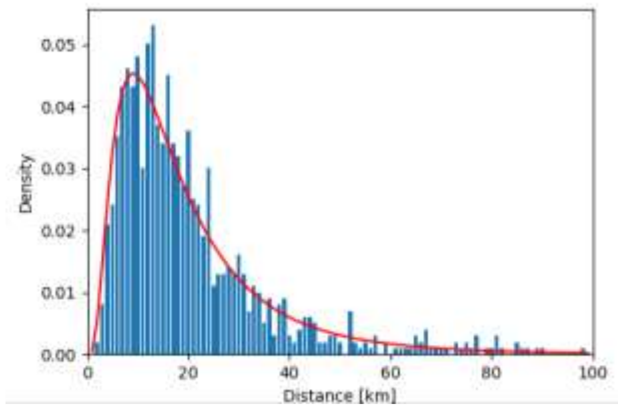
The energy demand and power profiles of the EV fleets depend on the trip mileages and the charging behavior of the drivers. Will people charge systematically when they are parked (at home and work), or only when needed (at home and/or at work)? Step by step, EV users will probably adapt their behavior and turn to a “charge when needed” approach, especially as the battery capacities are increasing.

In that case, a survey has been conducted[53] from the French mobility data to compare a “systematic” charging strategy and a “when needed” strategy. Two case studies of realistic French substations were carried out. The first substation is located in the Paris suburbs and the second one is located in a rural area in the south of France. Commuting travels have been considered from French mobility data. In this use case urban commuters have shorter mobility requirements, with a mean one-way distance of 8.4 km, whereas rural commuters do longer commuting trips, with a mean one-way distance of 24.6 km. In the model, the threshold for charging depends on the energy needed for the next trip, with a defined margin that can be seen as representative of the driver anxiety. A range anxiety factor (RAF) between 1.5 (50% margin) and 2.5 (150% margin) has been considered.

Considering a 100% EV adoption, the number of charging sessions per week has been analyzed for different battery sizes (24, 40 and 60 kWh), and for the rural and the urban substation. Simulations have been done for 1000 EV. In the figure A (below) we first give the distribution of French travel distances from a survey conducted by the French government in 2008. In the Figure 45 (B) the distribution of the number of charging sessions per week is assessed from the distribution of French trips. It can be seen that increasing the size of the battery reduces the number of charging sessions required per week. While 27% of EV users will need to recharge every day with a 24 kWh battery, this proportion falls to 4% with a 60 kWh battery pack. On the other hand, 42% of users need to charge only once or twice per week with a small battery pack, which in turns rises up to 81% with a large battery pack, with 60% only needing to charge once per week. Finally, figure (C) shows the number of charging sessions per week for the urban and rural substations, when considering a non-systematic plug-in behavior by EV users.

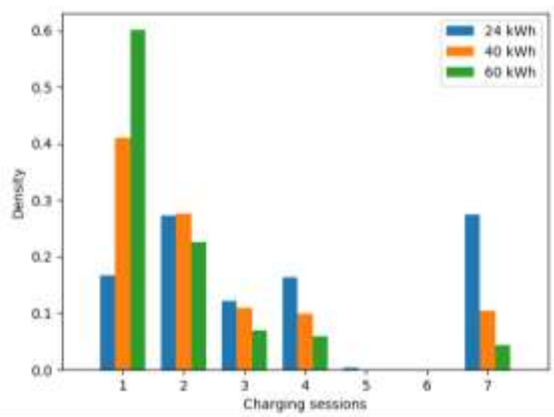
[53] F. Gonzalez Venegas, M. Petit, Y. Perez, “Impact of Non-Systematic Electric Vehicle Charging Behaviour on a Distribution Substation”, 2019 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe)

(A)



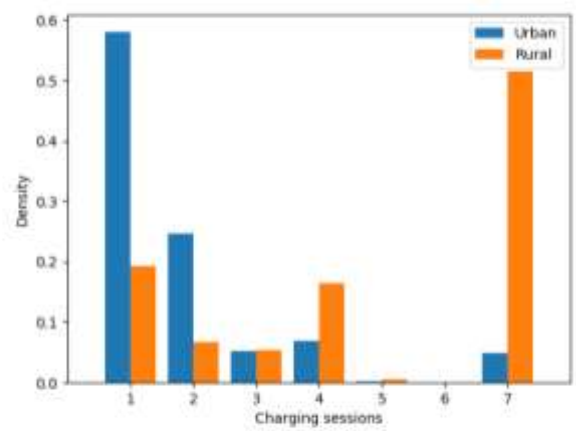
Data for French travels. Lognormal distribution for one-way distance, and histogram for 1000 points

(B)



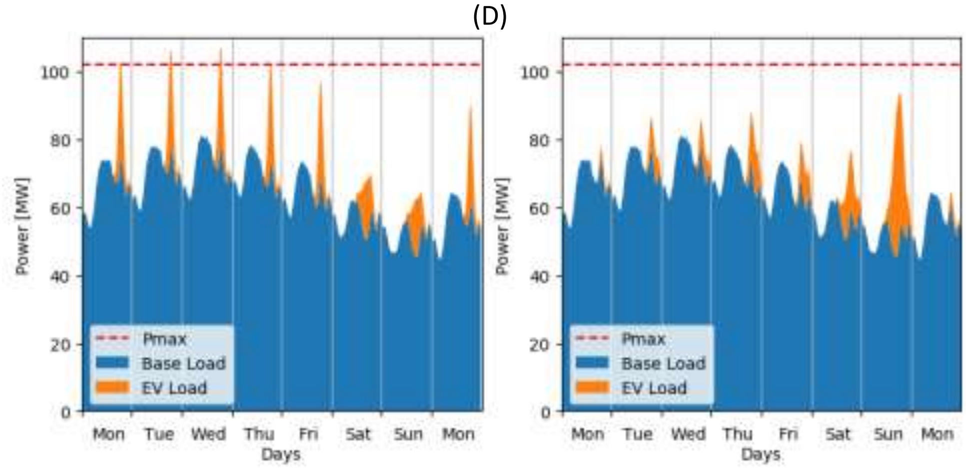
Distribution of the number of charging sessions per week, according to the battery size. RAF = 1.5.

(C)



Distribution of the number of charging sessions per week, for urban and rural substations. RAF = 1.5

(D)



Total load for the urban substation, considering a systematic (left) and non-systematic (right) plug-in behavior (100% EV adoption)

Figure 45: Results

It can be seen that higher mobility requirements from rural dweller leads to higher plug-in rates. Indeed, 51% of rural dwellers plug-in every day, whereas only 4% do on the Parisian suburb. On the contrary, over 58% of the habitants of the Parisian suburb would need to plug-in only once a week, whereas this happens only for 19% of rural EV users

6.2.2.2 STOCHASTIC ELECTRIC VEHICLE LOAD MODELING FOR HV/MV SUBSTATION CONSTRAINT ASSESSMENT

DSOs need to generate master plan based on mid-term to long-term electricity power demand projections to determine both appropriate investments decisions at the distribution level as well as the optimal reinforcement and location for the new HV/MV substations. However, the integration of EVs development projections calls for the development of new innovative approaches. Several studies have shown that new tools are needed to assess the EV impact on the electric distribution network and to identify the most suitable planning solutions to allow the effective integration of EV and boost electric mobility.

The French DSO ENEDIS carries out at each regional level an electrical distribution network master plan.

• These plans are updated by smaller geographical areas (5 to 10 substations) every 5 years
• Their purpose is to give a general direction and to help anticipating future network development needs (new feeders or new substations creation for example)
• They take into account power demand projections based on the past year's trends and new significant network connections scheduled in the area
• Studies are done for two temporal horizons: 10 and 30 years ahead.

A recent CIRED paper[54] presents a generic approach based on stochastic modeling that allows assessing the impact of various EV deployment scenarios on HV/MV substation.

In this work, an innovative method addressing this issue and designing an improved probabilistic model considering high EV penetration level is proposed. For each substation in the studied area, the model estimates the number of EVs in different categories: personal cars, corporate vehicles, car-sharing etc. It is assumed that vehicles assigned to a given substation are always charged by this substation, whether at home, on the street or at work. The model adds up the individual probabilistic load curve of each vehicle to estimate the total consumption due to EVs. The results could be used to review and assess the need for reinforcement at primary substation level. For this purpose, the probabilistic approach combines other parameters such as: battery capacity, travel distance, plug-in time and arriving charging power rate by considering unmanaged charging schemes as a baseline scenario. In addition, the proposed model is

[54] A. Bouallaga, B. Doumbia, «Stochastic Electric Vehicle Load Modeling for HV/MV Substation Constraint Assessment,» CIRED - *25th International Conference on Electricity Distribution*, Madrid, 2019

extended by considering the decision-making process of an EV user for daily charging. Based on human expertise and common sense, a Fuzzy Logic inference system is applied to simulate the EV charging decision. This method is well adapted to model human reasoning's imprecision's and doubts. Based on these models, a Monte Carlo (MC) simulation method is finally performed to estimate the daily load power generated by EVs fleet by simulating the random behavior. The proposed model is depicted in Figure 46. It shows the different factors that influence the charging load of EVs fleet.

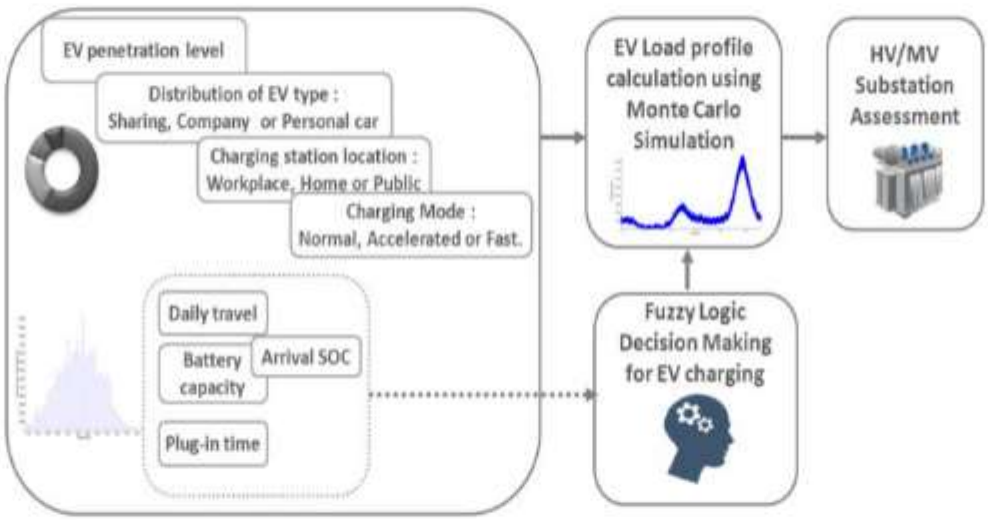


Figure 46: Flow diagram of the proposed approach.

To help understanding the problems of EV's charging from the electric grid point of view and even proposing solutions for load peak reduction, the proposed study aims to identify EVs charging pattern over a period of 24h through stochastic modeling. The model is precisely studied by including a combination of different factors that influence EVs charging demand behavior (Figure 46). All the corresponding features of the EVs load model, mentioned above, are discussed in detail in the paper[55].

