SMART EV CHARGING SYSTEMS FOR ZERO EMISSION NEIGHBOURHOODS

A state-of-the-art study for Norway

ZEN REPORT No. 5 – 2018

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Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

ZEN Report No. 5

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Smart ev charging systems for zero emission neighbourhoods
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Abstract

The increased use of electric vehicles (EVs) calls for new and innovative solutions for charging infrastructure. At the same time, it is desirable to improve the energy flexibility of neighbourhoods. This paper presents state-of-the-art for smart EV charging systems, with focus on Norway.

The aim of the study is to start investigating how smart EV charging systems can improve the energy flexibility in a Zero Emission Neighbourhood (ZEN). The intention is that the study will be useful when evaluating activities and technologies for the ZEN pilot areas.

The paper presents energy demand for EV charging and typical charging profiles. Further, it describes how charging stations can interact also with the energy need in buildings and neighbourhoods, local energy production and local electric and thermal energy storage. Examples of commercial smart EV charging systems are described.

The report lists some opportunities for testing smart EV charging in the ZEN pilot areas. Piloting of new technologies and solutions can provide more knowledge about smart EV charging systems, and how they can participate in matching energy loads in buildings and infrastructure with local electricity generation and energy storage.

Contents

Introduction

The Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN Centre) is a new Centre for Environment-friendly Energy Research from 2017, funded by the Research Council of Norway and 34 partners. The main objective of the ZEN Centre is to develop knowledge, competitive products and solutions that will lead to realization of sustainable neighbourhoods, that have zero emissions of greenhouse gases related to their production, operation and transformation. There are seven pilot areas in the ZEN Centre, where new technologies and systems will be implemented and evaluated. The Centre aims to speed up decarbonisation of existing and new building stock, use more renewable energy sources and create positive synergies among the building stock, energy, ICT, mobility systems and citizens.

This report is a part of Work Package 4 "Energy Flexible Neighbourhoods". The goal for WP 4 is to develop knowledge, technologies and solutions for design and operation of energy flexible neighbourhoods.

An energy flexible neighbourhood manages the local energy demand, energy production and storage capacity according to local climate conditions, user needs, grid constraints and prices. Flexibility is embedded in both thermal and electric systems and in the interplay between them. Flexibility can further be made available outside the neighbourhood to the grid.

This report describes state-of the art for Smart EV charging systems for Zero Emission Neighbourhoods. The aim is to investigate how smart charging systems can improve energy flexibility of ZENs. In this study, the main focus is on charging systems for Electric Vehicles (EVs), but also battery solutions connected to photovoltaic (PV) energy production is addressed. The intention is that the study will be useful when considering if and how smart charging systems can be tested in the pilot areas.

1 Smart EV charging systems

1.1 How to define "Smart EV charging systems"

The term "Smart" is used in a number of ways, for example related to "smart cities", "smart energy systems", "smart grids", "smart appliances" and "smart EV charging systems". The added value of the smart-term varies from case to case, and it is therefore difficult to give a general definition of "Smart EV charging systems".

In this chapter, we firstly refer to some descriptions and definitions for the smart energy and smart charging terms. Secondly, we describe how the term "Smart EV charging systems" is used in this paper, in the early phase of the research in the ZEN-centre.

1.1.1 Smart energy systems and smart technologies

It is a goal in the EU to move towards a smarter energy system in Europe. The Energy Union strategy (European Commission, 2015) is built on the ambition to achieve a fundamental cost-effective transformation of Europe's energy system. This will be achieved by moving to more flexible, more decentralized, more integrated and therefore *smarter*, more sustainable, secure and competitive ways of delivering energy to consumers (European Commission, 2016a).

The European Commission also addresses the *smart city market*. In the global smart city market, one of the key challenges is to provide solutions that significantly increase cities' overall energy and resource efficiency through actions addressing the building stock, energy systems and mobility (European Commission, 2016b).

The European Commission SET Plan has a strategic target to be global role model/market leader in technology integration for and deployment of net–zero energy/emission districts (ZEED) (European Commission, 2016b). The aim by 2025 is, to have at least 100 successful examples synergistically-connected to the energy system in Europe and a strong export of related technologies. The ZEED districts consist of different buildings that actively manage the energy flow between them and the larger energy and mobility system. They make optimal use of advanced materials, local RES, local storage, demand-response, electrical vehicle smart charging, cutting edge energy management (electricity, heating and cooling), user interaction and ICT in order to have a net–zero-energy/emission balance throughout their entire lifetime and a positive impact on the energy system (European Commission, 2016b).

Smart technologies will help consumers and energy service companies working for them to reap the opportunities available on the energy market by taking control of their energy consumption (and possible self-production). This will deliver more flexibility in the market and potentially reduce consumer bills. (European Commission, 2015)

The European project Transform (2012-2015) has defined a *smart energy city* (Transform, 2015):
The Smart Energy City is highly energy and resource efficient, and is increasingly powered by renewable energy sources; it relies on integrated and resilient resource systems, as well as insight-driven and innovative approaches to strategic planning. The application of information, communication and technology are common means to meet these objectives.

The Smart Energy City, as a core to the concept of the Smart City, provides its users with a liveable, affordable, climate-friendly and engaging environment that supports the needs and interests of its users and is based on a sustainable economy.

1.1.2 Smart EV charging systems

The "Global EV Outlook 2017" (OECD/IEA, 2017) describes that as the number of EVs increases, charging could have a sizeable impact on the capacity required by the grid at certain times and locations, with consequences for the adequacy and quality of the power supply, risks of cost increases for consumers and the potential for negative feedback on transport electrification prospects. OECD/IEA (2017) further point out that EVs are well suited to promote synergies with variable renewables. If charging practices strengthen demand-side management opportunities, EVs could allow a greater integration of these energy sources in the power generation mix. The report also describes that:

Large-scale electric car charging and demand response will require the joint optimisation of the timing and duration of recharging events, the modulation of power delivered by charging outlets (defining the speed of charge) and may involve a reliance on vehicle-to-grid solutions. For fast chargers, managing power demand is also likely to require the deployment and use of stationary storage at the local or grid level.

The Platform for electro-mobility in the EU states that "Smart charging of electric vehicles should benefit EV owners by reducing their electricity costs in return for the enhanced grid stability and reliability" (Platform for Electro-Mobility, 2016). Their definition of Smart charging is:

Smart charging consists of adapting EV battery charging patterns in response to market signals, such as time-variable electricity prices or incentive payments, or in response to acceptance of the consumer's bid, alone or through aggregation, to sell demand reduction/increase (grid to vehicle) or energy injection (vehicle to grid) in organised electricity markets or for internal portfolio optimisation.

The company FleetCarma describes Smart charging as the intelligent charging of EVs, where charging can be shifted based on grid loads and in accordance to the vehicle owner’s needs. The utility can offer EV owners monetary and/or non-monetary benefits in exchange for enrolment in a program that permits controlled charging at the times when curtailment capacity is needed for the grid. The result is a much more consistent/flattened load profile. (FleetCarma, 2017)

Smart charging systems can have several aims, depending on the preferences of the operator. For example, the research association EnergyVille in Belgium, describes three scenarios for the management of a charging process (EnergyVille, 2017):

- Peak shaving scenario: Charge when the grid capacity is high (off-peak), or manage the simultaneous charging of several electrical vehicles in the same street or car park by spreading their demand over time.
- Renewable scenario: Charge when the availability of renewable energy from sun and wind is high.
- Balancing scenario: Keep demand/supply balanced.

In each scenario it is guaranteed that the electrical vehicle will be charged by the time the driver wants it to be charged, and to the level requested.

Figure 1.1 shows different EV integration approaches for charging processes (García-Villalobos et al., 2014). Uncontrolled charging increases the energy peaks. This situation can be improved by off-peak charging or smart "valley filling". The last figure shows how peak shaving can be part of a smart charging approach.

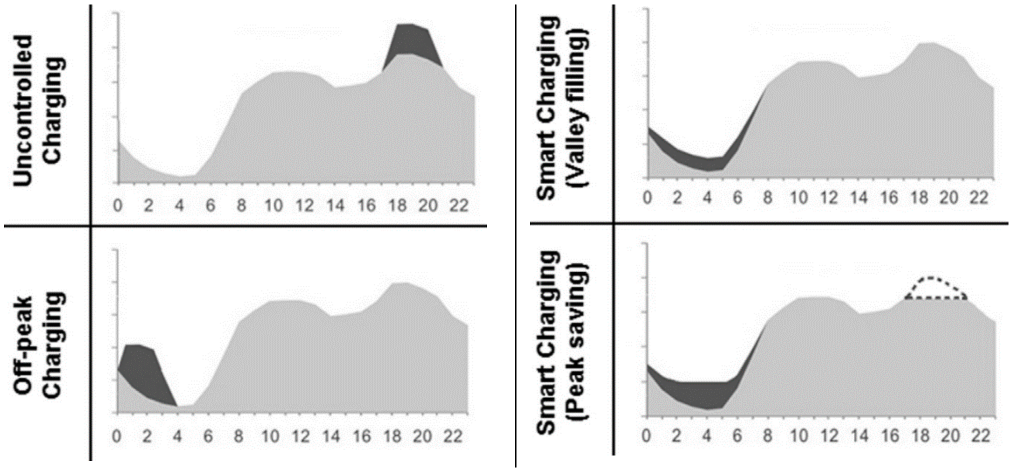


Figure 1.1 Different EV integration approaches (García-Villalobos et al., 2014)

EV charging strategies can be divided in three categories, based on the level of control, as shown in Figure 1.2 (Knezovic, 2016). Uncontrolled charging represents charging where the EV charges at maximum power as soon as it is connected to the grid. Passive control includes situations, where the EV owners are encouraged to charge their EV at a certain time, for example by having lower price tariffs during the night. The active smart charging is divided in two: unidirectional and bidirectional (V2G). With unidirectional charging, the EVs can modulate the charging power. With bidirectional charging (V2G), the EVs can also inject power back to the grid.

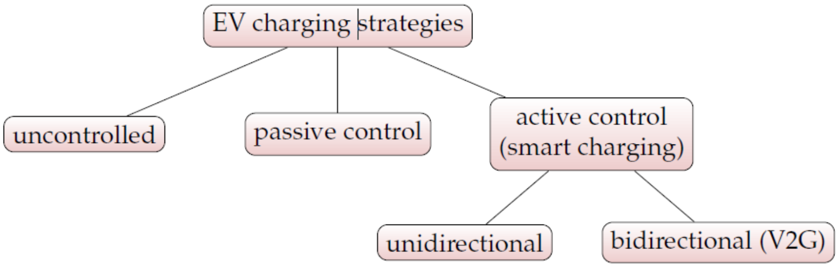


Figure 1.2 Classification of possible strategies for EV adoption (Knezovic, 2016)

Knezovic (2016) defines EV flexibility services as a power adjustment maintained from a particular moment for a certain duration at a specific location, characterised by: (1) the direction, (2) the power capacity, (3) the starting time, (4) the duration, and (5) the location. If EV is not V2G capable, the flexibility direction is always the same. This is illustrated in Figure 1.3.

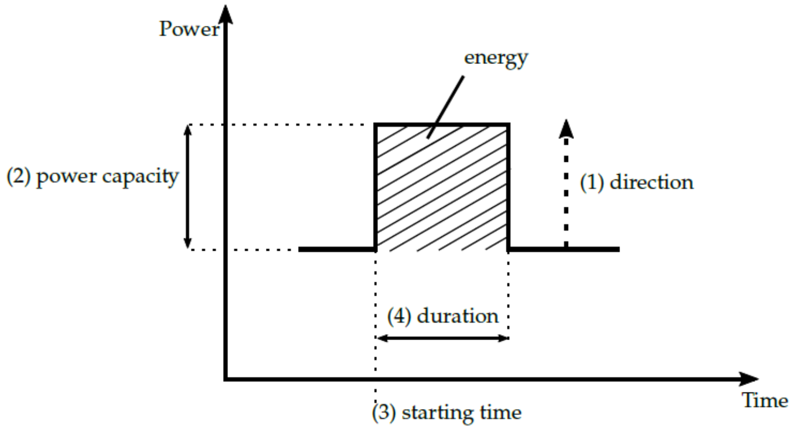


Figure 1.3 Theoretical attributes of an EV flexibility service (excluding the location) (Knezovic, 2016)

1.1.3 How the term "Smart EV charging systems" is used in this paper

There is no common definition or standard for a "Smart EV charging systems". The different Smart EV charging systems available on the market or described in literature therefore have different goals and specifications.

In this report, some control strategies and goals for smart EV charging systems, often found in descriptions of such systems are therefore summarized in Table 1.1. The possibilities are sorted from low to high "smartness". The methods to achieve the intelligent control of the charging can vary, as further described in Chapter 1.2.

Table 1.1 Examples of common control strategies and goals for smart EV charging systems (Sørensen et al., 2017b).

Low "smartness"		**High "smartness"**
Uncontrolled EV charging	Active control of charging, by shifting EV charging in time	Building/ neighbourhood energy management, with energy demand, production and storage
Passive control of charging, by encouraging EV owners	Load management of EV charging	Active use of stationary energy storage (batteries)
	Booking of charging services	Active use of bidirectional V2G solutions

Goals
Charging possibilities also with limited grid capacity
Efficient, practical, cost effective and reliable services for users
Enhanced grid stability and delay grid upgrades
Increasingly powered by local renewable energy sources
Empowering and engaging users
Energy efficient and climate-friendly
New business models and new companies
Secure, e.g. when it comes to fire safety and security of personal data

1.2 Intelligent control methods for charging

The architecture for implementing the control methods can be classified into centralized and decentralized control, also denoted as direct and indirect control (García-Villalobos et al., 2014). Direct control (or centralized control) is based on centralized decision making where a centralized party remotely controls the charging power to an EV. Indirect control (or decentralized control, distributed control) relies on EV owner making the decision and responding to signals from a third party, e.g., price or control signal.
An extensive number of research has been carried out on smart charging of EVs and the design of optimal charging strategies. Wang et al. surveys existing smart charging for EVs from the algorithmic perspective, focusing the smart interactions among the smart grid, aggregators and EVs from algorithmic perspective (Wang et al., 2016). The study shows that optimization-based approaches to achieving load flattening have been widely adopted. Direct control and indirect control approaches have been utilized to maximize the overall satisfaction of all EV customers. They consider real-time allocating charging power to multiple EVs as real-time resource scheduling problem or apply game theory. Stochastic optimization approaches have been used to design the optimal schedule for minimizing individual EV customers' charging cost.

Yang et al. gives a review of intelligent scheduling for integrating EVs with power systems based on their computational techniques (Yang et al., 2015). The scheduling methods are formulated as optimization problems and classified into *conventional methods* including linear and non-linear programming, dynamic programming, mixed integer programming, game theory and queuing theory; and *meta-heuristic methods* like genetic algorithm and particle swarm optimization.

According to the review of (García-Villalobos et al., 2014), the methods for intelligent EV charging control include contex optimization, quadratic optimization, dynamic optimization, meta-heuristic method, fuzzy logic, artificial immune systems, game theory, particle swarm optimization and graph search algorithm.

Below we describe some examples of methods for smart EV charging, i.e., methods for scheduling and optimization of EV charging.

Load management can reduce pressure on the grid by splitting the load and extending the charging time. Vandael et al. proposes a decentralized, multi-agent system based approach for load management of EV charging with reactive and proactive scheduling methods (Vandael et al., 2014). The reactive method postpones extra load above a maximum charging power, while the proactive method calculates the total load first and then divide it into several charging periods. Flexibility of a fleet of EVs is expressed using an "intention graph" and allows for rescheduling in real-time to reduce imbalances.

Shao et al. proposes a demand management approach for EV charge scheduling accomplished by staggering the EV charging time, or performing household load control (Shao et al., 2009). The approach is based on Advanced Metering Infrastructure (AMI) to monitor household loads together with an EV control unit and remote switches for controlling the household load. In the household load control method, real-time household load profile is continuously monitored and some non-critical but heavy domestic loads (such as electric hot water heaters and air conditioning units) can be deferred or shut down for a period of time to reduce the total load to support the EV charging.

Ottesen, Korpås and Tomasgard applies direct control methods on a charging site with capacity limits and proposes two different smart charging scheduling methods with the goal to reduce maximum power at a charging site: a rule-based algorithm and an optimization based model (Ottesen et al., 2016). The rule-based algorithm uses available information about current situation to schedule charging and try to handle capacity problem based on the rules that first by discharging storage units, then regulating down the charging power for normal mode charging points and finally reducing the charging power for priority mode charging points. The optimization-based model utilizes the flexibility represented by user preferences regarding departure time and charging volume to schedule charging to a later period instead of charging immediately from the connecting time. The study also considers smart charging in combination with storage and generation units (such as local PV production). The result shows that both methods reduce maximum power considerably, but the optimization-based approach outperforms the rule-based approach.

In smart home/building context, EV charging is typically integrated with the central energy management systems and considered in accordance with other energy consuming resources and energy generation sources in the individual homes/buildings. Wi, Lee and Joo proposes an EV charging method for smart homes/buildings with a PV system (Wi et al., 2013). The method predicts PV output and electricity consumption based on historical data and adjusted with weather sensitivity, and optimizes EV charging scheduling based on constraints such as vehicle charge level, battery capacity, charging rate, price information and user preference.

In contrast to scheduling EV charging in an individual home/building/charging site, the CoSSMic approach schedules EV charging in coordination with other energy consumption tasks, local renewable energy sources (RES) and batteries in a neighbourhood (e.g., a group of buildings) according to users' needs and preferences (Jiang et al., 2016). CoSSMic adopts a hybrid control mechanism combining distributed planning and scheduling based on predictions with a reactive feedback loop to cope with the unpredictability of the fluctuating insolation. The optimization is based on time-continuous scheduling and uses predicted profiles, with load profiles based on statistical learning and predicted PV production based on weather forecast and installation parameters.

1.3 Market for energy flexibility

If the consumers are energy flexible, this has a value for the grid companies (European Commission, 2013). With the new smart meters (AMI), it is possible to introduce market mechanisms to increase the use of energy flexibility – as an economically attractive alternative to grid investments.

In the White Paper on Norway's energy policy (Ministry of Petroleum and Energy, 2016), it is stated that flexibility both on the production and the consumer side is favourable for security of energy supply. In the future, new technologies can manage the energy use to a larger degree than today. The report states that the price signals will be crucial to what elements of the short-term flexibility which will be utilized.

The Norwegian Water Resources and Energy Directorate (NVE) are investigating opportunities for using market mechanisms for flexibility to handle capacity constraints in the grid (NVE, 2015, NVE, 2017).

THEMA Consulting Group (2016) wrote a consultancy report to NVE on this topic. The report states, that over the next ten years, investment plans in the Norwegian distribution grid and regional grids amount to up to 80 billion NOK. It is expected that a substantial share of the grid investments will be made in order to avoid bottlenecks occurring only a few hours each year. In such cases, the use of local flexibility resources emerges as an economically attractive alternative to grid investments. When the full load hours decrease, the grid companies' willingness to pay for local flexibility increases. (THEMA Consulting Group, 2016)

Based on this, it seems likely that new market mechanisms for energy flexibility will be developed in Norway. With such a mechanism, building owners and neighbourhoods may be able to play a more active role in the energy system – together with the utility company.

2 Balancing energy and power in a ZEN

A smart EV charging system can contribute to balancing the energy and power in a Zero Emission Neighbourhood. This chapter describes the electricity use in households and non-residential buildings, as well as the flexible electricity loads in Norwegian households. Lastly, the principle of balancing energy and power in a ZEN is described.

2.1 Electricity use in households and non-residential buildings

Figure 2.1 shows typical hourly electricity use in households and non-residential buildings (Ericson et al., 2016). The peak in a household is typically in the morning and afternoon/evening, while the peak in a non-residential building typically is during office hours. Figure 2.2 shows a calculated load profile for a household during a cold winter day (Ericson et al., 2016). Heating and domestic hot water is typically a large share of the electricity load during the winter: Up to 75% during a cold day.

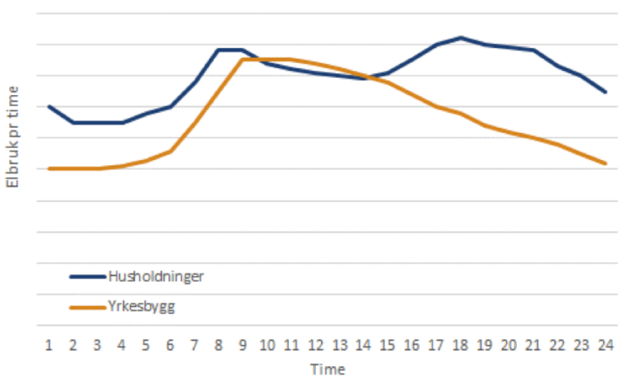


Figure 2.1 Hourly electricity use in households and non-residential buildings (Ericson et al., 2016)

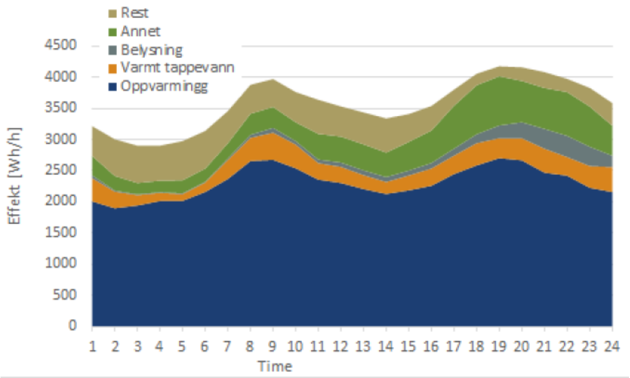


Figure 2.2 Calculated load profile for a household during a cold winter day (Ericson et al., 2016)

Figure 2.3 shows the breakdown of electricity consumption in a Norwegian household, based on Dalen and Larsen (2013). The figure also show how the electricity consumption for different end uses has changed over time, from 1990 to 2006.

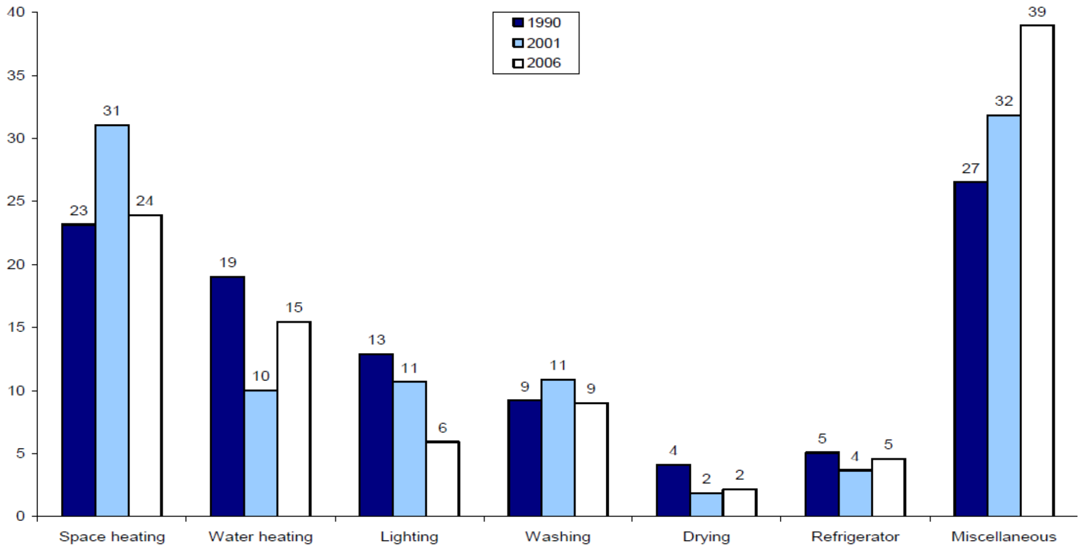


Figure 2.3 Temperature-corrected electricity consumption for different end uses in 1990, 2001 and 2006. Average for Norwegian households. Per cent (Dalen and Larsen, 2013)

Electricity is the main heating source for households in Norway. According to Statistics Norway, electricity accounted for about 73% of household heating in 2012 (SSB, 2014). Many Norwegian buildings use heat pumps, including close to half of the detached houses in Norway (Ericson et al., 2016). The air-to-air heat pumps are most common, as shown in Figure 2.4, with an installed capacity of under 10 kW in each household.