Main assumptions are built by distributing the scenarios as follows:

E-mobility development characterization:

- Use of Enedis e-mobility development scenarios on a National scale.
- Projections are given at a local scale for the 35 000 French municipalities
- This allows an allocation of EVs by substation by identifying possible locations for associated charging points on distribution networks.

[55] A. Bouallaga, B. Doumbia, «Stochastic Electric Vehicle Load Modeling for HV/MV Substation Constraint Assessment,» CIRED - 25th International Conference on Electricity Distribution, Madrid, 2019

Network impact models:

- Specification of a dedicated set of hypotheses to describe with probabilities:
- The distribution of the vehicles by motorisation (plug-in hybrid electric vehicles and battery electric vehicles) and into three categories: private cars, company cars and vehicles dedicated to car-sharing
- The daily charging needs for each category of vehicles by defining daily travel distances, vehicles' electrical consumption and charging frequencies
- The charging of the vehicles itself with the characterization of its location (type of charging points), its power level, its starting hours and of the possible smart charging scenarios

These hypotheses are different according to the type of area (urban/suburban/rural/very rural)

Framework of the studies:

- Focus on day-to-day mobility for passenger and light-duty vehicles
- At this point, our evaluation is only suitable at the substation scale (uncertainties on the localization of EVs at the feeder scale is too high to use a similar methodology to produce coherent results)
- Analysis is not carried out for N-1 situations
- For each time period, a worst-case hypothesis is taken into account by assuming the synchronization of the peak loads for EVs and for the other uses

Evaluation of e-mobility contribution for the studies

- For the analysis of a substation with a specific number of EVs:
- Simulation for a significant number of potential days (500 at least) of the behavior of the vehicles (covered distances since the last connections, charging places, charging power levels…) to generate e-mobility load curves at the substation level Vehicles' behavior is modeled with probability distributions
- For each time period: Realization of a ranking of the maximum power demands evaluated for each day and determination of the median value

Main results are displayed in the figure as below.

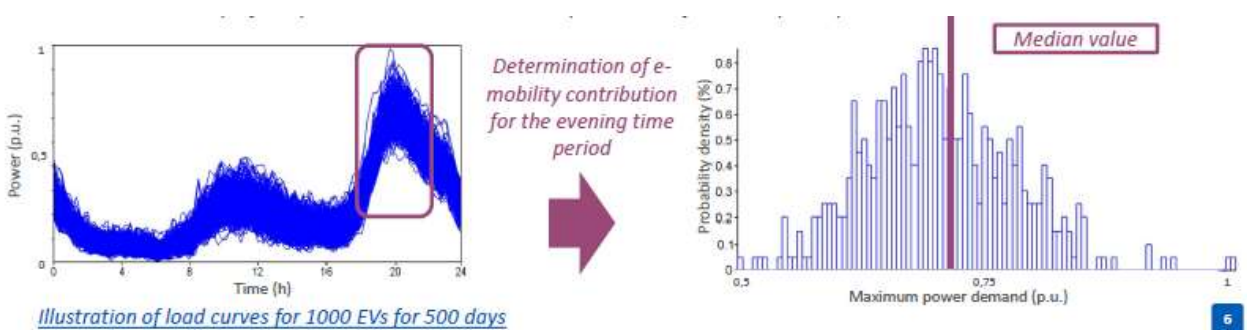


Figure 47: Results of the simulations

The Figure on the left provides an example of a probabilistic simulation scenario (N=500) with 1000 EV in dense urban area. First, it can be seen that the expected EV charging load could take many forms with different peaks power rate, which is the interesting on the Monte-Carlo simulation. Then, by analyzing the load behavior two peaks power can be observed in the morning and evening when EV's users are arriving at workplace or at home area. Likewise, it can be noted here that the charging at residential area is relatively higher than at workplace or in a public area.

In addition, Figure on the right gives a statistical comparison of different peaks values observed at each simulation. It shows the occurrence of extremes values and all possible situations. In this way, MC simulation provides a much more comprehensive view of how EVs load profile may behave in future. Therefore, the assessment of the potential EV impact on HV/MV substation can be achieved by accepting a certain risk level.

Further simulations and analysis of different cases can be performed to show each geographical type, the evolution of the ratio p.u or kW/EV depending on the EV fleet size at a given risk level. This conclusion can be considered as a simplified tool to model and assess the EVs impact on HV/MV substation.

It is to note that the median value is the value chosen for this period to be added to the associated sizing peak load of conventional uses (it seems too pessimistic to define for e-mobility a value representing a higher risk level since it is added to a power of reference for conventional uses which already has a low occurrence probability and since in reality solutions will be implemented to avoid a perfect synchronism between the two peak loads of the time period).

6.3 MV Network

6.3.1 Use cases to be considered

Use case	To be considered
Home charging	+
Street	+
Highways	++
Employer charging	++
Commercial area / Mall	++
Car parks	++
Batteries swapping charging facilities	+++
Public Buses	+++

Table 6: summary use cases for MV network

The effects on the MV network from the loads connected to the LV network must be taken into account.

As the connection points for Public charging on highways are made at the MV side, there is no risk of phase imbalance or over-current. Indeed, this power level is quite common for the MV network and the transformer at the connection point exerts a (re)balance of the phases. We describe potential issues on voltage and power quality.

6.3.2 Best Practices and tool for the planner

The impact of electric vehicles on medium voltage has been relatively little studied. Indeed, at this level of planning, these impacts are combined with residential, industrial and decentralized production loads. Although it is to note that the aggregation is lower than at the level of the primary sub-station. As consequences, neither a stochastic approach, which is only valid on a large number of loads and time series nor the peak computation by simultaneity factor, which de facto considers only a single peak moment, do not seem sufficiently correctly to establish the maximum flux on this equipment. Nevertheless, the next section provides some highlights on these issues.

6.3.2.1 MV feeder as a cluster of EV loads

As already shown, the penetration of EVs can be significantly different in individual regions. But recent studies also assume that it can lead to local peaks in some parts of the networks. An example is a cluster of private charging stations in one street or a quarter. Factors such as income levels, type of construction, availability of private parking spaces, demographic characteristics (age…) or the diffusion behavior of neighbors can affect this. A detailed analysis of correlations is not part of this study. In order to estimate a result corridor, however, it should be shown how local clusters can influence the effects in individual network areas.

A simultaneity factor equal to 1 is taken into account in case of Street and highway public charging

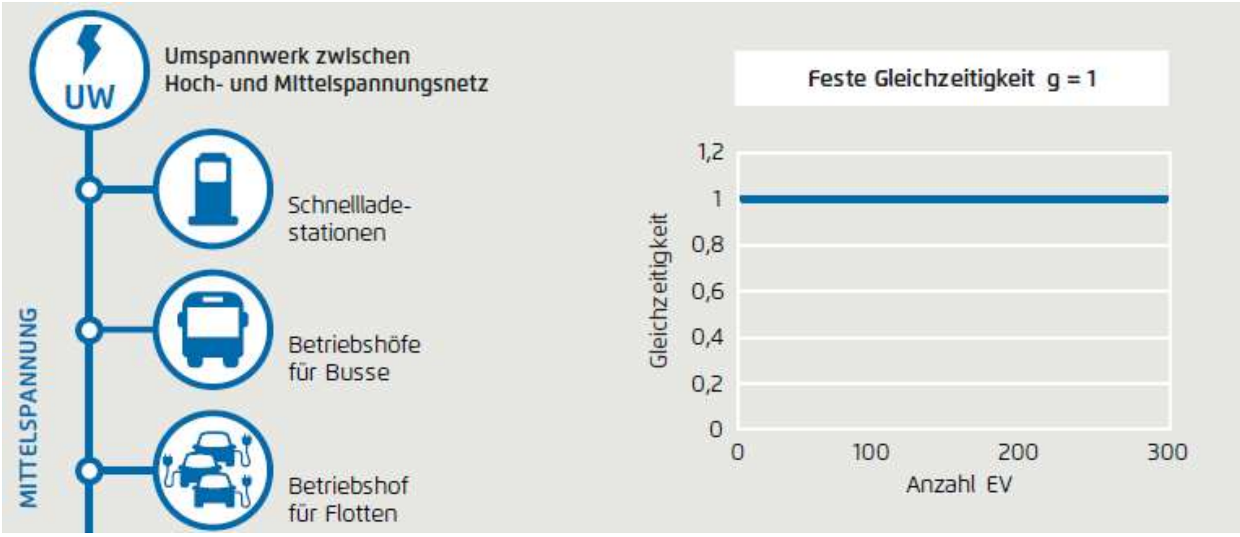


Figure 48[56] Simultaneity factor for street and highway charging

6.3.2.2 Simultaneity factor for workplace

The charging at work will increase and more and more factories and offices will be equipped with charging points. As these facilities are connected on the MV network, the Figure 48 illustrates the simultaneity factor considered for workplaces according to [2]:

[56] Maier U., Ropenus S., Jahn A., Jörling K., Knapp J., Nabe C., Steinbacher K., Tiedemann S., Greve M., Tretschock M., Kippelt S., Burges K., Verteilnetzausbau für die Energiewende Elektromobilität im Fokus, Navigant, RAP, Agora Energiewende, Agora Verkehrswende, August 2019, Berlin

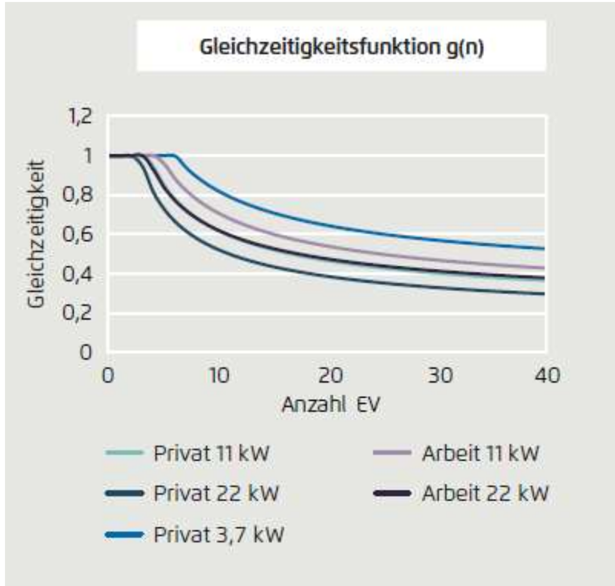


Figure 49:*Simultaneity factor for Workplace charging*[57]

6.3.2.3 Simultaneity factor for car park lot connected on MV network

Based on the data presented in Figure 39: Overall charging profile of car park in inner city (Simulation) it is possible to compute a simultaneity factor as depicted on the next figure.