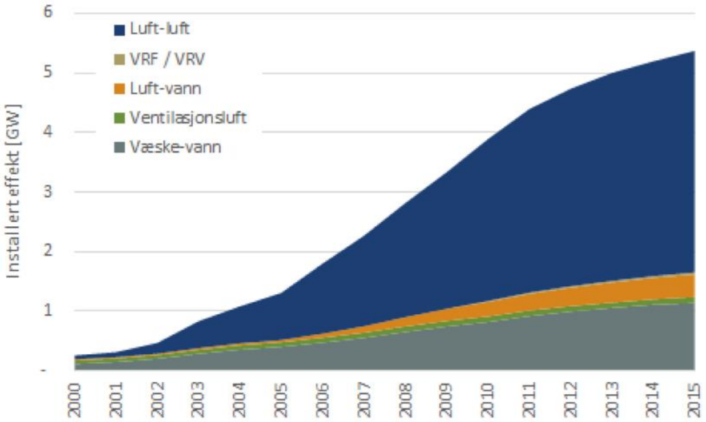


Figure 2.4 Installed power of heat pumps in Norway (Ericson et al., 2016)

The high penetration of electric heating makes national electricity consumption very temperature dependent and high peak consumption can occur on cold winter days. Figure 2.5 shows the hourly load curve month by month, where the consumption is highest during winter months (Dromacque et al., 2017).

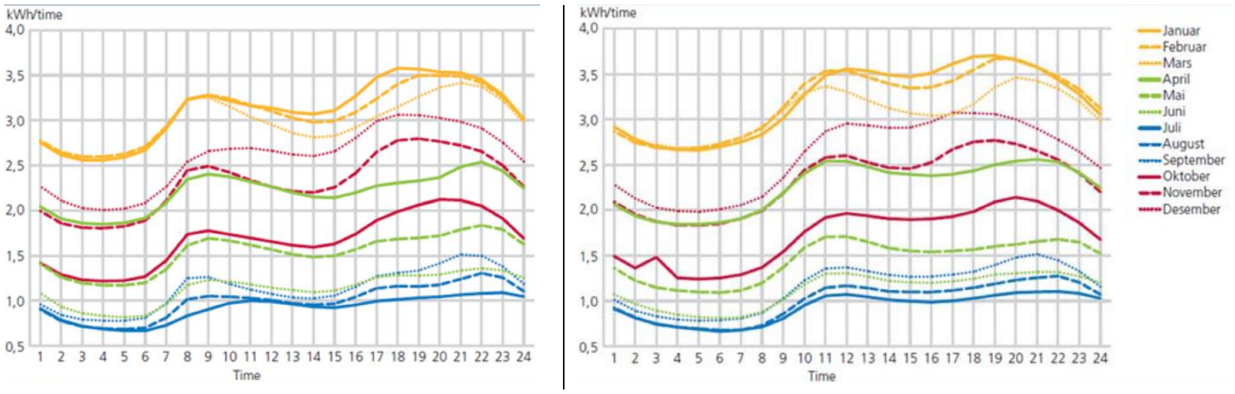
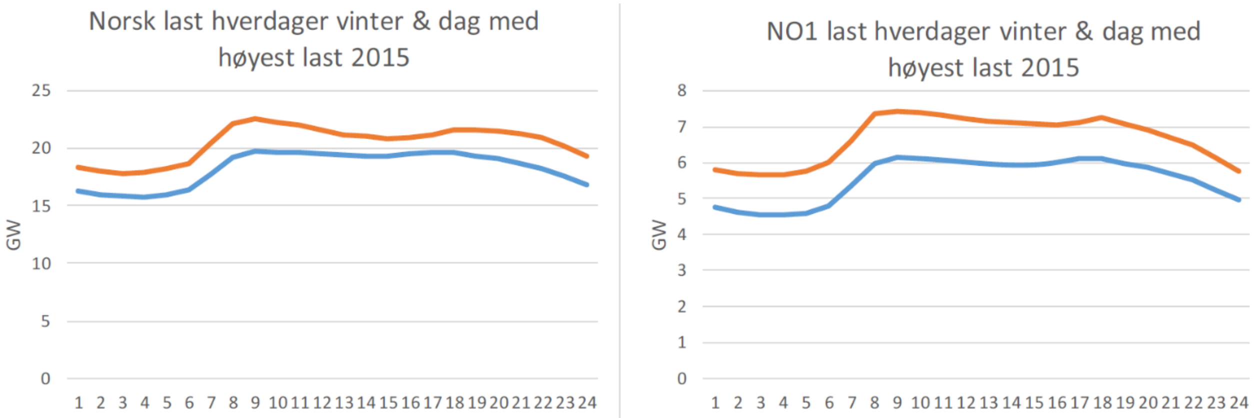


Figure 2.5 Seasonal Variations in electricity consumption, weekdays (left) and weekends (right) (Dromacque et al. (2017), from Statistics Norway 2008).

In general, it is often during the winter that shortage of power can occur in Norway (Henden et al., 2017). The consumption profile for a weekday during the winter is shown in Figure 2.6, for Norway in total. The figure shows that from a power system perspective, there is a load in the morning. A reduced load from hour 6 to hour 9 would be an advantage, especially during cold days.


Norsk last hverdager vinter & dag med høyest last 2015

NO1 last hverdager vinter & dag med høyest last 2015

Figure 2.6 Energy consumption profiles for Norway (left) and the area NO1 (right), during a weekday in the winter. The blue line is average during winter, while the red line is the curve for the day with the highest consumption (Henden et al., 2017)

2.2 Flexible electricity loads in Norwegian households (not including EV charging)

Other electricity loads can also be flexible in a building, not only EV charging. Flexible loads can be shifted in time (turned off / on), and for some flexible loads also the load can be regulated (turned lower or higher).

Heating

With electricity as the primary heating source, peak consumption is closely related to the weather. However, electric heating and heat pumps can be considered as a source of flexibility (Dromacque et al., 2017). Heating loads can be shifted in time or regulated. Buildings with waterborne systems are more energy flexible than buildings with direct use of electricity (e.g. panel ovens or air-air heat pumps), since heating can be stored in the waterborne systems. The heat storage capacity of the building itself also impact the flexibility. Further, buildings with several heating sources are more flexible. Flexibility of heating systems is further studied in another ZEN task (WP 4-1 and 4-3).

Electric water boilers

Electric water boilers are intuitively very suitable for flexibility, as water can be heated during off-peak hours and remain warm as the boiler is switched off during peak hours. This makes the loss of comfort almost imperceptible to consumers. (Dromacque et al., 2017) Electric water boilers can be shifted in time or regulated.

White goods

A number of smaller appliances that can be grouped in the category of white goods (i.e. refrigerator, freezer, tumble dryer, washing machine, dish washer), represent a significant proportion of electricity consumption in Norwegian homes (Dromacque et al., 2017). The timing of using such appliances can be shifted in time.

2.3 Local electricity production from solar cells (PV)

PV systems generate electricity during the daytime. Figure 2.7 shows a conceptual diagram of power supply from solar cells (PV) (IEA-PVPS, 2009). Usually, there are energy need in households and non-residential buildings during the day, which can be covered directly by PV. Still, PV systems cannot supply electricity in the evening when the demand usually remains high. In addition, the electricity production during the winter is low in Norway (Norsk solenergiforening, 2015).

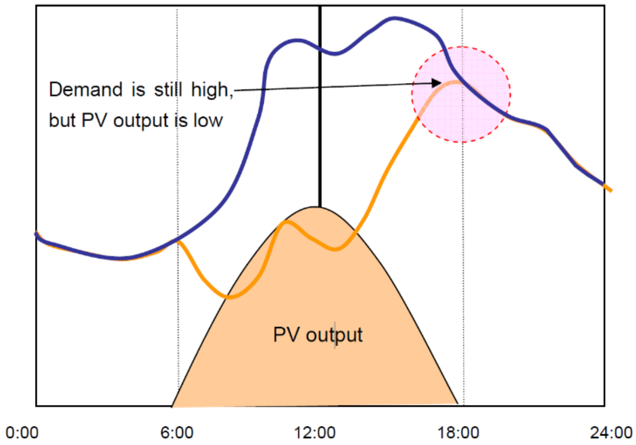


Figure 2.7 Conceptual diagram of power supply from solar cells (PV) (IEA-PVPS, 2009)

A prosumer agreement exists in Norway, for locally produced electricity ("Plusskundeordningen"). Smart meters (AMI) measure electricity sale and buy on an hourly basis. Financially, consumers receive less payment for electricity sold to the utility than what they pay for buying electricity from the utility. This makes it beneficial to maximise self-consumption, i.e. minimising export of electricity to the grid. In such a case, most households would benefit from having PVs orientated east-west as they will produce more electricity in the morning and in the afternoon, following the load profile. In the case of an office building, the PVs might be orientated south, as peak load normally occurs during midday. (IEA-PVPS, 2009)

2.4 Balancing energy and power in a neighbourhood

As described in Chapter 1.1, EnergyVille (2017) describes three scenarios for the management of a charging process. The same scenarios are examples of energy management in a ZEN:

- Peak shaving scenario: Managing the energy consumption in a neighbourhood, spreading the flexible energy demand over time.
- Renewable scenario: Increase the flexible energy demand when the availability of renewable energy from sun and wind is high.
- Balancing scenario: Keep demand/supply balanced.

Getting back to how smart EV charging systems can contribute to this, Figure 2.8 shows the additional residential load from electric cars during a typical day under the beyond-two-degree scenario in the European Union in 2030 (OECD/IEA, 2017). The uncontrolled EV charging in the first figure, is compared with controlled EV charging in the second figure. According to current best knowledge, such controlled EV charging could be enabled through price and control signals, without impacting travel demand.

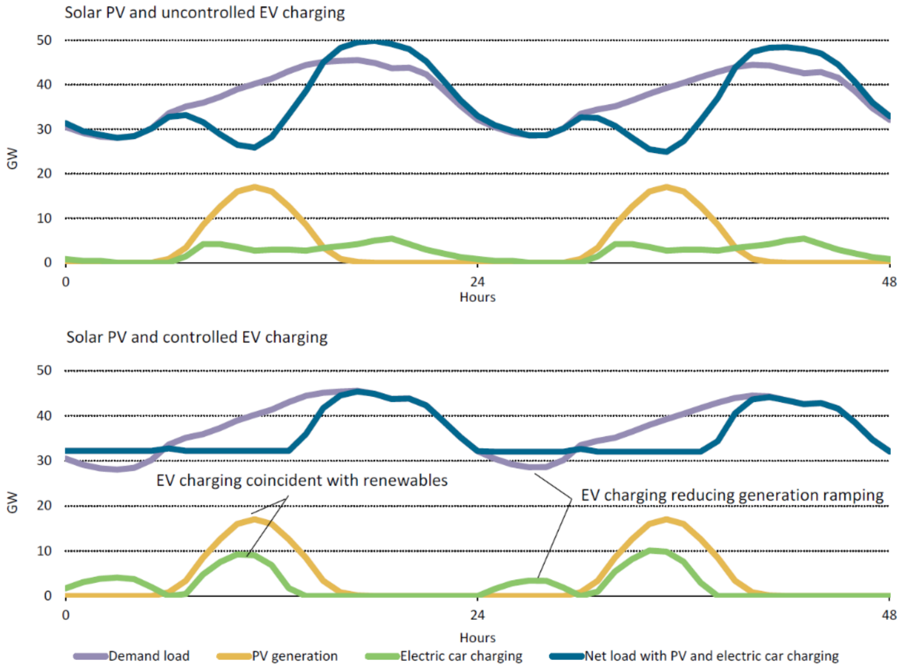


Figure 2.8 Local demand profile and electric car charging in the European Union on a typical day, beyond-two-degree scenario, 2030 (OECD/IEA, 2017). The first figure shows uncontrolled EV charging, while the second figure shows controlled EV charging.

Skotland et al. (2016) illustrates controlled and non-controlled EV charging in a typical Norwegian household, see Figure 2.9. The authors state that increased electrification of the transport sector can be a challenge for the Norwegian grid, but that it is possible to reduce the challenges by shifting the timing of the charging. This can for example be initiated by lower energy tariffs during off-peak periods. The energy provided to the EV in Figure 2.9, is the same in the controlled (yellow) and non-controlled (green) example, but the controlled case takes the household consumption into account when charging the car. In both cases the car is fully charged at 7 am in the morning. The aim of such a control strategy is, that the EV does not increase the maximum load in the household. It is further possible to also shift other electricity loads in the building or to utilize locally produced electricity, as discussed in this report.

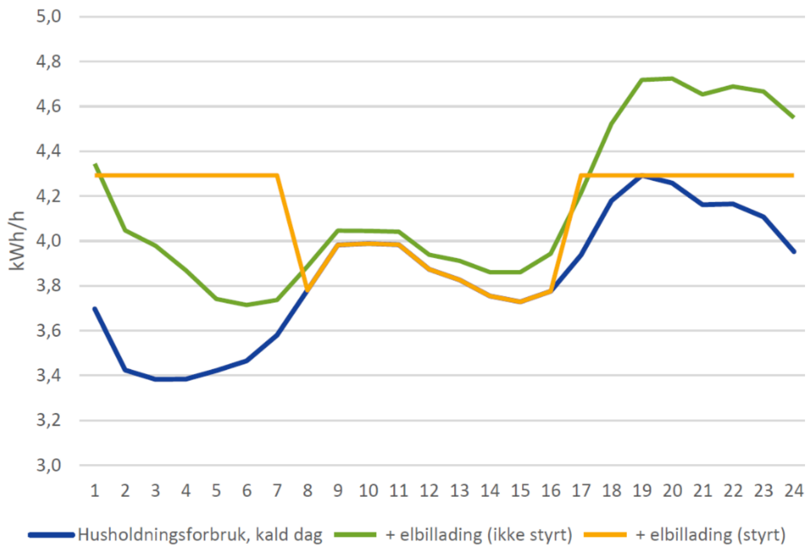


Figure 2.9 Controlled and non-controlled EV charging in a typical Norwegian household (Skotland et al., 2016)

OECD/IEA (2017) describes three options as particularly relevant for electric car charging, when developing charging infrastructure in buildings with rising numbers of electric cars. The first option is the buildout of charging infrastructure itself and deploying it both at locations and with technologies that minimise any negative impacts. A second option is through incentivising end users to maximise self-consumption through solar systems installed on consumers’ homes combined with the available storage and recharging infrastructure. In this second phase, challenges start to arise as the number of charging points must be limited to the available power in the building (or neighbourhood). In the third phase, the available power of the entire building needs to be distributed between the apartments in the building (or the network of dwellings in the neighbourhood) and the charging points.

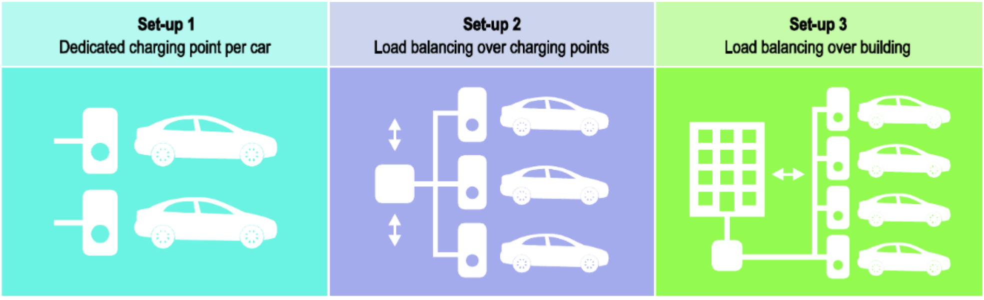


Figure 2.10 Development of charging infrastructure in buildings with rising numbers of electric cars (OECD/IEA, 2017)

Ideally, when installing the initial charging points in e.g. an apartment building or neighbourhood, the set-up should be prepared also for future charging needs. Otherwise, existing instalments may lead to higher infrastructure costs at a later stage. However, this can be challenging since there are normally few users in such an initial phase, compared to the larger number of users which may arise later. Incentives can address this issue, to make it possible to prepare the infrastructure already in an early phase. Some Norwegian municipalities offer such incentives, e.g. (Oslo municipality, 2017, Asker municipality, 2017).

3 EV charging standards

Electric vehicle supply equipment (EVSE) suitable for electric cars has three main characteristics (OECD/IEA, 2017):

- Level, describing the power output of an EVSE outlet,
- Type, referring to the socket and connector being used for charging,
- Mode, which describes the communication protocol between the vehicle and the charger.

The International Organization for Standardization and the International Electrotechnical Commission are developing standardization of electrotechnology for road vehicles (ISO, 2017, IEC, 2017). These norms and standards have been widely adopted by industry and national norming institutes (Dronia and Gallet, 2016). This Chapter lists some of the main standards.

In Norway, the committee NK69 (NEK, 2017b) deals with issues related to national, European and international standardization, related to electric vehicles and charging systems.

Electric vehicle charging system

EN/IEC 61851-1 specify general requirements for charging Electric Vehicles (EVs). Four charging modes are specified, as described in Table 3.1. E.g. the use of household socket-outlets and extension cords is Mode 1, while for Mode 2 protection device is built into the cable. Public charging columns is an example of Mode 3, while fast charging stations use Mode 4, for example the CHAdeMO chargers or the CCS2 (Combo2).

Table 3.1 Charging modes according to IEC-61851-1 (CIRCUTOR, 2017)

	Specific connector for EV	*Type of charge*	*Maximum current*	*Protections*	*Special features*
Mode 1	No	Slow in AC	16 A per phase (3,7 kW - 11 kW)	The installation requires earth leakage and circuit breaker protection	EV connection to the AC network using standard power connections
Mode 2	No	Slow in AC	32 A per phase (3,7 kW - 22 kW)	The installation requires earth leakage and circuit breaker protection	Special cable with intermediate electronic device with pilot control function and protections
Mode 3	Yes	Slow or semi-quick, Single-phase or three-phase	In accordance with the connector used	Included in the special infrastructure for EV	EV connection to the AC power supply using a specific device (SAVE)
Mode 4	Yes	In DC	In accordance with the charger	Installed in the infrastructure	EV connection using a fixed external charger

Plug types

EN/IEC 62196 defines different plug types for EVs and Electric Vehicle Supply Equipment (EVSE) for AC and DC charging. This standard refers to the connector types 1, 2, 3 and 4, where the Type 2 connector is used for charging electric cars within Europe.

Illustration 3.1 Type 2 connector (photo from ladestasjoner.no)

Vehicle to grid (V2G) communication interface

OECD/IEA (2017) states that, as electric car penetration increases, charging infrastructure will require common standards and interoperable solutions between charging stations, distribution networks and the electric cars themselves. Interoperability is necessary both on the physical-electricity-network side but equally at the ICT interface, where information will need to flow efficiently across the range of stakeholders along the value chain of the charging service.

ISO 15118 specifies the communication between Electric Vehicles (EV), including Battery Electric Vehicles and Plug-In Hybrid Electric Vehicles, and the Electric Vehicle Supply Equipment (EVSE).

ISO 15118 is already integrated in the newest version of the CHAdeMO-standard, which mean that such cars are prepared for V2G (TU.no, 2017a). V2G is currently not fully implemented in cars with CCS charging contact.

4 EV charging systems in Norway

4.1 Electric vehicles in Norway

Norway is a leading market for electric vehicles (EVs). The evolution of the global electric car stock from 2010 to 2016 is shown in Figure 4.1 (OECD/IEA, 2017).

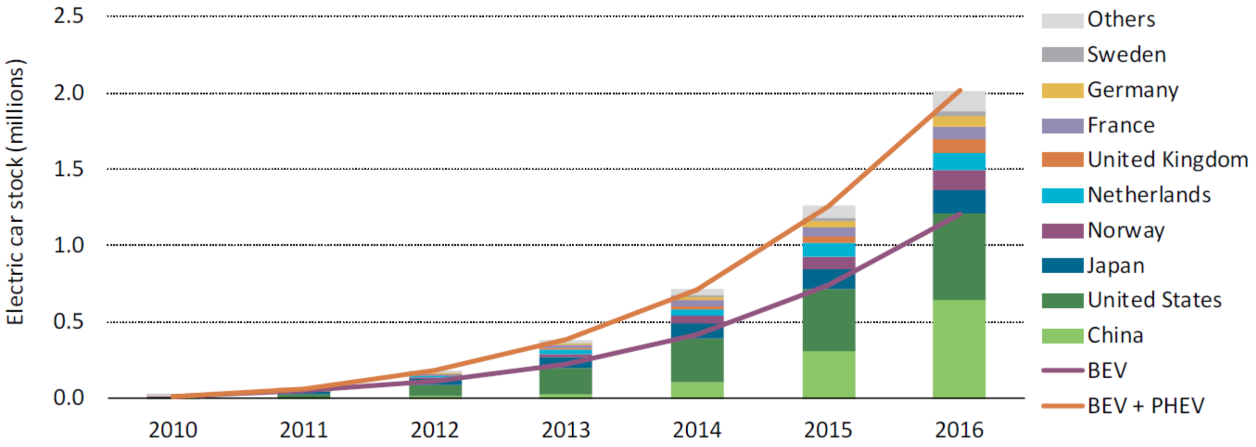


Figure 4.1 Evolution of the global electric car stock from 2010 to 2016 (OECD/IEA, 2017)

The number of EVs in Norway from 2010 to September 2017 is shown in Figure 4.1. By September, there where above 126 000 EVs and 58 000 plug-in hybrid cars. The market share of EVs is 20 % and 17% for plug-in hybrids (Norwegian Electric Vehicle Association, 2017).

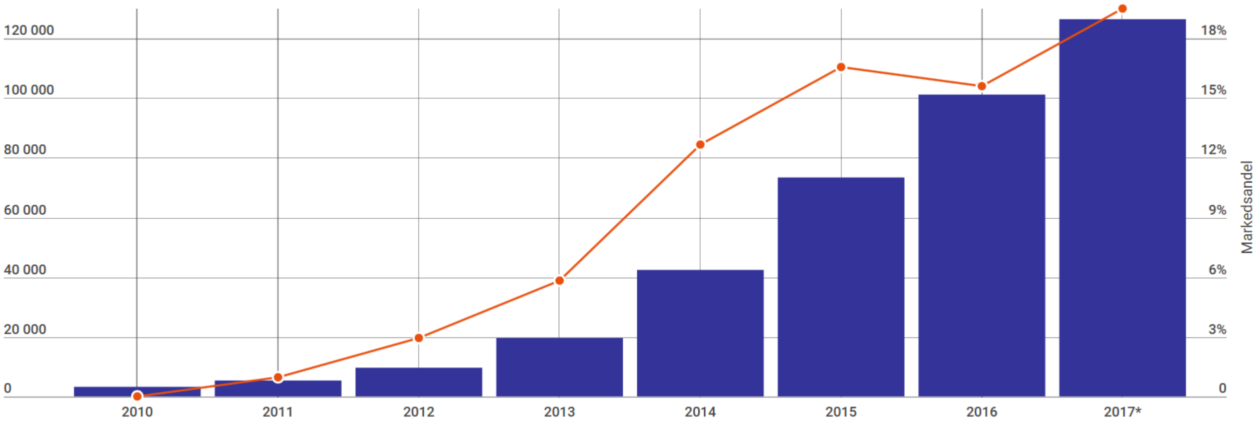


Figure 4.2 Number of EVs in Norway (blue columns) and their share of the market (red line), as per September 30 2017 (Norwegian Electric Vehicle Association, 2017)

Frydenlund (2017) analysed the car park when there were 110 000 EVs registered in Norway, by March 31, 2017. Most of the EVs (105 803) are registered as personal cars. The ten most popular EVs in Norway cover about 92% of these, see Table 4.1.

The battery capacity of the cars in Table 4.1 varies from 14.4 to 100 kWh. By June 2016, the average battery capacity for all the EVs in Norway was 30 kWh (Henden et al., 2017). Within short time, new cars with battery capacity of 50 to 60 kWh will be released (Skotland et al., 2016). It is expected that the average battery capacity for EVs in Norway will increase to 80 to 100 kWh towards 2030 (Henden et al., 2017).

Figure 4.3 shows electricity use per kilometre for various EVs used in Norway today, during summer and winter conditions. During the winter time the range is shorter, due less capacity in cold batteries, heating need in the car and increased rolling resistance (elbil.no, 2016b). As an average, it is normal to use 0.18 to 0.2 kWh per kilometre (ibid.).