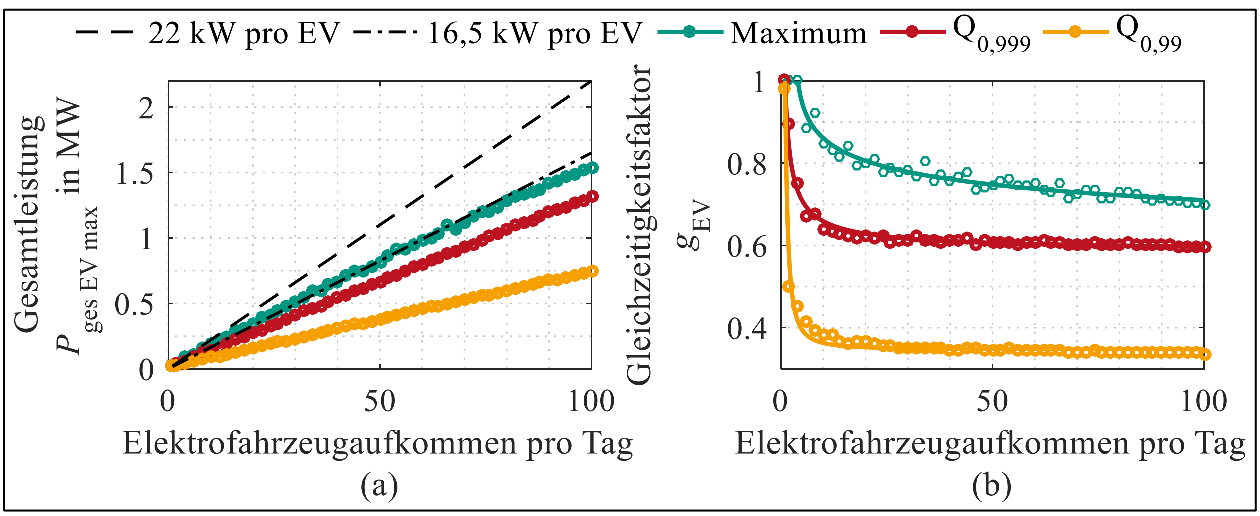


Figure 50: Simultaneity factor for Park Lot

[57] Maier U., Ropenus S., Jahn A., Jörling K., Knapp J., Nabe C., Steinbacher K., Tiedemann S., Greve M., Tretschock M., Kippelt S., Burges K., Verteilnetzausbau für die Energiewende Elektromobilität im Fokus, Navigant, RAP, Agora Energiewende, Agora Verkehrswende, August 2019, Berlin

6.4 Secondary substation and LV feeders

6.4.1 Use cases to be considered

The following table summarizes the use case a LV network planner needs to consider.

Use case	To be considered
Home charging	+++
Street	++
Highways	
Employer charging	+
Commercial area / Mall	
Car parks	+
Batteries swapping charging facilities	
Public Buses	

Table 7: Summary use cases for LV network

Obviously, the dwellings are connected on the LV network. The impact of home charging is to be evaluated on the LV feeders and the secondary substations (where there is the MV/LV transformer). Upon large-scale adoption the impact on higher voltage networks will also have to be considered.

6.4.2 Best Practices and tool for the planner

For LV feeders and secondary substation, we propose two different approaches.

The first one is a quick assessment method based on simultaneity factor without considering unbalance that can be easily used for secondary substation load. The second tool is a power flow computation that is more suitable for LV feeder analysis.

6.4.2.1 Typical Simultaneity factors

Simultaneity factors are a common tool in network planning. For conventional consumption, the simultaneity factor serves as an estimation that takes into account that all the devices in a system are never switched on simultaneously and at full power. With regard to EV, a simultaneity factor can determine the number of charging stations likely to be operated simultaneously on the grid. Statistically, it can be assumed that with the higher EV number in the network area, the lower the probability that all EVs will be charged at the same time. It should be noted that the charging with low power takes longer than the charging with higher power, which is why the probability of simultaneous use decreases with increasing power. It is also necessary to differentiate how the charging station is used. It can be assumed that the simultaneity in the use of private charging columns is lower than when using charging points at work. [2] Deduced from the simultaneity function shown in Figure 50 **Error! Reference source not found.**, which is also used within this study. For public and semi-public charging points, a simultaneity factor of is generally assumed as part of a worst-case analysis.

This next chart presenting the Simultaneity factor is built considering the following underlying assumptions:

- The recharging equipment are well distributed between the different phases (in LV) as well as on the length of the cable.
- This table takes into account the impact of the classical Time Of Use tariff, with a lower tariff after 10 PM.
- These coefficients were established on the basis of the study [1] for a residential urban network. Although the study mentioned shows that this hypothesis is rather in the direction of security, it is advisable to be careful about the study of a rural, industrial or commercial network.

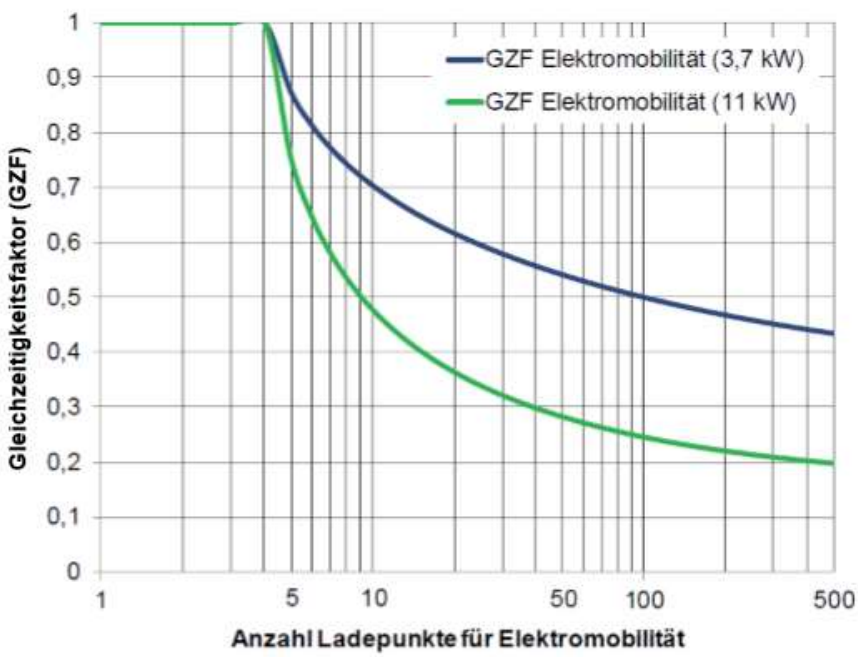


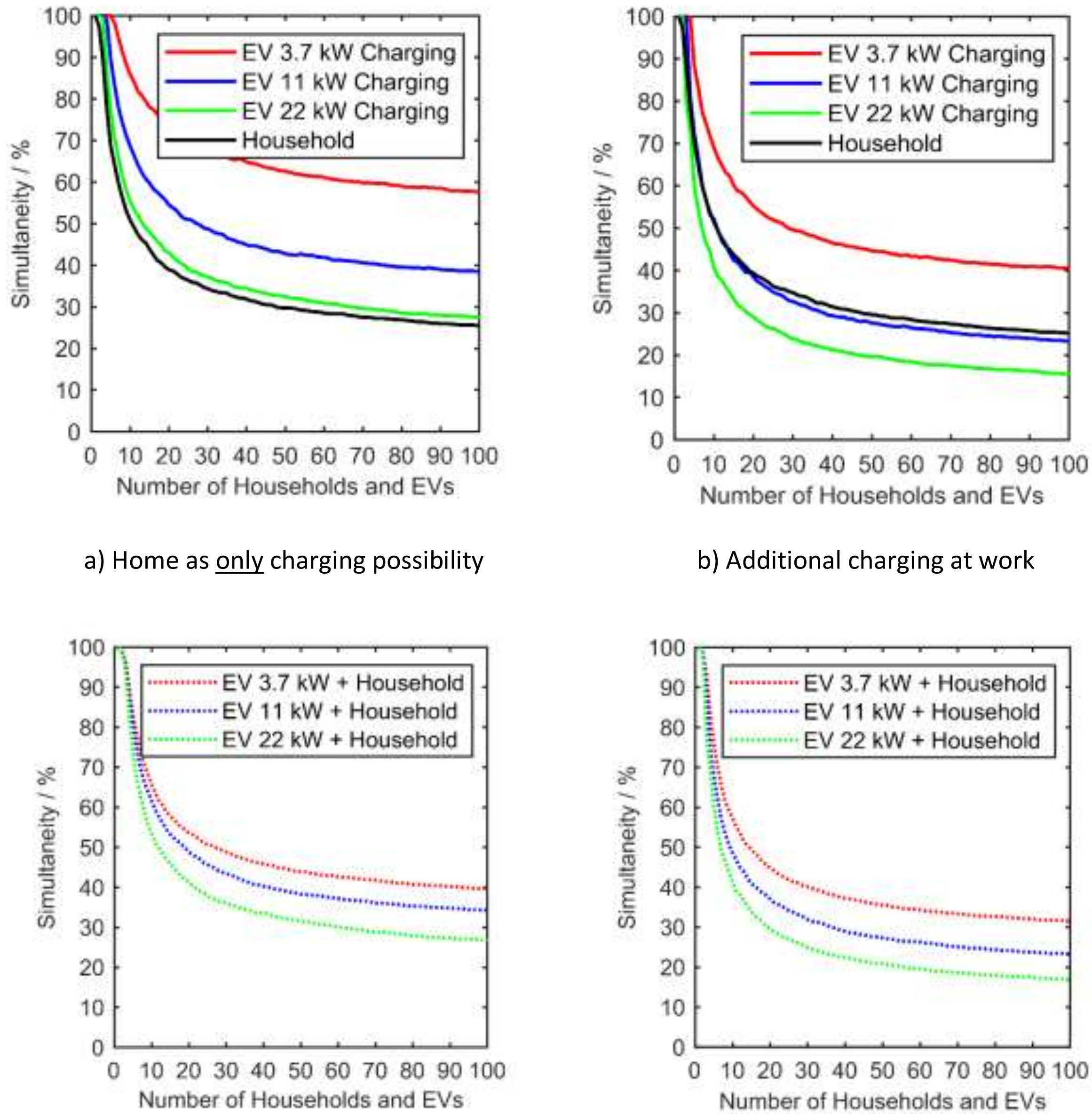
Figure 51: Simultaneity factor of EV (LV connected)[57]

For some planners, it could be also useful to directly compute the load of the EV added to the load of the household. Therefore, they can use the next charts[58] considering the context:

a. EV load on the top of households load when home charging is the only possibility
b. EV load on the top of households load when home charging is not the only possibility (e.g work charging)
c. Combined Simultaneity for EV Home Charging and Households (each dwelling is equipped with EV charger) and home charging is the only possibility
d. Combined Simultaneity for EV Home Charging and Households (each dwelling is equipped with EV charger) and is not the only possibility (e.g work charging)

[58] *P. Wiest und D. R. K. Groß, „Probabilistische Verteilnetzplanung zur Analyse der Gleichzeitigkeit von Elektromobilität,“ in Zukünftige Stromnetze für erneuerbare Energien 2018, Berlin, 2018.*

Important note: These charts have to be taken with caution. They represent a general context with a generalized behavior. For a specific DSO with specific mitigation action (e.g. tariff structure), it would be necessary to build their own simultaneity factor.



a) Home as only charging possibility

b) Additional charging at work

c) Home as only charging possibility

d) Additional charging at work

Figure 52: Single Simultaneity for EV Home Charging and Households

Nevertheless, as shown on the next figure, the real EV charging profile could differ strongly from these assumptions.