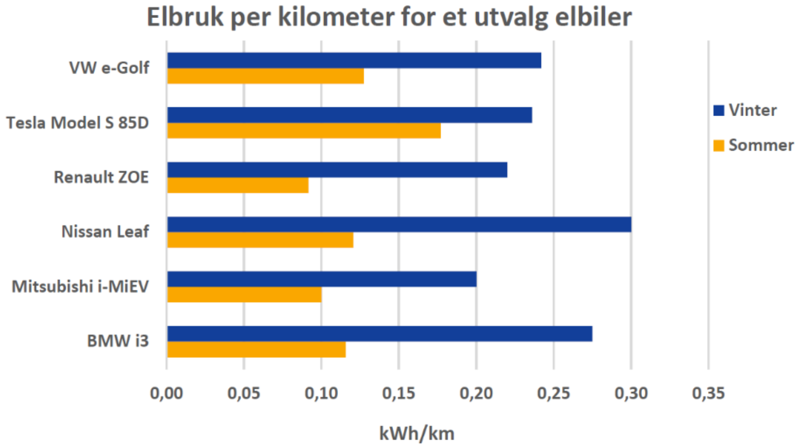


Figure 4.3 Electricity use (kWh) per kilometre (km) for six EVs in 2015, during summer and winter conditions (Skotland et al., 2016)

For fast charging, the ten most popular cars use CHAdeMO (44-100 kW DC), Combo (40-50 kW DC) and Tesla supercharger (135 kW DC). Fast charging stations have fixed external chargers, according to Mode 4 in the standard IEC-61851-1. In general, fast charging from 0 to 80% capacity with CHAdeMO or Combo takes about 30 minutes during the summer. During the winter the charging can take up to three times longer, due to battery chemistry in cold temperatures. Charging with Tesla supercharger takes about 45 minutes. For slow/semi-fast charging, the power is normally from 3 to 22 kW. Example of charging times with normal charging is shown in Table 4.1. (Frydenlund, 2017)

Table 4.1 Charging information and battery capacity of the top-10 electric vehicles in Norway, as per March, 2017 (based on Frydenlund (2017), elbil.no and (Skotland et al., 2016))

EVs in Norway	Number (%) EVs in Norway		Net battery capacity (kWh)	Approx. range in Norway (km)	Fast charging (kW DC)	Normal charging (kW AC)	Example of charging times (hours)			
							2.3 kW/ 10 A	3.6 kW/ 16 A (Type2)	11 kW/ 16A (3phase)	22 kW/ 32 A
1 Nissan LEAF	29 509	(27.8)	21.6 (24 gross)	100-160	CHAdeMO, 50	3.3	10 h	6-7 h		
			27.2 (30 gross) (new: 40 gross)	125-200	CHAdeMO, 50	6.6	+25% time	+25% time		
2 Volkswagen e-Golf	16 965	(16.0)	21.8 (new: 35.8)	100-190	Combo, 40	3.6	13 h	8 h		
3 Tesla Model S	12 287	(11.6)	67.5 (new: 100 gross)	~400	Supercharger, 135	11 Avail.: 22	Up to 40 h	23 h		3-5 h
4 BMW i3	9 953	(9.4)	18.8 (22 gross)	80-160	Combo (CCS), 50	3.7	8 h	6 h		
			27.2 (33 gross)	125- 200		7.4	+ time	+ time		
5 Kia Soul Electric	7 803	(7.4)	27	100-180	CHAdeMO, 100	6.6	12-14 h	7-8 h		
6 Volkswagen e-up	6 982	(6.6)	16.8	80-165	Combo, 40	3.3	8-10 h	6 h		
7 Renault Zoe	4 379	(4.1)	41	~300		22	20 h	12-13 h	3h 20m	1h 40m
8 Mercedes-Benz B250E	3 967	(3.7)	28-32	120-200		11	14-15 h	10 h	3 h	
9 Mitsubishi i-MiEV	3 460	(3.3)	16	75-150	CHAdeMO, 45	3	8 h	6 h		
10 Peugeot iOn	2 414	(2.3)	14.4	75-150	CHAdeMO, 44	3	8 h	6 h		
Other personal EVs	8 084	(7.6)								
Total personal EVs	105 803	(100 %)								
Total number of EVs	110 000									

4.2 Status EV charging systems in Norway

The power in normal charging facilities for EVs in Norway is typically 2.3 kW when using a household one-phase power plug, and 3.6 kW or 7.3 kW when using a one-phase Type 2 connector (Skotland et al., 2016). For normal charging, Type 2 connectors (EN/IEC 62196) are recommended (Norwegian Electrotechnical Committee, 2015). However, household sockets are still frequently in use, especially in households, but also in commercial buildings and at public charging points. Semi-fast chargers are typically between 22 kW and 50 kW, and fast chargers 50 kW or above (Skotland et al., 2016). Table 4.2 shows normal charging facilities for EVs in Norway (Skotland et al., 2016). This is not a standardized definition and is only used to give an overview of the different EV chargers.

Table 4.2 Typical power use during EV charging, based on (Ladestasjoner.no, 2017).

Type of charger	Voltage / Current	Power
Power plug for use in households	230 V / 10 A / 1-phase	2.3 kW
Households / commercial buildings	230 V / 16 A / 1-phase 230 V / 32 A / 1-phase 230 V / 32 A / 3-phase	3.6 kW 7 kW 12 kW
Semi fast chargers	400 V / 32 A / 3-phase	22 kW
Fast chargers (AC)	400 V / 63 A / 3-phase	43 kW
Fast chargers (DC)	500 V / >100 A	>50 kW

In the Norwegian low-voltage network, the most common line voltage is 230 V and the network configuration is IT network. This is in contrast to the rest of the world where TN networks with 400V line voltage is the dominating low-voltage system. Three-phase EV chargers designed for 230V line voltage are therefore rare and EVs in Norwegian households are normally connected using one-phase chargers. This limits the power that can be transferred to EVs before power quality issues occur. In households with access to 400 V TN network, it is more common to use three-phase chargers. Fast chargers (three-phase AC or DC) are normally found in industrial and commercial areas, such as public shopping malls and gas stations. NELFO et al. (2015) have developed guidelines for installers of EV chargers in Norway.

By May 2017, there are more than 2000 fast and semi-fast charging stations registered in Norway. Table 4.3 shows statistics for the charging stations.

Table 4.3 Statistics charging stations in Norway per May 10th, 2017 (NOBIL, 2017)

Charging stations in Norway		CHAdeMO fast chargers	602
Total charging stations in Norway	2069	CHAdeMO semi fast chargers	1
Total charging points registered	9080	Combo fast chargers	555
Public charging points	8083	Combo semi fast chargers	1
Schuko	4783	AC Type 2 fast chargers	63
AC	1717	AC Type 2 semi fast chargers	811
Semi/fast charging stations	499	AC Type 2 11kW	137
Charging points with real-time information	584	Tesla Supercharger charging points	246

Enova is supporting the infrastructure for fast charging stations in Norway financially, having tenders for stations along national transport corridors.

Fortum Charge & Drive, Grønn Kontakt and Tesla are currently the largest providers of fast charging stations in Norway, with about 130, 75 and 31 fast charging stations accordingly - by August 2016 (elbil.no, 2016a).

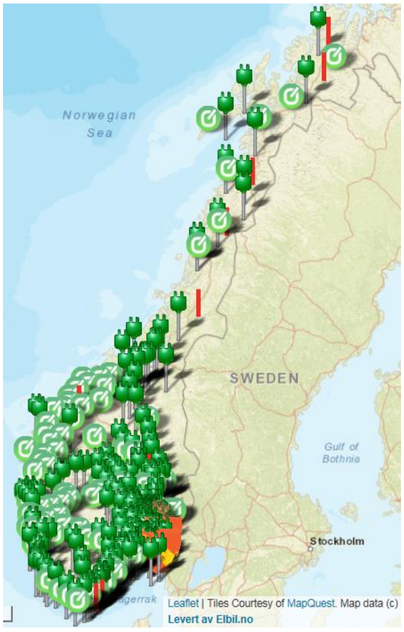


Figure 4.4 Map of the fast charging stations in Norway, as per May 2017 (elbil.no, 2017b)

4.3 Grid connection of EV charging

An increased number of grid-connected EVs can be challenging for the grid. There are mainly three kinds of challenges related to EV charging; capacity, voltage variation and voltage imbalance. The capacity in the grid is normally given by the thermal limits of transformers and cables in the low-voltage networks. Voltage variation, on the other hand, is directly related to the impedance and current flowing in the low-voltage network. In the Norwegian grid codes for electricity supply (OED, 2004), it is stated that the voltage supply to a customer in the low-voltage network shall always be within ± 10 % of the nominal voltage level. Restrictions on permitted voltage variations may be a limiting factor in low-voltage networks with high power flow and high impedance (weak grids). If the load in the network is not balanced across the three phases, voltage variations can also cause voltage imbalance. According to the Norwegian grid codes, the voltage imbalance shall not exceed 2 % in the point of delivery (OED, 2004). Due to capacity issues and low-voltage grids with high impedance, household charging normally occurs at lower power than commercial charging. In addition, as not all households have access to 400 V TN network, one-phase EV chargers are often used. Besides capacity issues and voltage variations, this can cause problems with voltage imbalance, especially in weak grids.

The connection of EV chargers to the grid may impose problems to the grid. Household chargers are in most cases connected to the existing low-voltage grid without any need for reinforcement or other measures. Semi-fast chargers can in most cases be connected to an existing low-voltage network, given that there is sufficient transformer capacity and that the charger is not connected in a weak part of the grid. However, if too many EV chargers with high charging power (especially one-phase chargers) are connected to an existing secondary substation (MV/LV transformer), this could cause problems for other households. Thus, if a charging station with several semi-fast chargers is planned to be connected to the grid, the grid company must do a thorough analysis and consider whether it should be connected to a separate MV/LV transformer, or if the capacity of the existing transformer must be expanded. Fast chargers are normally connected to the grid via a dedicated MV/LV transformer with no additional load connected. However, if the existing MV/LV transformer has sufficient capacity and suitable voltage level (400 V TN network), fast chargers can also be connected to an existing low-voltage network. In some cases, fast chargers demand other AC voltage levels than 400 V (e.g. 480 V for Tesla). In such cases, a dedicated MV/LV transformer must always be installed by the grid company.

Even though this chapter gives a description of how different EV charging stations are connected to the grid in Norway, there is no definitive answer to how this should be done. Thus, the grid company must evaluate the impact of the EV charger or charging station on the external grid in every case to limit high-power and unbalanced EV charging in the low-voltage grid. For example, Hafslund Nett does not recommend one-phase chargers with more than 20 Ampere (Hafslund, 2017). The norm NEK 400-7-722 addresses charging of EVs, and is currently being revised (NEK, 2017a).

In Figure 4.5, a simplified one-line diagram showing how different EV chargers and charging stations can be connected to the grid is presented. The number of households and loads in the low-voltage grid are reduced for simplicity.

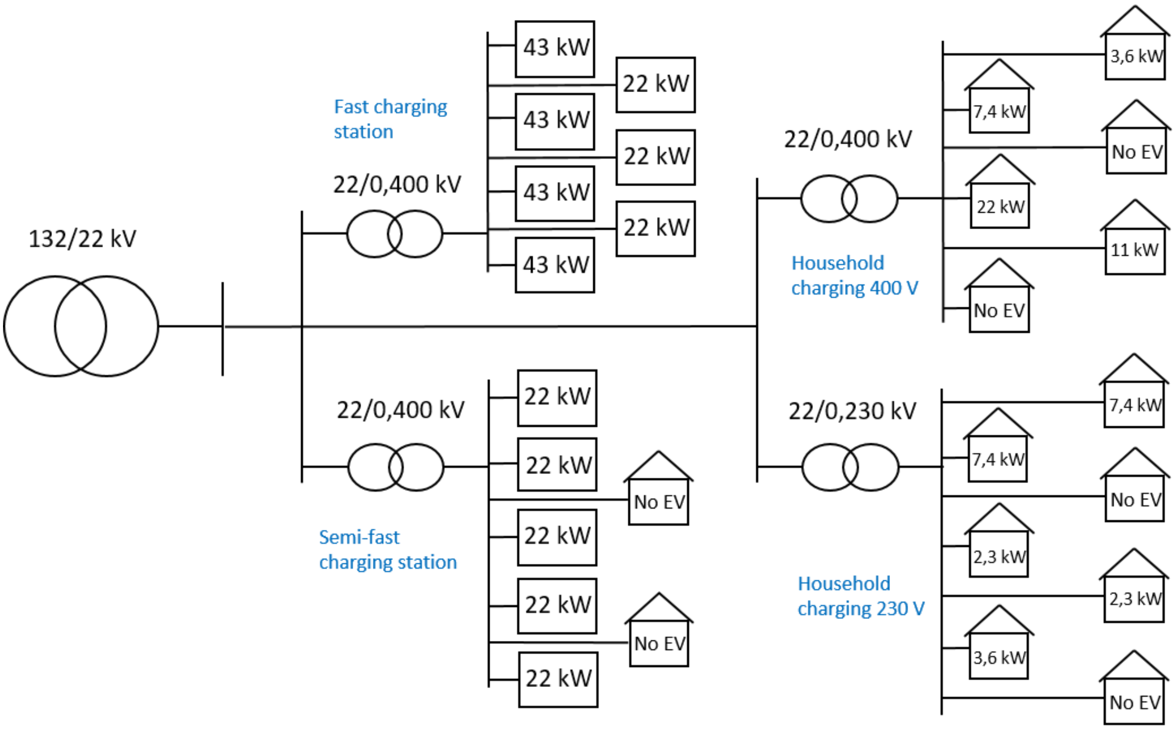


Figure 4.5 Grid connection of EV charging stations and household chargers

This figure shows that the power of chargers connected to 230 V line, voltage (IT network) is limited compared to the power of chargers connected to 400 V (TN network). The figure also shows how semi-fast and fast charging stations can be designed. It is important to underline that the grid connection of chargers and charging stations can have different designs and compositions from what is depicted in the figure.

4.4 EV charging profiles

A survey of electric car owners in Norway shows that, the owners most frequently charge their vehicles at home or at work, relying on slow chargers. The third most frequent charging choice is publicly available slow chargers, followed by chargers located in commercial facilities (charging at a destination). Fast charging primarily takes the form of planned stops for long distance trips, and is not used frequently (Figenbaum and Kolbenstvedt, 2016).

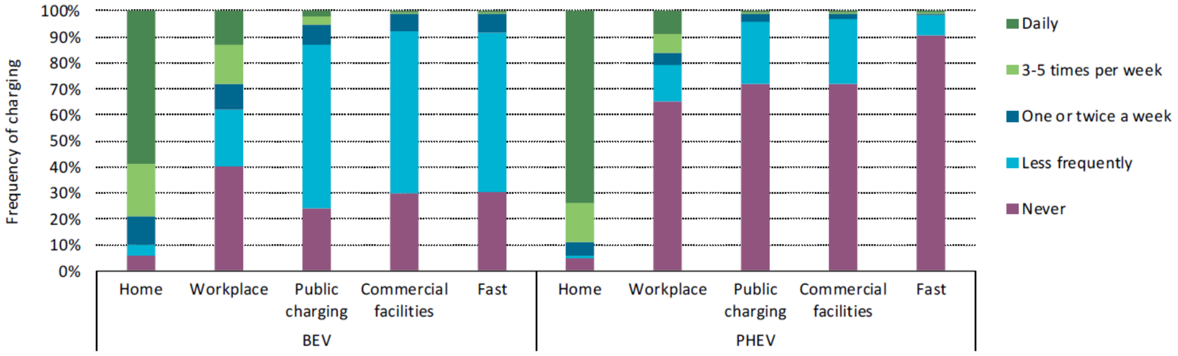


Figure 4.6 Charging habits for a sample of Norwegian electric car users, 2016 (OECD/IEA, 2017), based on (Figenbaum and Kolbenstvedt, 2016).

Also an earlier questionnaire among EV owners (Tveter, 2014) confirms the charging habits. 397 EV owners answered when they normally charged their EVs, as shown to the left in Figure 4.7. The majority is charging during the night-time and there is also a peak during morning/mid-day. Probably the night-time charging is normally at home, while the day-time charging normally is at the workplace. The respondents use fast charging to a little degree. Only about 1% of the respondents said that they charge daily with a fast charger and 38% said that they never use a fast charger (Tveter, 2014).

Cars with different battery capacity probably has different charging patterns. To the right in Figure 4.7, the charging patterns of Nissan Leaf and Tesla are shown. Compared to Nissan Leaf, Tesla is charged less during the day-time. This indicates that cars with larger battery capacity may mainly charge during the night. As the battery capacity of the EVs are increasing, there may therefore be expected other EV charging profiles than today. If future EV owner are less anxious about having enough battery capacity for the evenings, even more EV owners may charge their car during the night time. However, this will also depend on other factors, such as convenience and costs. The EV charging profiles of the future may differ significantly from today.

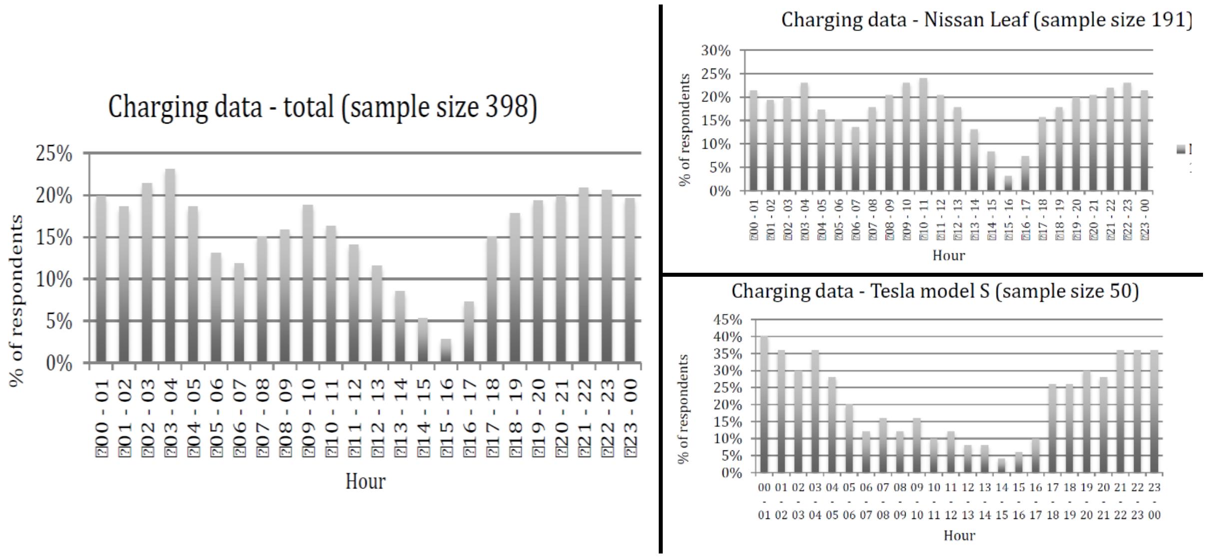


Figure 4.7 Charging profile based on questionnaire among EV owners (Tveter, 2014)

The EV owners were also asked when they would use fast charger during a day, if this was their regular way of charging. The majority answered that this fast charging would happen from 12 to 19, with a peak around 16 – after normal working hours. It is therefore likely that the average charging profile will change, if fast charging becomes the standard way of charging.

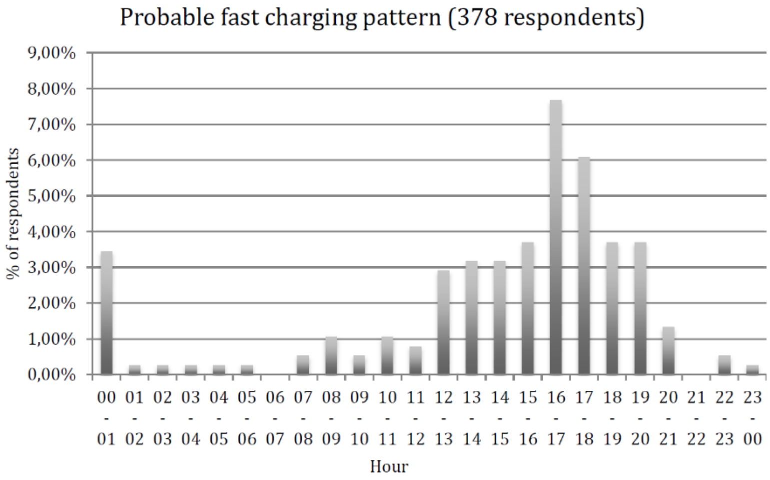


Figure 4.8 Charging profile for probable fast charging, based on questionnaire among EV owners (Tveter, 2014)

4.5 Energy and power use during EV charging

4.5.1 Single charging events

As described in Table 4.2, the power use during EV charging in a household or commercial buildings, are typically 2.3 kW when using a Schuko power plug (230 V / 10 A) and 3.6 kW or 7.3 kW when using a Type2 charging station with 230 V and 16 A or 32 A. Semi fast chargers are typically 22 kW and fast chargers 50 kW or above.

Figure 4.9 shows a typical charging profile for a single residential EV charging, from the project "Low Carbon London" (Aunedi et al., 2014). The project analysed residential EV charging data from 54 vehicles that were monitored over a period of more than a year. The charging event is considered to be typical for an individual vehicle, with respect to the power and time involved. However, newer cars have larger battery capacity than for the EV shown in the figure. The vehicle charges at 3.7 kW (i.e. 16 A) for about 2.5 hours, during which 6.6 kWh is consumed from the grid. It is observed a gradual decrease of charging power (at about 0.12 kW per minute) towards the end of charging. Such decrease only occurs when the EV battery is being charged to its full capacity, and is most likely caused by the control actions of the battery management system. If charging is terminated before the battery is full, the charging power drops to zero instantaneously.

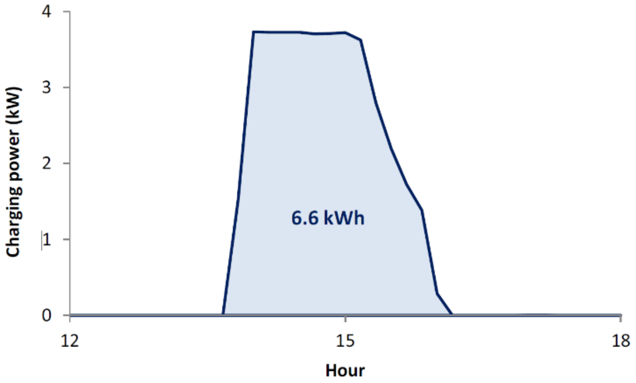


Figure 4.9 Demand profile for a typical charging event (charged to full capacity) (Aunedi et al., 2014)

Seljeseth et al. (2013) presents high resolution measurements of the network impact from EVs during slow and fast charging. Their paper presents measurement results from slow charging of three different EV models, while Figure 4.10 in this report shows the results for one of these three cars. The EV represents a quite good and stable load considering voltage quality, and even more stable than the two other cases presented by Seljeseth et al. (2013). Like in Figure 4.9, there is a load decrease towards the end of the charging cycle, as the traction battery gets close to being fully charged. Voltage variations are limited during this charging cycle and both flicker values and harmonic voltages are moderate to low.

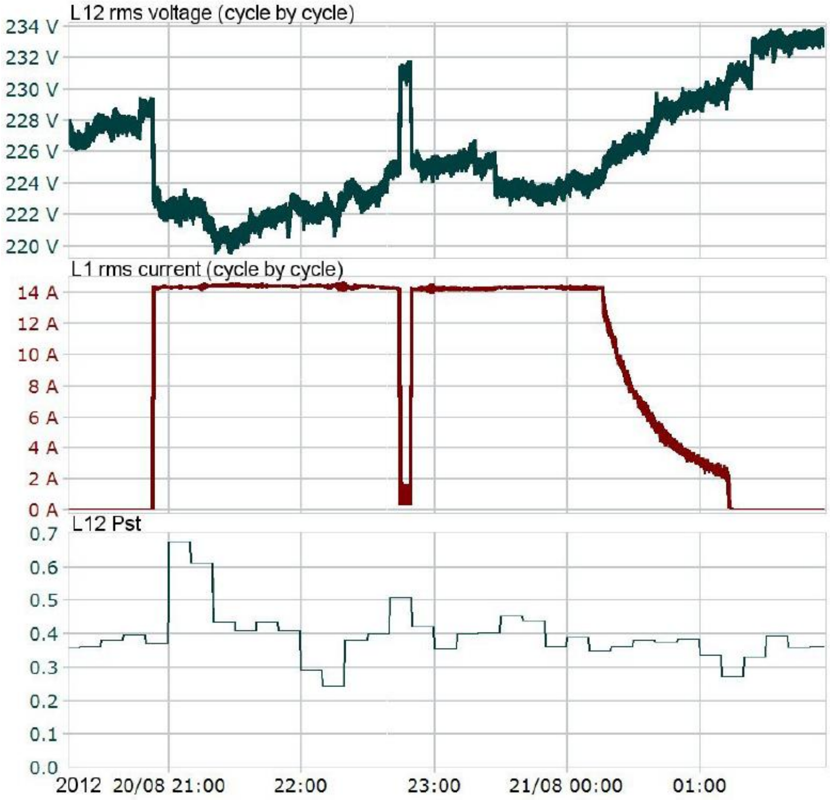


Figure 4.10 Load current, voltage variations and flicker level (Pst) during charging of an Electric vehicle (Seljeseth et al., 2013)

Seljeseth et al. (2013) also present measurements on a charging location in the City Centre of Trondheim, with 15 outlets for charging up to 15 electric vehicles at one phase 230 V 16 A. Figure 4.11 shows the typical load distribution during a working day.