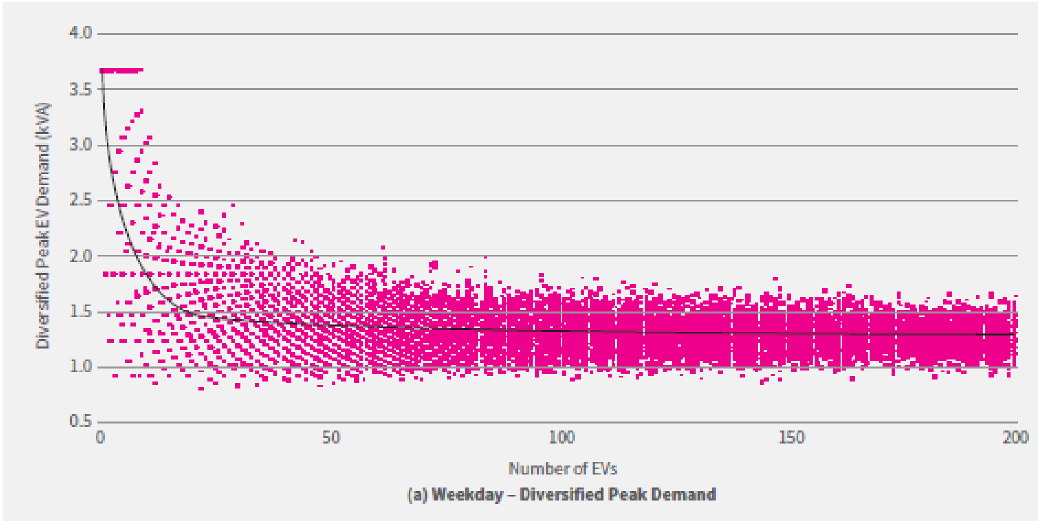


Figure 53: Diversified EV peak demand for varying number of EVs (assuming 3,7kW charger)[59]

6.4.2.2 Three-phase Power Flow Calculation Tool

6.4.2.2.1 Introduction

Within the work of this working group, an unbalanced power flow tool was developed in Excel. Especially, it is useful to investigate the effect of unbalanced charging of electric vehicles in low voltage grids. It is open-source and can be adapted to individual applications. It can be downloaded at: http://doi.org/10.5281/zenodo.4415631.

Many professional power flow tools exist already. They can be used to model low voltage grids in a high level of detail. Disadvantages are that they are complicated to use, and a lot of input data is needed. The tool presented here can be used in Excel, so no extra software has to be installed. Additionally, it is easy to use, and the level of complexity can be chosen by the user. In the following sections, the simulation framework is presented and basic instructions for the tool are given. Furthermore, an example to determine the effect of EV charging is shown.

6.4.2.2.2 Simulation Framework

The program code for the tool was written in Visual Basic for Application (VBA). VBA was developed to adapt Microsoft Office applications to the user's need. The tool was mainly developed by Pit Maier.

To solve the load flow problem, the simulation framework uses the Newton-Raphson method or Gauss-Seidel method. If no settings are changed, the Gauss-Seidel method is used automatically as it was faster during performance tests.[60] .

[59] EA Technology, The University of Manchester, Western Power Distribution: My Electric Avenue: November 2015.
[60] The used algorithm is described in Pit Maier, "Integration der Ladeinfrastruktur von Elektroautos in die Verteilnetze und deren Auswirkung auf den Netzausbau", Bachelor thesis, Hochschule Karlsruhe, 2020

The calculations are performed in the per-unit system. For modelling the grid, a transformation of the grid data to symmetrical components is used to solve load flow problem. Loads can be modelled as constant-power or constant-impedance loads.

The tool consists of simulation core and a graphical user interface (GUI). The following sections focus on the GUI and possible applications in the context of this working group. Nevertheless, the simulation core can also be adapted to further purposes and additional settings can be changed there. Using the unhide function of excel, additional sheets can be shown to where the input data is processed.

The load flow tool has been validated using the commercially available tool DIgSILENT PowerFactory.

6.4.2.2.3 Instructions

The graphical user interface of the tool is divided in three areas. With an increasing number of the area, more detailed input data can be entered into the tool. All input data fields are already prefilled with realistic data, which can be modified according to the user’s needs.

Area 1

A screenshot of Area 1 is given in Figure 53. At first, the number of details considered for feeder as well as the total number of feeders in the regarded low voltage grid can be defined. For a detailed feeder, Area 2 & 3 are available to enter more detailed data especially for this feeder. The input data for all feeder that are not considered detailed will be entered in a common form of Area 2 & 3.

Additionally, data for the MV/LV-transformer can be entered here as well as calculation result for the transformer (Load and Workload) are shown in Area 1.

Besides that, voltage limits for all points in the grid are defined here. The voltage limits affect the coloured highlighting of the calculation results.

Grey coloured fields are input data and green to red coloured fields are for simulation results.

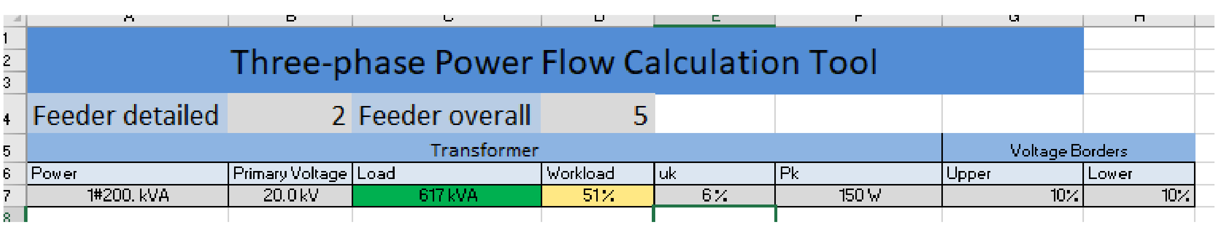


Figure 54: Screenshot of Area 1

Area 2

A screenshot of Area 2 is given in Figure 54. Input data in Area 2 are the predefined line type for the whole feeder, the total number of nodes in the feeder and the feeder length. Additionally, data of equipment can be entered for an automatic calculation of the power of the equipment. This includes the number of charging points and their respective charging power. Further input data is the number of households in the feeder. This data is used to calculate the concurrency of charging processes. At the end of Area 2 is a summary of the assumed power for households, EV charging and PV generation. All values are added to calculate the total power. As PV systems generate energy, this is considered through subtraction.

Input data in grey fields is used to calculate the input data for light blue fields. However, the data in light blue fields can still be modified by the user if necessary. In green to red coloured fields simulation results are shown.

1		Low voltage knots	Feeder length	Lines(Typ, Number parallel lines)			
		20	500 m	N(A)YY 4x150		1	
Charging power of EV		3.7 kW	11.0 kW	22.0 kW	Number households	Peak Power [kVA]	Concurrency
Number EV		3	2	1	10	30	0.23
Concurrency		1.00	1.00	1.00	Power per household	6.938073745	
Power							
Households		E-Mobility		PV		Additional	
S	cos(φ)	S	cos(φ)	S	cos(φ)	S	cos(φ)
69.38 kVA	0.95	55.10 kVA	1	0.00 kVA	0.95	0.00 kVA	0.95
		Max ΔU		Current			
		-3.20%		177.97 A			

Figure 55: Screenshot of Area 2

Area 3

A screenshot of Area 3 is given in Figure 55. For each node in the feeders that are regarded in detail exists a data area as in Figure 56. The power of loads and generators is displayed here for each phase independently. Each power can be modified, and the total sum will then be updated automatically.

For each line segment, the line type and length can be chosen independently in Area 3. In the field Max ΔU, the voltage drop between each point and the MV/LV transformer is given. In the field Unbalanced, it is shown if the loads and generators at these points generate a balanced or unbalanced power flow. In the field Max Current, the maximum current flowing through a phase is shown.

All fields for input data are light blue. Grey coloured fields from Area 2 are used for the calculation of the light blue input data. Nevertheless, input data in light blue coloured fields can be modified by the user manually. In green to red coloured fields simulation results are shown.

The field of the maximum current is grey coloured as no review of the utilization is given here.

Knoten					Lines		
Nr.	S	cos(φ)	Max ΔU	Unbalanced	Max Current	Length	Linetype
1	6.15 kVA	0.98	-0.74%	No	177.97 A	25.00	N(A)YY 4x150
2	6.15 kVA	0.98	-0.99%	No	169.07 A	25.00	N(A)YY 4x150
3	6.15 kVA	0.98	-1.22%	No	160.17 A	25.00	N(A)YY 4x150
4	6.15 kVA	0.98	-1.44%	No	151.26 A	25.00	N(A)YY 4x150
5	6.15 kVA	0.98	-1.65%	No	142.36 A	25.00	N(A)YY 4x150
6	6.15 kVA	0.98	-1.84%	No	133.46 A	25.00	N(A)YY 4x150
7	6.15 kVA	0.98	-2.03%	No	124.56 A	25.00	N(A)YY 4x150
8	6.15 kVA	0.98	-2.19%	No	115.66 A	25.00	N(A)YY 4x150
9	6.15 kVA	0.98	-2.35%	No	106.76 A	25.00	N(A)YY 4x150
10	6.15 kVA	0.98	-2.49%	No	97.86 A	25.00	N(A)YY 4x150
11	6.15 kVA	0.98	-2.62%	No	88.97 A	25.00	N(A)YY 4x150
12	6.15 kVA	0.98	-2.74%	No	80.07 A	25.00	N(A)YY 4x150
13	6.15 kVA	0.98	-2.84%	No	71.17 A	25.00	N(A)YY 4x150
14	6.15 kVA	0.98	-2.93%	No	62.27 A	25.00	N(A)YY 4x150
15	6.15 kVA	0.98	-3.01%	No	53.38 A	25.00	N(A)YY 4x150
16	6.15 kVA	0.98	-3.07%	No	44.48 A	25.00	N(A)YY 4x150
17	6.15 kVA	0.98	-3.12%	No	35.58 A	25.00	N(A)YY 4x150
18	6.15 kVA	0.98	-3.16%	No	26.69 A	25.00	N(A)YY 4x150
19	6.15 kVA	0.98	-3.19%	No	17.79 A	25.00	N(A)YY 4x150
20	6.15 kVA	0.98	-3.20%	No	8.90 A	25.00	N(A)YY 4x150

Figure 56: A screenshot of Area 3

Nr.	S	cos(φ)	Max ΔU	Unbalanced	Max Current	Length	Linetype
1	6.15 kVA	0.98	-0.74%	No	177.97 A	25.00	N(A)YY 4x150

	L1		L2		L3		N
	S	cos(φ)	S	cos(φ)	S	cos(φ)	
Households	1.16 kVA	0.95	1.16 kVA	0.95	1.16 kVA	0.95	
E-Mobility	0.92 kVA	1.00	0.92 kVA	1.00	0.92 kVA	1.00	
PV	0.00 kVA	0.95	0.00 kVA	0.95	0.00 kVA	0.95	
Additional	0.00 kVA	0.95	0.00 kVA	0.95	0.00 kVA	0.95	
Sum	**0.92 kVA**	**1.00**	**0.92 kVA**	**1.00**	**0.92 kVA**	**1.00**	
ΔU	-0.74%		-0.74%		-0.74%		
I	177.97 A		177.97 A		177.97 A		0.00 A

Figure 57: Detailed view of the input data for a specific node

6.4.2.2.4 Exemplary simulation

The setting used for this exemplary simulation is the standard setting, which is chosen automatically, when the tool is started.

No EV

The setting consists of five low voltage feeders that are identical. They are 500 metres long (NAYY 4x150), consists of 20 node and ten households are connected to each feeder with a peak power of 30 kVA. As concurrency is considered, the real power demand of each household is 6.15 kVA. This leads to a maximum current of 98.58 A and a maximum voltage drop of 2.06% of the nominal voltage.

Balanced charging

To determine the effect of EV charging, it is assumed that six EV (3x3.7kW, 2x11kW, 1x 22kW) are connected. This setting is the standard setting that is assumed automatically when the Excel file is opened. As no further input data is entered, the additional load by the EV is distributed equally between all points and phases in the feeder. This leads to a maximum current of 177.97 A and a maximum voltage drop of 3.2% of the nominal voltage. Hence, a significant effect of the EV charging can be regarded.

Unbalanced charging[61]

For a third scenario, the EV charging is now considered more detailed. The same amount of EV and the same charging powers are assumed as in the previous scenario. At Point 4,5,6, a charging point for 3.7 kW at Phase A is considered. Furthermore, at Point 8 and 11, a 11 kW charging point is installed. Finally, a 22 kW charging point is considered at Point 15. In this scenario, the maximum current is on Phase A with 210.63 A (Phase B: 162.01 A, Phase C: 161.85 A). The maximum voltage drop can also be regarded on Phase A with 3.71% of the nominal voltage (Phase B: 2.82%, Phase C: 3.17%). Assuming unbalanced charging as in this scenario for the 3.7 kW charging points leads to significantly different results as for balanced charging.

[61] See also M. Abdel-Akher, K. Mohamed Nor and A. Abdul-Rashid, "Development of unbalanced three-phase distribution power flow analysis using sequence and phase components," *2008 12th International Middle-East Power System Conference*, Aswan, 2008, pp. 406-411, doi: 10.1109/MEPCON.2008.4562347.

7 Mitigation actions and recommendations

The ramp up of electric vehicles is only just beginning. This document presents some first findings based on the developments in different European countries. Nevertheless, it is important for distribution grid operators to pay close attention to the activities in the field of personal electric mobility. Three different fields of action can be identified based on the observations of this working group:

- Need for better data
  There is an extensive need for different kind of data that allows for better understanding what happens at the low voltage level of distribution grids. Here, data about grid utilization in various level of details should be collected and analyzed to allow for an adaption of planning and operation principles based on changing grid utilization due to electric vehicles. This is particularly important as current planning and operation principles are based on current mobility pattern of driving behavior, where traditional fuels are dominating the number of vehicles. As the charging requirements for electric vehicles differ in space and time from the requirements of combustion fuel vehicles, these changing requirements might also affect the driving behavior and subsequently grid utilization in a way that cannot be foreseen at the moment. Hence, continuously collecting and analyzing data of driving behavior and grid utilization is an important task for the future.
- Execution of extensive academic research with focus on improved models
  While the data collection mainly needs to be executed by the distribution grid operators themselves, it is advised, that the collection and in particular the data analysis, is carried out in close cooperation with research institutes. There are two reasons for this:
  On one hand, the main field of distribution grid operators is the secure, stable and economically efficient planning and operation of distribution grids. Hence, their core competence is mainly on the distribution grid side. In contrast, research institutions with focus on distribution grid planning and operation normally don't have access to a large database grid data but have knowledge about working and analyzing data with state-of-the-art methods that can support distribution grid operators to not care about the analysis of their data and focus more on their daily business.
- Development of advanced planning tools that better reflect reality
  Although it is state-of-the-art in practice to use simultaneity factors for distribution grid planning purposes, several publications have been released in the past years indicating that in the long term, with more complex system participants in the low and medium voltage grid as well as expected smart grid and smart market mechanisms, simultaneity factors might not be suitable anymore for medium and long term distribution grid planning. An alternative for simultaneity factors could be the utilization of time series reflecting the time and geospatial dependencies between grid assets and markets. Applied to the increasing share of electric vehicles, the proposal of using time series requires more research on the question, if and how time series can be used to support distribution grid planning in the sense that holistic, cross-sector simulations are carried out to derive grid utilization patterns. These holistic simulations require the

cooperation between research institutions in distribution grid operation and planning field as well as in the field of traffic and transportation planning. This cooperation becomes even more crucial for future development, when the sector of heavy goods vehicles becomes electrified. Generally spoken, the development of detailed, bottom-up and cross-sector simulation models is an important task for research institutions in the coming years. Based on these models, researchers and distribution grid operators can than investigate the impact of new technologies and sector-coupling on the electricity grids to derive operation and planning recommendations for the future.

8 Outlook

8.1 Collaboration with Mobility Market role

In the December 2019 European Green Deal[62] communication[63], which aims to reboot the EU's efforts to tackle challenges related to climate change and the environment, the European Commission proposed to review the Alternative Fuels Infrastructure Directive. The Directive was adopted in 2014 to encourage the development of alternative fuel filling stations and charging points in EU countries and required Member States to put in place development plans for alternative fuels infrastructure. However, according to a 2017 Commission evaluation, the plans did not provide sufficient certainty for fully developing the alternative fuels infrastructure network, and development has been uneven across the EU. Car-makers and alternative fuels producers, clean energy campaigners and the European Parliament have called for the revision of the Directive, to ensure that sufficient infrastructure is in place in line with efforts to reduce emissions in the transport sector and to help meet the climate and environment goals set out in the Paris Agreement and the Green Deal. On 27 May 2020, in response to the coronavirus pandemic, the Commission proposed the recovery plan for Europe in which it puts even greater focus on developing alternative fuel infrastructure, electric vehicles, hydrogen technology and renewable energy, repeating its intention to review the 2014 Directive.

The e mobility is in accordance to the Directive treated as a free market service: Directive establishes a common framework of measures for the deployment of alternative fuels infrastructure in the Union in order to minimize dependence on oil and to mitigate the environmental impact of transport. This Directive sets out minimum requirements for the building-up of alternative fuels infrastructure, including recharging points for electric vehicles and refueling points for natural gas (LNG and CNG) and hydrogen, to be implemented by means of Member States' national policy frameworks, as well as common technical specifications for such recharging and refueling points, and user information requirements.

Each Member State shall adopt a national policy framework for the development of the market as regards alternative fuels in the transport sector and the deployment of the relevant infrastructure.

[62] https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf
[63] https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/652011/EPRS_BRI(2020)652011_EN.pdf

Present actors on the market:

- Users
- CPOs are the operators of the stations,
- The recharging service providers are the MSP (Mobility Service providers).

Usually and legal entity can be only in one role, but in some cases an entity could be also in both. Specific role in this new market has the DSO, the connections for e-mobility do concern them, but they should not be active in providing services. The directive requires that the Member States shall ensure that distribution system operators cooperate on a non-discriminatory basis with any person establishing or operating recharging points accessible to the public.

ICT are the main enabler of the market and services. Modern EV charging station management systems give a complete control of the charging infrastructure and consisted of several modules, assets, Billing, CRM- customers, Roaming and Settings.

Enabling recharging between MSPs or CPOs is covered with roaming. Most popular in Europe are the Hubject and Gireve roaming platforms. Not so usual are beside the platforms the so called direct connections between two management systems, via Open Charge Point Interface (OCPI)[64] enables.

The OCPI protocol enables a scalable, automated EV roaming setup between Charge Point Operators and e-Mobility Service Providers. It supports authorization, charge point information exchange (including live status updates and transaction events), charge detail record exchange, remote charge point commands and the exchange of smart-charging related information between parties. It offers market participants in EV an attractive and scalable solution for (international) roaming between networks, avoiding the costs and innovation-limiting complexities involved with today's non-automated solutions or with central roaming hubs. As such it helps to enable EV drivers to charge everywhere in a fully-informed way, helps the market to develop quickly and helps market players to execute their business models in the best way. What does it offer (main functionality):

- A good roaming system (for bilateral usage and/or via a hub).
- Real-time information about location, availability and price.
- A uniform way of exchanging data (Notification Data Records and Charge Data Records), before during and after the transaction.
- Remote mobile support to access any Charge Point without pre-registration.

[64] https://evroaming.org/app/uploads/2020/06/OCPI-2.2-d2.pdf

8.2 Smart charging (V1G) levers

Due to the increasing number of electric vehicles, the energy and power demand from the power grid is rising. Normally, an increasing demand for energy and power is accompanied by the strengthening of the grid, if necessary.

In order to enable the connection of the required charging infrastructure and maybe to avoid grid expansion, the use of smart charging makes sense. If needed, the grid expansion is performed regarding the principles of cost-effectiveness, efficiency, reliability and security.

Smart charging possibilities can be divided into the consumer side and the DSO side options.

Therefore, the optimization on the consumer and on the DSO side can be performed regarding economic aspects under consideration of various constrains (e.g. power demand, grid limits) but with different optimization goals.

Consumer side options:

Smart charging systems can be driven by three means of optimisation:

- adjusting the charging power (power management) to reduce the vehicle's power demand, thus avoiding increasing subscribed power of the premises;
- time-shifting the charging process (time of use management) incentivised by price offers from suppliers ;
- maximising self-consumption, with solar production surplus during the day rather than charging in the evening...

DSO side options:

To integrate a huge number of electric charging stations in the LV grid the following options are conceivable to prevent excessive LV grid expansion in advance:

- Time-limited thresholds for maximum charging power of flexible electric charging stations to prevent overloading during peak hours and to maintain grid stability[65]
- Autonomous control strategy e.g. reduced charging power depending on the grid voltages P(U) or P(U,Z) function
- Reduced power to comply with the permissible resource utilization rates[66]
- Time of use tariffs (peak and off-peak)
- Time depending grid tariffs

[65] EnBW / Netze BW: "Positionspapier zur Ausgestaltung des §14a EnWG: Kunden, Netz und Vertrieb integrativ gedacht", Stuttgart, Germany, 2020
[66] ELBE: "Electrify Buildings for EVs", https://elbe-hh.de/elbe/innovation, Hamburg, Germany, 2020

- Electricity tariffs with a stronger peak power component (smart meter essential to measure the peak power)

Time-limited thresholds for maximum charging power of flexible electric charging stations can be used in special cases to prevent grid violations (e.g. impending overloading, etc.) during peak hours and to maintain grid stability. If required, this might result in a reduced charging power (e.g. $0,5 \cdot P_N$) only for specific hours in special cases during the day (e.g. 17-19 h). This could enable a reliable integration for electric charging stations in a case of a faster time run-up of the electric vehicles as well as a contribution to an efficient grid expansion. Therefore, a solution could be to integrate more measurement equipment in the LV grid specially to measure the load of transformers and low voltage feeders together with node voltages at specific points, which can result in a more efficient network use.

To reduce the charging power of the electric charging stations a communication between the DSO and the electric charging station with an analogue or a digital interface can be used. As a result, existing reserves at the LV grid can be used and under certain circumstances grid measures can be avoided. However, a technical and economic analysis of the total costs (operating and maintenance costs) for the whole system (communication and the measurement system) have to be carried out in advance. In Germany regarding the VDE-AR-N-4100 an electric charging stations with an installed power ≥ 12 kVA requires a contact to control/regulate the charging power. The electricity industry representations of interests in Austria, Switzerland and Czech Republic (A-CH-CZ) assigned an agreement that the electric mobility should be controllable under certain circumstances[67]. Additionally, with this controllability after a regional power outage or a total blackout when re-energizing the grid, the simultaneous start of the charging process of electric vehicles can be avoided at this critical time.