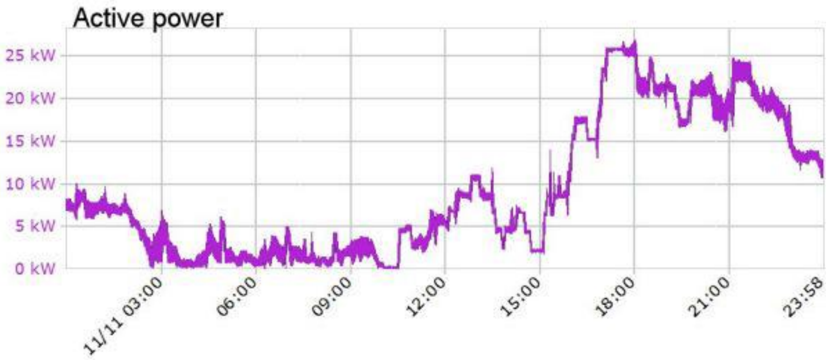


Figure 4.11 Power drawn by an EV pool on a typical day. The peak load occurs at 5 PM (Seljeseth et al., 2013)

For fast charging stations, Seljeseth et al. (2013) present measurements from 2013, from two stations with maximum current 70 A and connected to 400 V supplies. Figure 4.13 presents power drawn from a fast EV charger during a typical day, while Figure 4.16 shows example of an EV fast charging characteristics.

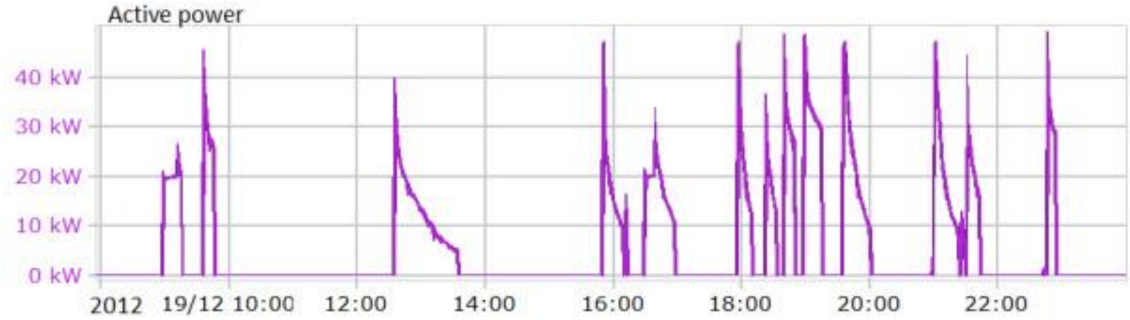


Figure 4.12 Power drawn from a fast EV charger during a typical day (Seljeseth et al., 2013)

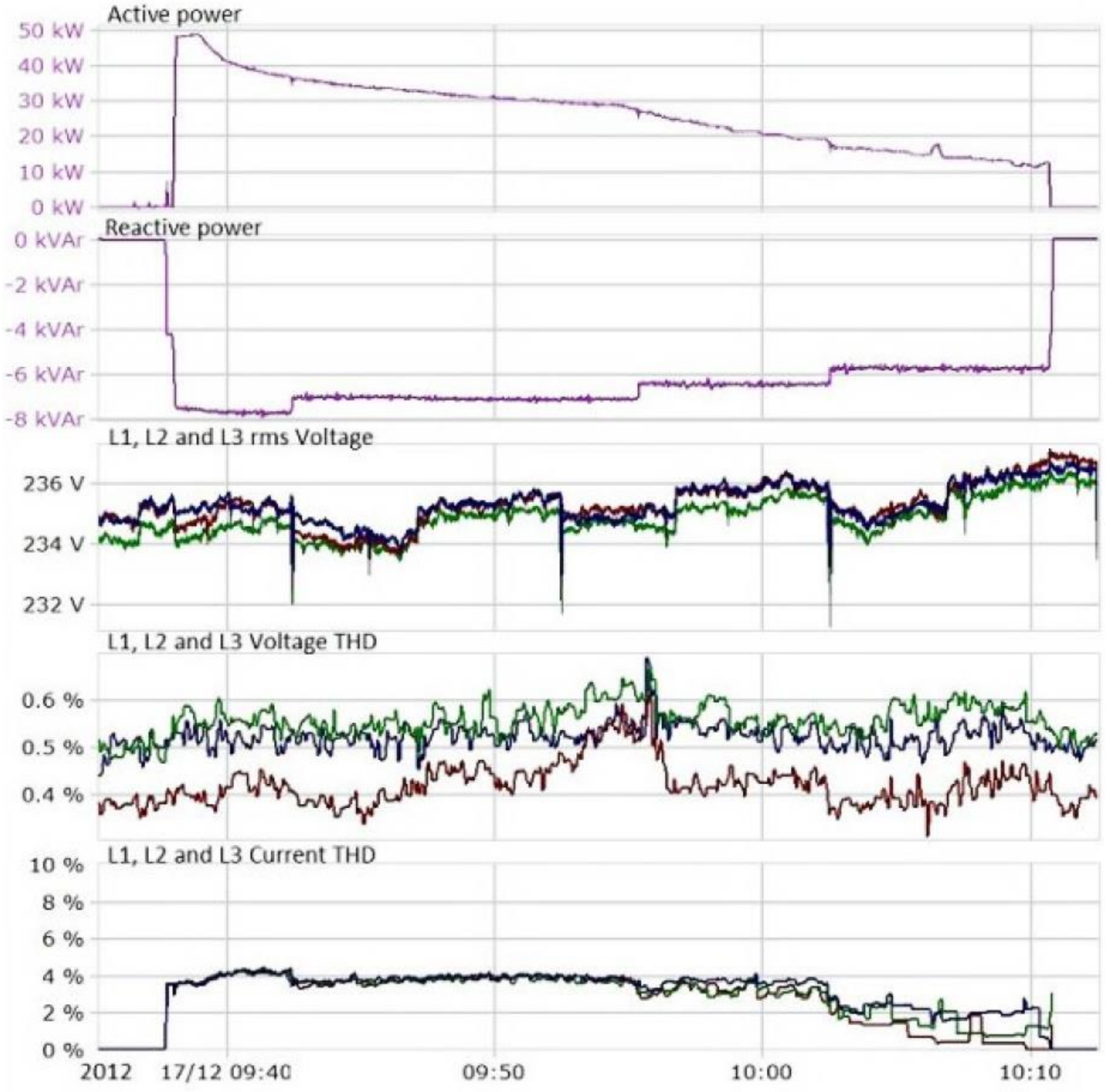


Figure 4.13 Example of an EV fast charging characteristics from Seljeseth et al. (2013)

The MSc thesis (Nes, 2017) describes EV fast charging data from a charging station at ZEN pilot Campus Evenstad. Figure 4.14 and Figure 4.15 show the mean charging power (kW) and the energy consumption (kWh) for 111 fast charging events. The figures show that most charging events lasted for less than 35 minutes and the maximum mean power and the maximum energy demand were 45 kW and 26 kWh respectively.

The measurements differ from Seljeseth et al. (2013) in Figure 4.12, where maximum charging power of 45 kW was only delivered for a few minutes. In the analyses from (Nes, 2017), the mean charging power of several charging events were close to 45 kW although lasting for up to 35 minutes. The reason may be, that fast charging curves today are different to the ones in 2013, due to newer technology and batteries.

At Evenstad, the mean charging power and the energy consumption varied by up to 30 kW and 12 kWh respectively on charging events which lasted for approximately the same time. This may be caused by varying charging curves on different charging events according to for example variation of vehicle type and battery condition.
Studying the charging events which lasted between 45 – 55 minutes, it seems that the battery was close to SOC 100 % since the mean power and the energy demand were lower compared to many of the charging events which lasted for less than 35 minutes. (Nes, 2017)

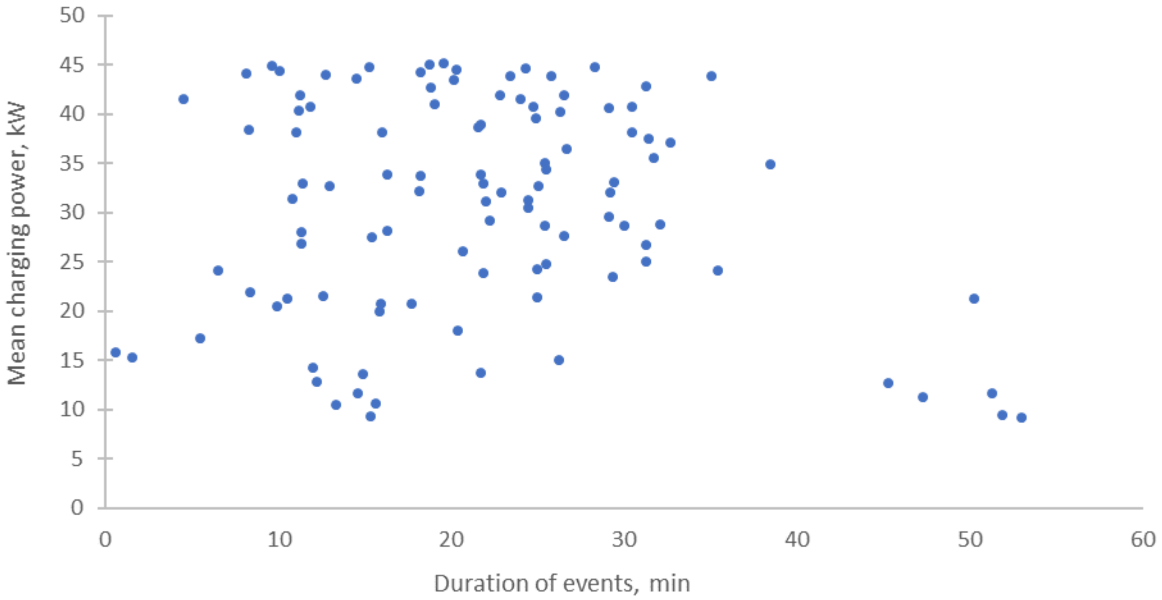


Figure 4.14. **The mean charging power and the duration of 111 fast charging events at ZEN pilot Campus Evenstad (Nes, 2017).**

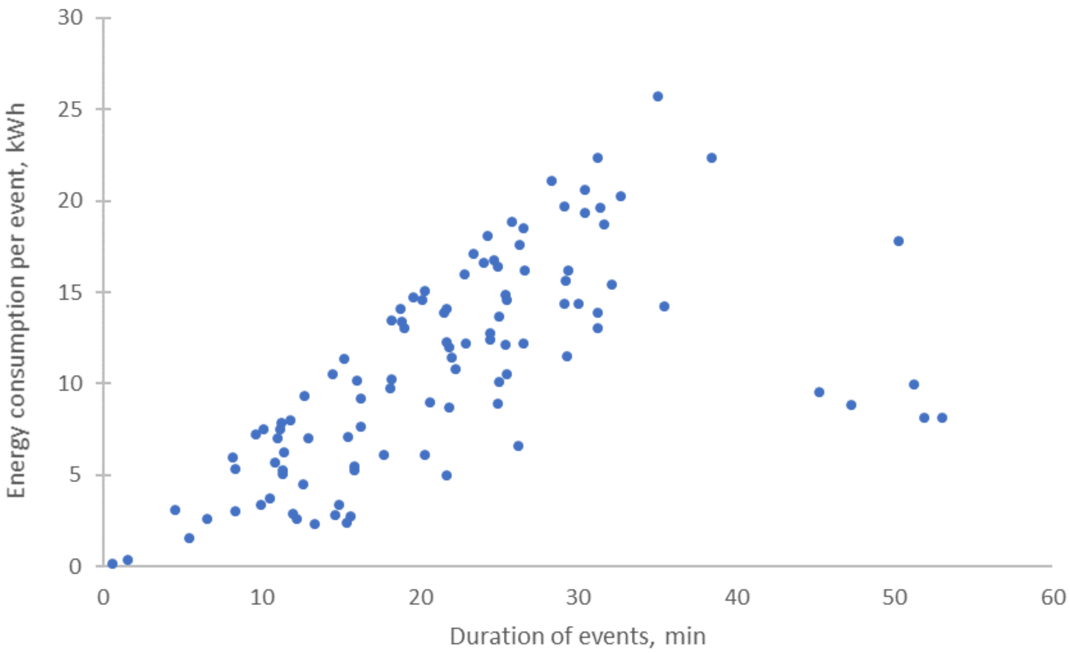
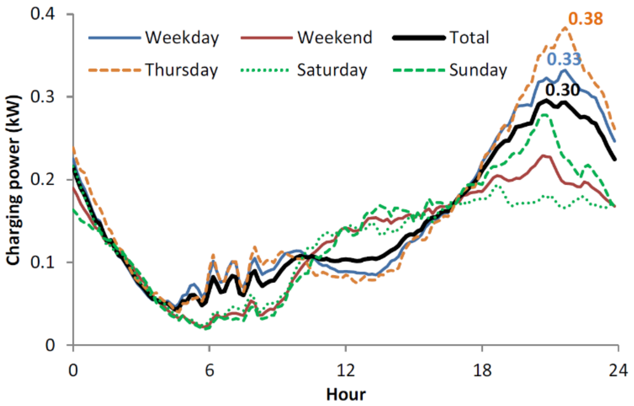


Figure 4.15. The energy consumption and duration of 111 fast charging events at ZEN pilot Campus Evenstad (Nes, 2017).