An autonomous control without using ICT technologies to reduce the charging power of the electric charging stations in rural LV grids depending on the actual voltage situation could be performed by using an integrated P(U) function in the electric charging station. As a result, if the voltage at the pcc (point of common coupling) is near the limit regarding EN 50160 the charging power will be automatically reduced. The additional consideration of the location (line impedance Z from transformer to charging station) for each electric charging station in the low voltage grid enables an even participation of all electric charging station using a P(U,Z) function[68]. In urban LV grids the probability to overload electrical equipment (like transformers and cables) is normally higher compared to violate voltage limits regarding EN 50160. This is due to fact that the cable cross-section and the load density in urban LV grids compared to rural LV grids is higher.

With the rising interest in distributed control mechanisms combined with machine learning an artificial intelligence, one could also imagine extending or even replacing the P(U)-control functionality with a more sophisticated machine learning approach. While this field of application is currently still ongoing research some preliminary simulation results indicate the applicability of machine learning could reduce

[67] R. Nenning: „Laststeuerungsansätze für Ladestellen“, OE Energie E-Mobilitätstage 2020, 2020, Vienna, Austria
[68] OE Energie: „Aktuelle und zukünftige Anforderungen an Ladeeinrichtungen für Elektrofahrzeuge“, 2018, Austria

charging station load in the distribution grid. In particular for charging stations operated at public places, intelligent charging or curtailment schemes could be beneficial from a DSO perspective.

In Hamburg, a system for controlling charging stations outside the public area is currently being integrated. The system is based on a funding project called ELBE (Electrify Buildings for EVs). The aim is to control these charging points with the involvement of the responsible charge point operators. The charging points from buildings used as residential or commercial properties, as well as at commercially areas are used. Specifically, the system monitors the critical equipment, the transformer and the cables coming from the charging station. In the case of an imminent overloading, Stromnetz Hamburg sends a signal to the charge point operators of the affected charging stations with the aim of reducing the charging power drawn. In contrast to the challenge of voltage in rural areas, the threat of equipment overloading is the main challenge concerning to the urban LV grid environment.

Impact and Interaction between the different options

Electricity tariffs with a stronger peak power component could also lead to a sufficient low charging power and could reduce unnecessary grid measures in the low and the medium voltage level. Time of use tariffs are normally used to obtain cheaper energy and cheaper grid tariffs at day off-peak periods (e.g. after 22:00) using a separate meter. If the charging processes of the electric cars starts automatically at e.g. 22:00 this will also lead to a high simultaneity factor, which is obvious at the recharging process for hot water boilers in the residential households. Time depending grid tariffs can be used in future to avoid grid violations (using measurement equipment to detect e.g. overloading, voltage band violations) which are triggered by a flat market signal to recharge the electric vehicles in a certain area.

Security of supply is one of the most important objectives of distribution system operators. In the future, an alternative technical possibility could be to limit active power at the point of common coupling (pcc) in the case of imminent equipment and/or voltage band violations.

This leaves it up to the end consumer to decide how to use the available active power. For example, in times of high grid utilization, any available electrical storage behind the pcc can be used to charge the electric vehicle to the maximum despite power limitation. The keywords are local charging and energy management systems. For an optimal management of free grid capacities in the LV grid it is necessary to integrate more measurement equipment together with communication technologies to evaluate the grid state.

The recent reports published in 2019, by both French DSO Enedis, and TSO RTE, show smooth and seamless integration of e mobility at minimum cost on both distribution grid and bulk system. This is due to well-designed networks (to cope with electric heat use in winter) and the ToU tariffs (peak / off peak) which have been used for decades in France. However, more advanced smart charging and V2X might play a further role in reducing integration costs and extract best value from the future EV usage through its storage device.

8.3 Energy bill reduction

Currently, the simple charge shifting at off-peak times can enable consumer to save, in average, up to 90 euros per year per vehicle for Zoé type city car, compared to a "natural", unmanaged charge. Depending on user profile and type of EV consumption, additional savings through avoided power capacity increase cost, and self-consumption charging optimization could reach a total of €300/year/EV.

8.4 Future Bi-directional Smart charging (V2X)

Bi-directional smart charging allows power flow to circulate in both directions: from the grid to the car but also from the car back to the grid, when power injection is needed. The principle of Vehicle-to-Home (V2H), Vehicle-to-Building (V2B), and Vehicle-to-Grid (V2G) consists of reinjecting the electricity contained in the battery into the household or building's private grid or the public electricity distribution network, respectively. These technologies could offer further flexibility to the grid (for bulk system at national level or distribution grid at local level) and might be called through specific B2C – B2B contracts.

The highest value of V2G has been assessed for frequency system participation and the amount for French System (Analysis by RTE see figure below) ranges between 100 € - 900 €/per car/year, depending on competition environment with other vehicles or storage devices.

8.5 In a longer term, future local flexibilities

In case of hot spots (power draw exceeds the capacity of the network) occurrence on the distribution grid, the DSO might request to interrupt EV charging in a given area, limiting the risk of power supply outage. This is kind of local flexibility service that is provided by EV infrastructure. From the DSO perspective, these additional flexibilities could be kind of virtual asset that can be mobilised during the operating phase, for outage management or planned works. Furthermore, local flexibility contract can be part of planning process through smart connection contracts, allowing cost reduction (limiting connection costs or postponing reinforcement) while reduced or variable Power capacity is proposed prior to connection request/work.

The value created by local flexibility through load shedding - to be shared among market players, operators and network users - can range from a few dozen euros per electric vehicle per year to 200 euros per electric vehicle in the event of network incident. We refer to table below where value of postponing local investment is 24€/kW/year and to the report as a whole for the value of smart grids in general. However, to achieve a targeted reduced power, the electric vehicles must be aggregated among other types of flexibility means, awaiting a significant uptake of EV fleet. The use of these flexibilities could be most valuable in areas where the network would be subject to constraints in terms of network availability.

8.6 New charging technologies

- There are some emerging technologies that may change the sizing frameworks in grid connection, as their way to connect and charge are quite different from usual plug in charge. However, EV charging infrastructure is evolving towards a larger share of fast charging stations, which is currently the most dynamic segment. Charging technologies are expected to remain centered around plug-in charge, with wireless charging addressing specific use cases such as highways and bus lanes, battery swapping being limited to large fleet owners or light vehicles, and charging robots covering only niche markets.

In the following we are sharing last innovation on battery swap systems, wireless charging and autonomous robots.

- The battery swap allows to exchange empty battery for a full one instead of recharging it. This allows full recharging in a few minutes, but it represents a significant investment and requires standardization of batteries and vehicles systems. Thus, given the many car manufacturers in Europe, this technology will have difficulty becoming the norm. For two-wheeled vehicles, however, the system is much less complex and could develop in Europe as early as 2020.
- Thanks to induction routes, it would be possible to completely forget about recharging. Indeed, this would be done wirelessly, while the vehicle is in use, dynamically (while driving) or statically (at traffic lights, parked, ...). This elegant solution could allow long distances but is cumbersome and requires standardization. By 2025, the development of induction roads for public transport and fleets can be envisaged, and public roads can be envisaged by 2035.
- The autonomous recharging robot (see below).

8.7 Autonomous recharging robot

The autonomous recharging robot is an electric vehicle recharging technology. It consists of an automation present in car parks or parking areas, which, after receiving a recharging instruction, moves towards the vehicle and recharges it automatically.

This technology has several advantages. Firstly, it facilitates the user experience. Indeed, the driver of an electric vehicle no longer has to look for an electrified parking space but can park in any space. All he then has to do is call the recharging robot and go about his business.

This robot is also beneficial for car park managers, whether they are private companies, condominiums or public car parks. The electrification of parking spaces via terminals can be expensive for these managers. With this autonomous robot, less work is required. All that is needed is to modify a single space in the car park, where the robot station will be installed.

In addition, this recharging method avoids unnecessary occupation of the charging stations. With recharging stations, if a vehicle remains connected for longer than its recharging time, the space is then "lost". As soon as a charging robot is installed, all spaces become electrified. This is how we avoid this problem.

There are different projects for recharging robots. For the moment, the companies interested are Volkswagen[69], Mob Energy[70] (a French startup) and Aiways[71] (a Chinese EV manufacturer). These 3 robots have globally the same functioning, except for a few details.

For example, the Volkswagen robot brings a portable battery, plugs it into the vehicle, then returns to its station, before recovering the battery when the EV is charged. The other two have a built-in energy storage unit and charge the vehicle by this means.

[69] Charging robots: Revolution in the underground parking garage (volkswagenag.com)
[70] Home | Mob-Energy (mob-energy.com)
[71] Aiways U5 Europe I Electric car (ai-ways.eu)

9 Appendix

Table A1: (based on https://en.wikipedia.org/wiki/Template:Automobile_classification)

Market segment (British English)	Euro Market Segment	Examples
Microcar	Quadricycle	Bond Bug, Isetta, Mega City, Renault Twizy
City car	A-segment mini cars	Citroën C1, Fiat 500, Hyundai Eon, Peugeot 108, Renault Twingo
Supermini	B-segment small cars	Ford Fiesta, Kia Rio, Opel Corsa, Peugeot 208, Volkswagen Polo
Small family car	C-segment medium cars	Honda Civic, Hyundai Elantra, Mazda3, Ford Focus, Toyota Corolla, Volkswagen Golf
Large family car	D-segment large cars	Ford Mondeo, Opel Insignia, Peugeot 508, Mazda6, Volkswagen Passat
Compact executive car		Alfa Romeo Giulia, Audi A4, BMW 3 Series, Lexus ES, Mercedes-Benz C-Class
Executive car	E-segment executive cars	Audi A6, Cadillac CTS, Mercedes-Benz E-Class, Tesla Model S
Luxury saloon	F-segment luxury cars	BMW 7 Series, Jaguar XJ, Mercedes-Benz S-Class, Porsche Panamera, Audi A8

Table 8 Automobile classification

Personal luxury car	D-segment	Cadillac Eldorado, Ford Thunderbird, Mercedes-Benz 450 SL/SLC
Grand tourer	S-segment sports coupés	Aston Martin DB9, Bentley Continental GT, Ferrari GTC4Lusso, Jaguar XK, Maserati GranTurismo
Supercar		Bugatti Veyron, LaFerrari, Lamborghini Aventador, Pagani Zonda, Porsche 918 Spyder
Convertible		Chevrolet Camaro, Mercedes CLK, Volvo C70, Volkswagen Eos
Roadster		BMW Z4, Lotus Elise, Mazda MX-5, Porsche Boxster, Mercedes-Benz SLK
Mini MPV	M-segment multi purpose cars	Citroën C3 Picasso, Ford B-Max, Opel Meriva, Fiat 500L
Compact MPV		Chevrolet Orlando, Ford C-Max, Opel Zafira, Renault Scénic, Volkswagen Touran
Large MPV		Chrysler Pacifica (RU), Kia Carnival, Citroën C4 Grand Picasso, Renault Espace, Toyota Sienna
Mini 4x4	J-segment sport utility cars (including off-road vehicles)	Daihatsu Terios, Ford EcoSport, Jeep Renegade, Peugeot 2008, Suzuki Jimny
Compact SUV		Chevrolet Equinox, Ford Escape, Honda CR-V, Jeep Cherokee, Kia Sportage
Large 4x4		Ford Edge, Hyundai Santa Fe, Jeep Grand Cherokee, Volkswagen Touareg, Volvo XC90
		Range Rover, Cadillac Escalade, Toyota Land Crui

Table A.2: Energy consumption by vehicle model

Company / Model	Battery capacity	Range NEDC	Range EPA	Range WLTP	conversion NEDC	Range ref.	consumption (kWh/km)
BMW i3 2014	22,00	190	130		68%	130	0,17
Chevrolet Spark EV 2015	18,40		132			132	0,14
Citroen C-Zero 2014	14,50	150	107			107	0,14
Fiat 500e 2015	24,00		140			140	0,17
Ford Focus electric 2015	23,00	162	122		75%	122	0,19
Honda FIT EV 2014	20,00		132			132	0,15
Jaguar i Pace 2018	90,00		480			480	0,19
Kia Soul EV 2015	27,00	212	150		71%	150	0,18
Mercedes B-class electric 2015	36,00	200	140		70%	140	0,26
Mitsubishi i-MiEV 2014	16,00	160	100		63%	100	0,16
Nissan Leaf (Visia) 2015	24,00	199	135		68%	135	0,18
Nissan Leaf (Acenta) 2016	30,00	250	172		69%	172	0,17
Nissan e-NV200 2015	24,00	170	121			121	0,20
Peugoet iOn 2014	14,50	150	107			107	0,14
Renault Zoe 2015	22,00	240	171			171	0,13
Renault Zoe R110	41,00		300			300	0,14
Smart fortwo ED 2014	17,60	145	109		75%	109	0,16
Tesla Model S 2015	85,00	502	426		85%	426	0,20
Volkswagen e-Golf 2015	24,20	190	134		71%	134	0,18
Volkswagen e-Up! 2013	18,70	160	114			114	0,16
Peugeot E 208	50,00			340		340	0,15

Peugeot E 2008	50,00			340		340	0,15
DS3 e-tense	50,00			340		340	0,15
Seat Mii Electric	36,80			260		260	0,14
Opel corsa e	50,00			330		330	0,15
Tesla Model Y	75,00			440		440	0,17
Polestar 2	78,00			450		450	0,17
Volvo XC40	78,00			400		400	0,20
VW ID Cross	83,00			500		500	0,17
Tesla Model S 2020	100,00		647			647	0,15
Audi Etron 2019	95,00			436		436	0,22
Ford Mustang Mach E	98,80			420		420	0,24
BMW i4	80,00			600		600	0,13
Porsche Taycan	93,40			463		463	0,20
SMart fortwo ED 2020	17,60			119		119	0,15

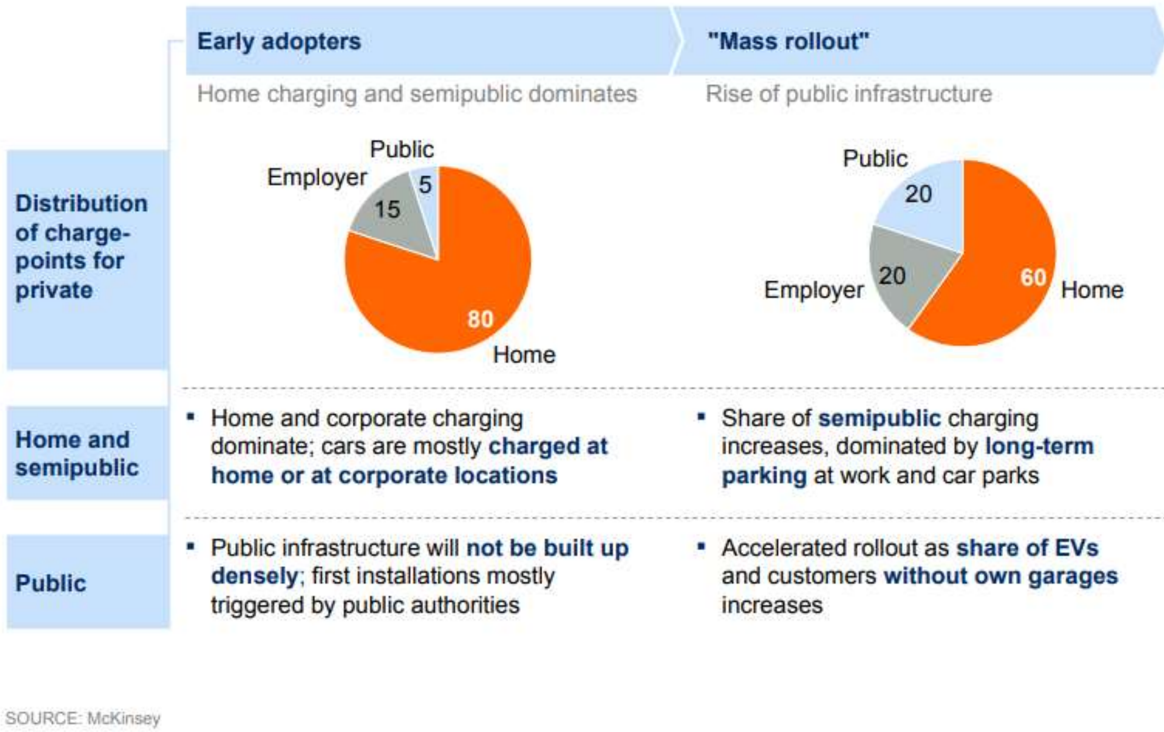
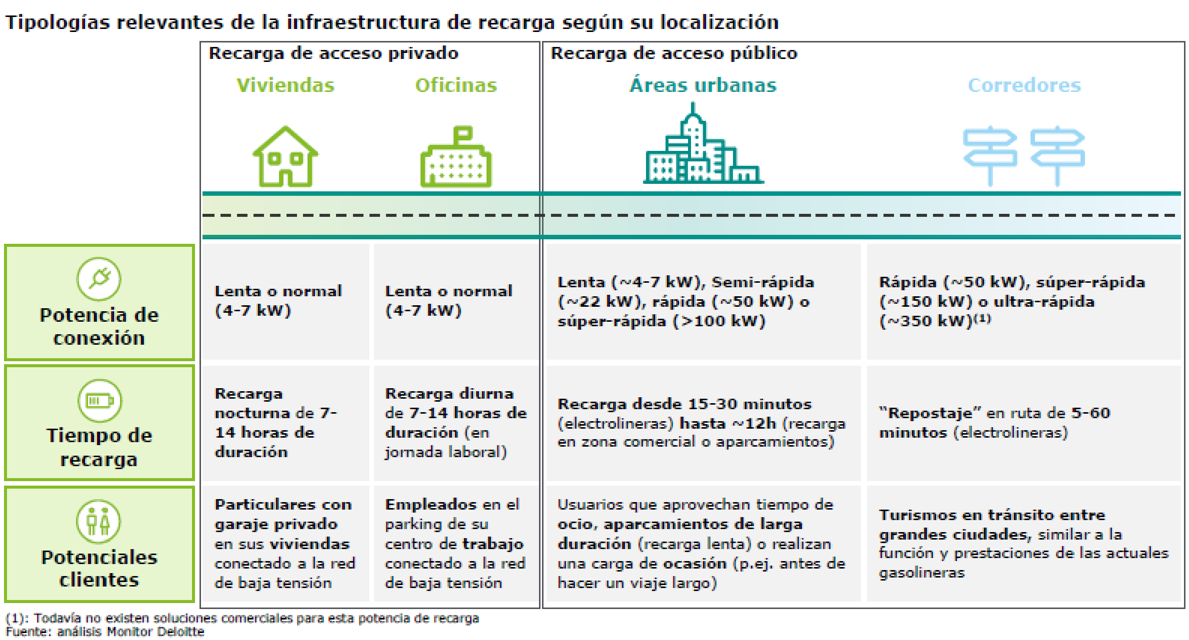


Figure 58


Tipologías relevantes de la infraestructura de recarga según su localización

	Recarga de acceso privado		Recarga de acceso público	
	Viviendas	Oficinas	Áreas urbanas	Corredores
Potencia de conexión	Lenta o normal (4-7 kW)	Lenta o normal (4-7 kW)	Lenta (~4-7 kW), Semi-rápida (~22 kW), rápida (~50 kW) o súper-rápida (>100 kW)	Rápida (~50 kW), súper-rápida (~150 kW) o ultra-rápida (~350 kW)(1)
Tiempo de recarga	Recarga nocturna de 7-14 horas de duración	Recarga diurna de 7-14 horas de duración (en jornada laboral)	Recarga desde 15-30 minutos (electrolineras) hasta ~12h (recarga en zona comercial o aparcamientos)	"Repostaje" en ruta de 5-60 minutos (electrolineras)
Potenciales clientes	Particulares con garaje privado en sus viviendas conectado a la red de baja tensión	Empleados en el parking de su centro de trabajo conectado a la red de baja tensión	Usuarios que aprovechan tiempo de ocio, aparcamientos de larga duración (recarga lenta) o realizan una carga de ocasión (p.ej. antes de hacer un viaje largo)	Turismos en tránsito entre grandes ciudades, similar a la función y prestaciones de las actuales gasolineras

(1): Todavía no existen soluciones comerciales para esta potencia de recarga
Fuente: análisis Monitor Deloitte

Figure 59

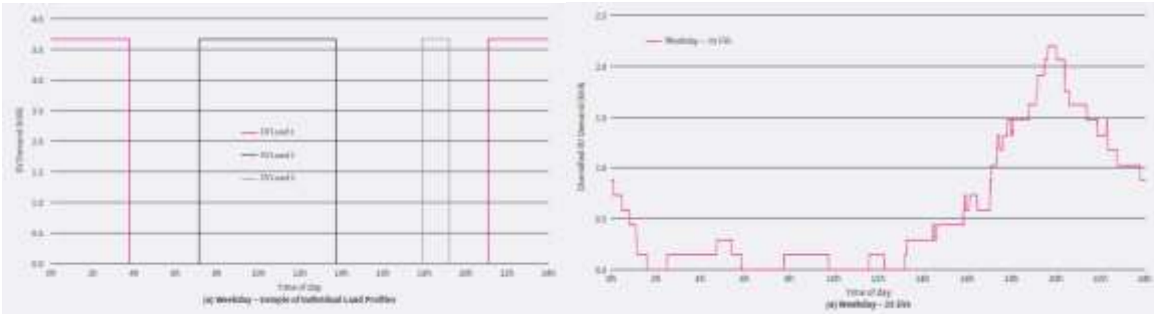


Figure 60: Example of average load profile for 1 (left) and 25 (right) EVs [24]

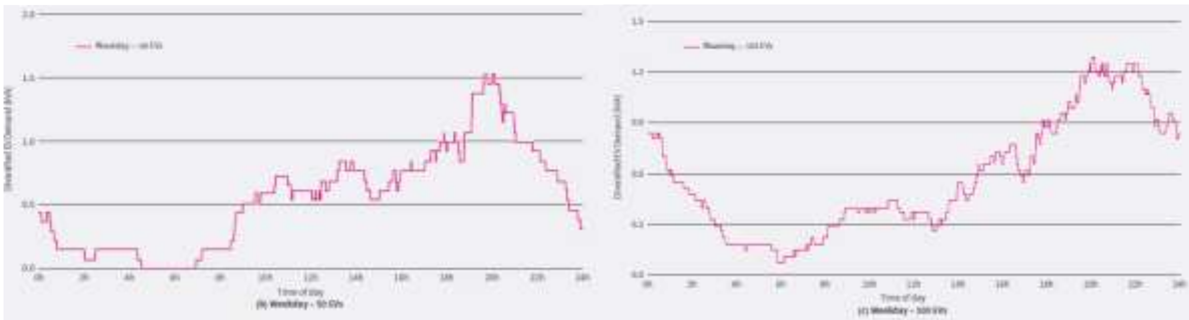


Figure 61: Example of average load profile for 50 (left) and 100 (right) EVs [24]

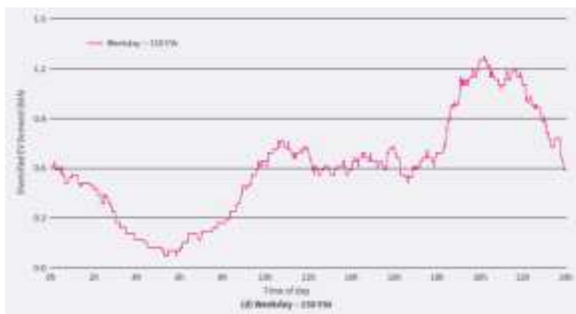


Figure 62: Example of average load profile for 150 EVs [24]

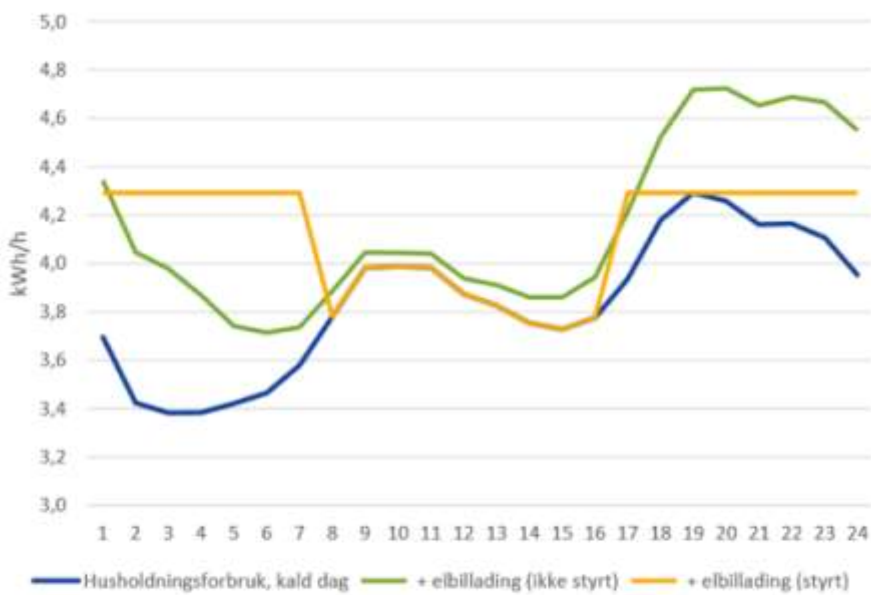


Figure 63: Controlled and uncontrolled loading for an average private household (blue: electric energy consumption of a private household on a cold day, green: uncontrolled loading of an EV, yellow: controlled loading of an EV) [72]

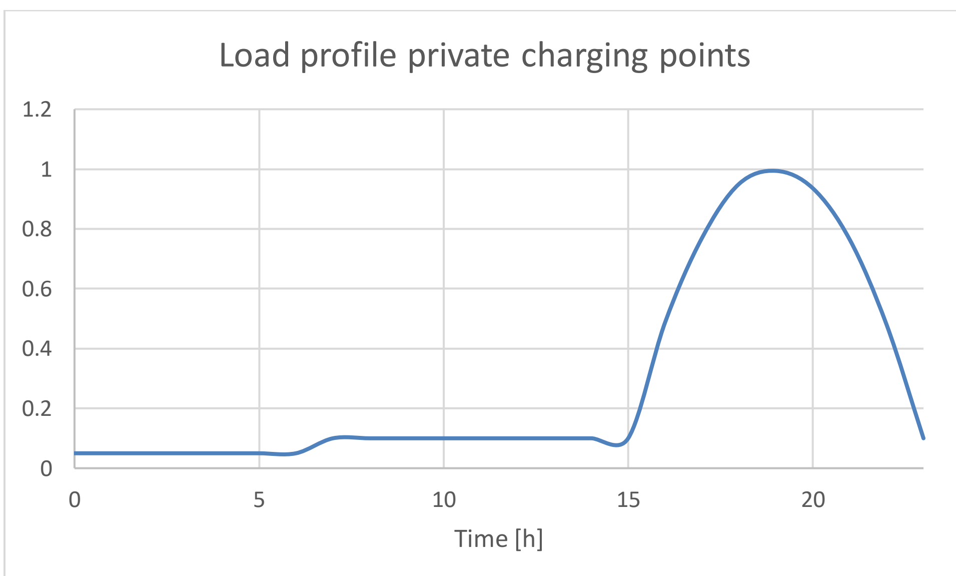
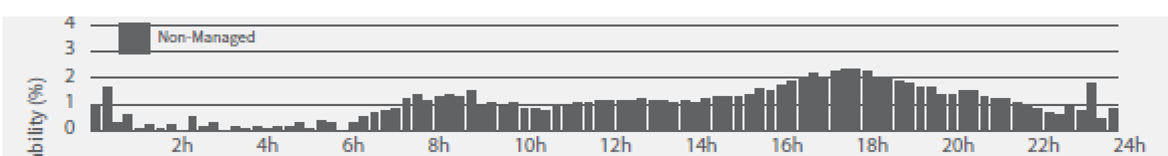


Figure 64: Load profile of private charging points (simulated)[73]



[72] Skotland C. H., Eggum E., Hva betyr elbiler for strømnettet? NVE Rapport nr. 74-2016. September 2016, Oslo (in Norwegian)

[73] The Y axis is a normalized values (1 = peak). This chart is an image of the probability to encounter the peak. Source Support for the integration of electric vehicle charging stations into the distribution network in Greece, FGH Report, 2019-0541-FGH, October 2019

Figure 65: Start charging time

Technical Appendix: Evaluation of street charging profile: Methodology aspects.

The data required for the evaluation of each charging event is available to the charge point operator and can be found in the following table.

Field	Name / Content	Description
1	Charging point ID	Identification of the location
2	User RFID	Identification of shared vehicles and charging power estimation
3	t_{PS}	Time of Day Connection Start
4	t_{PE}	Time of Day Connection End
5	ΔE	Total charged energy

Table 9: Charge point data structure

With the help of the required data a clustering of the individual charging events is possible. The first cluster represents the "car sharing" users. These can be identified by their individual RFID. In order to further differentiate the charging events that still exist after deduction of the "car sharing" users, the connection times are examined more in detail. Thereby it is considered that the time of day connection end does not correlate to the time of day charging end t_{CE}. The relationship between the time of day connection start and the time of day charging start is shown in Figure 65, as well as the relationship between the end times.

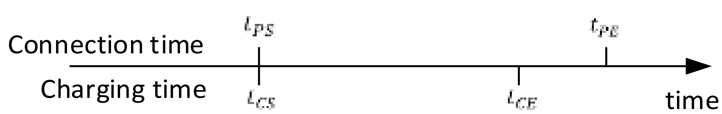


Figure 66: Relationship between connection time and charging time

The analysis of the remaining charging events leads to three further clusters, the "charge near Home (CnH)", the "charge near Work (CnW) and the "Park to Charge (PtC)". The criteria of the individual clusters can be found in the next table.

Name	Description / Criteria
Shared Vehicle	User RFID
Charge near Home	$[06{:}00 > t_{PS}\ AND\ (t_{PS} - t_{PE}) > 5.5\ h]\ OR$ $[02{:}00 > t_{PS} \geq 06{:}00\ AND\ t_{PS} > t_{PE}]\ OR$ $[t_{PS} \geq 12{:}00\ AND\ t_{PS} > t_{PE}\ AND\ t_{PE} \geq 04{:}00]$
Charge near Work	$12{:}00 > t_{PS} \geq 06{:}00\ AND$ $(t_{PS} - t_{PE}) > 5.5\ h$
Park to Charge	All others

Table 10: criteria for the classification of different charging events

The cumulated result of clustering the remaining charging events of the various charging events in the period from December 2017 to November 2018 for one day is shown in **Error! Reference source not found.**6.

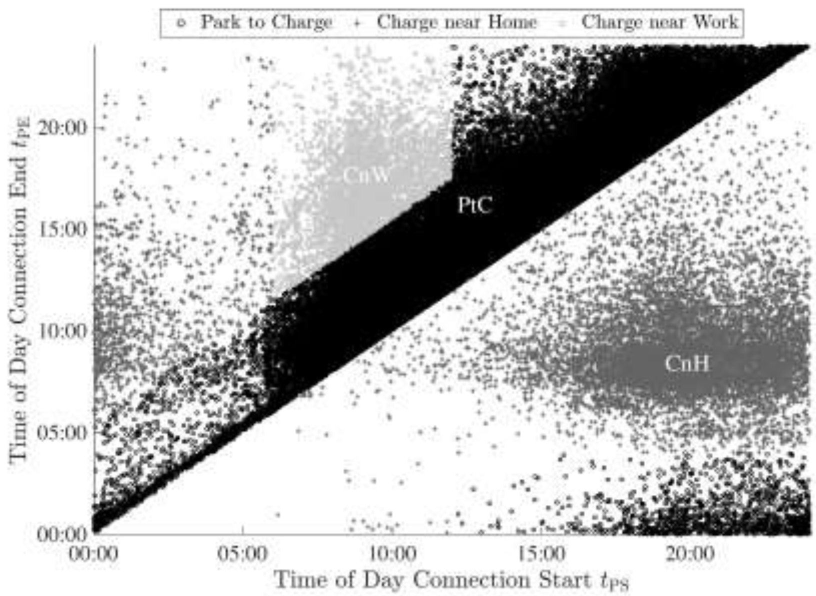


Figure 67: Classification of different charging events by using the connection time

10 References

(note: the reference are generally mentioned where they are used)

[1] Maier U., Ropenus S., Jahn A., Jörling K., Knapp J., Nabe C., Steinbacher K., Tiedemann S., Greve M., Tretschock M., Kippelt S., Burges K., Verteilnetzausbau für die Energiewende Elektromobilität im Fokus, Navigant, RAP, Agora Energiewende, Agora Verkehrswende, August 2019, Berlin

[2] Vennegeerts H., Tran J., Rudolph F., Pfeifer P., Metastudie Forschungsüberblick Netzintegration Elektromobilität, FGH e.V., Dezember 2018, Aachen

[3] Support for the integration of electric vehicle charging stations into the distribution network in Greece, FGH Report, 2019-0541-FGH, October 201