4.5.2 Average load profiles and diversity factors

The British project (Aunedi et al., 2014) describes *average* load profiles for residential EVs. The averages have been found across 54 EVs, for each weekday in the week. Average daily requirements for different days, as well as maximum values of average demand per EV are summarised in Figure 4.16. The peak average demand is lower than for an individual charging event, since not all the 54 EVs are charged simultaneously.



Day type	Energy requirement for charging (kWh)	Peak average demand (kW)
All days	3.52	0.30
Workdays	3.68	0.33
Weekend	3.09	0.23
Monday	3.33	0.34
Tuesday	3.84	0.35
Wednesday	3.57	0.30
Thursday	3.80	0.38
Friday	3.88	0.30
Saturday	2.96	0.22
Sunday	3.22	0.28

Figure 4.16 Average charging profiles and peak average demand per EV for a residential EV sample of 54 EVs (Aunedi et al., 2014)

Figure 4.17 presents the average charging profiles for commercial users with 3-phase meters, i.e. delivery van fleet. The energy requirements and peak demand are higher for delivery vans than for households.

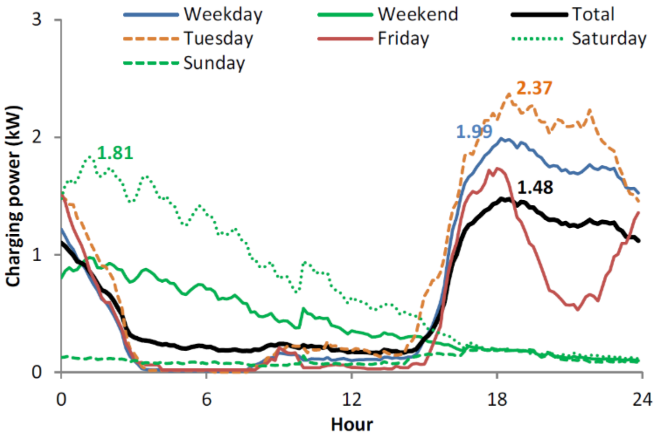


Figure 4.17 Average charging profiles per user among the 3-phase commercial participants (delivery vans) for different days of week (Aunedi et al., 2014)

Aunedi et al. (2014) also study diversity factors for households. In the context of increasing number of EVs being connected to distribution networks, it is important to estimate how their diversified peak increases with lower EV population sizes. For that purpose, the maximum and average demand profiles have been quantified for the following sample sizes: 7, 10, 21, 32, 43 and 54 EVs. Figure 4.18 show diversity factor for different subsample sizes of residential EVs.

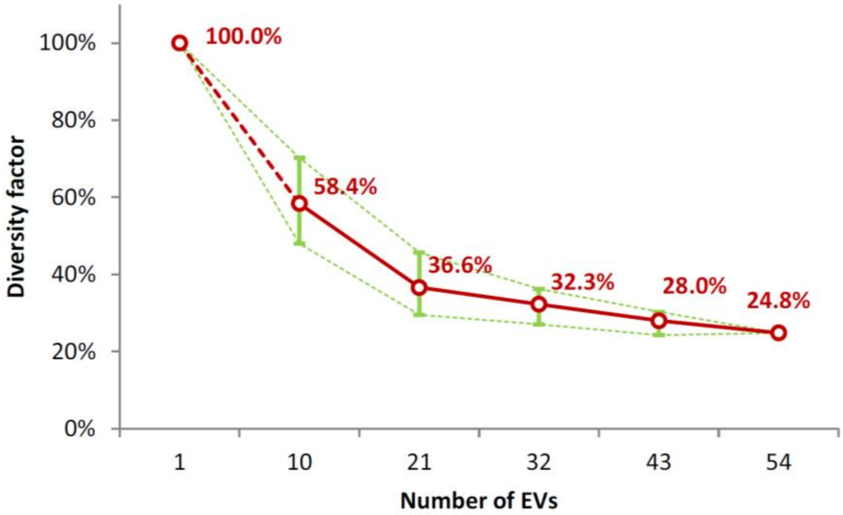


Figure 4.18 Diversity factor for different subsample sizes of residential EVs (Aunedi et al., 2014)

NVE has analysed EVs charging habits in Norway, based on e.g. measurements from SINTEF and two questionnaires among EV owners (Skotland et al., 2016). For home-charging, an average charging profile of four EV owners are illustrated in Figure 4.19, not taking consideration to weekdays, seasons or charging station. The average includes days with no changing, which lead to a low demand. The charging profile still illustrates the timing of the charging.

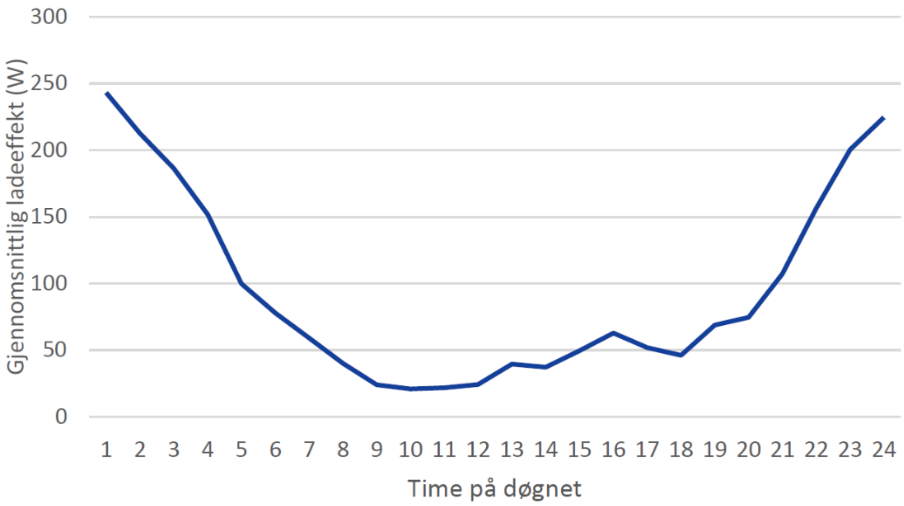


Figure 4.19 Average charging profile for home-charging, based four EV-charging points (Skotland et al., 2016). The average includes days with no charging.

Figure 4.20 shows average energy use in a Norwegian household during a cold day, with and without EV charging (Skotland et al., 2016). The figure is based on AMI-data from a grid company in southern Norway, with a peak consumption in the afternoon of 4 kWh/h. For the EV charging, the EV charging profile described in Figure 4.19 is used, and NVE assumes that the average peak consumption will increase with about 0.5 kW. This peak consumption is an average between several households, where not all the households are charging their EVs simultaneously. Such average is therefore useful for a neighbourhood situation, while for an individual household with EV charging, the peak consumption will be higher than in the illustration.

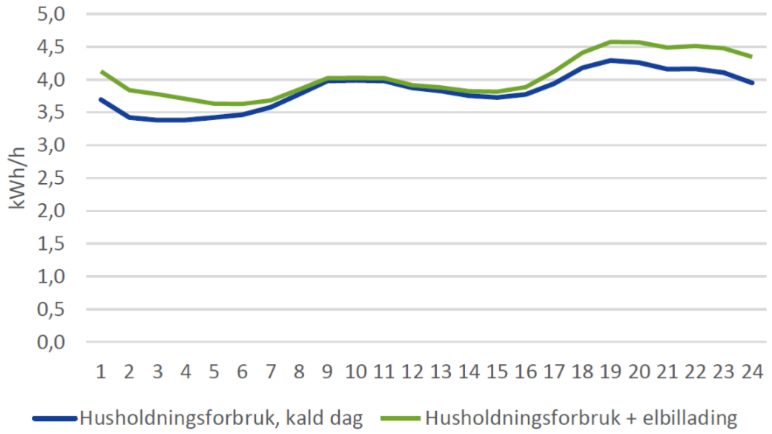


Figure 4.20 Average energy use in a household during a cold day, with and without EV charging (Skotland et al., 2016). The figure shows an average between several households, where not all the households are charging their EVs simultaneously.

For an area or neighbourhood, NVE has created three scenarios (Skotland et al., 2016), as described in Table 4.4. Scenario 3 has a large share of simultaneous charging, and can represent a neighbourhood or cabin area where the residents have a large degree of homogeneous behaviour.

Table 4.4 Scenarios with increased power need per household due to EV charging (Skotland et al., 2016)

Scenario	Number of EVs per household	Charging capacity (kW)	Simultaneous charging	Added capacity per household in max load (kW)
1	0.5	5.1	30%	1
2	0.75	6.0	50%	2
3	1	7.1	70%	5

In the NVE study described further in Chapter 4.6, NVE is evaluating how the current distribution transformers in the grid would manage the added capacity for the three scenarios. There are about 120 000 such distribution transformers in Norway. The results show that with scenario 1 or 2, less than 10% of the current distribution transformers will be overloaded. With an added capacity per household of 5 kW max load in Scenario 3, 30% of the current distribution transformers will be overloaded.

4.6 Norwegian grid scenario with 1.5 million EVs

NVE has also studied a scenario describing which consequences 1.5 million EVs in 2030 will have on the Norwegian grid and distribution network (Skotland et al., 2016). The total energy need for such number EVs is in the range of 4 TWh, which is about 3 % of the electricity use in Norway.

NVE has analysed the load on the grid in a number of grid companies. The average load from charging EVs is low, and the results show that the grid in Norway will handle a relatively large transition to electric cars. However, if many cars are charged simultaneously in one area, this may create local challenges for transformers and cables in the distribution network. This applies especially in areas with low capacity in the grid, such as areas with cabins.

Measurements and surveys show that much of the electric charging today takes place during the evening and the night. If charging can be shifted to the night, this is a major advantage for the grid, since the power demand in general is lower at night-time.

By 2030, many of the transformers and power lines in the distribution network need to be upgraded, due to age. NVE recommends that the grid companies consider reinvesting in components with somewhat higher capacity than today, so the grid is even better equipped to deal with full electrification of the transport sector. It may also be relevant to undertake reinvestments on the basis of increased EV charging.

In areas with a weak grid, the voltage quality may deteriorate with large EV charging activity. In particular, stress due to high single-phase charging power can be a challenge, but NVE state that the extent of this is difficult to predict.

Systems for smart charging and relocation of power loads can reduce the potential challenges in the grid due to EV charging. Advanced Metering Infrastructure (AMI), which includes smart meters installed in all households by 2019, becomes an important tool for managing smart charging systems. NVE describes that the introduction of power tariffs, where the tariffs varies with the used power during a certain period, can motivate consumers to take advantage of the opportunities new technology provides.

4.7 EV charging in apartment buildings

In Norway there are approximately 600 000 apartment blocks (SSB, 2017). EV owners in flats and apartments cannot necessarily charge at home so easily. While 83% of house owners state that they charge at home, only 13% of residents in apartment buildings state the same (Norsk elbilforening, 2017).

Especially in older housing associations with old garages and infrastructure, this is an obstacle, since the grid is not dimensioned for many EVs charging at the same time. Smart charging solutions and load sharing can therefore be a solution. This is further described in Chapter 7.5.

Many apartment associations also face non-technical challenges. An investment challenge is, that the set-up should ideally be prepared for a larger number of users, as mentioned in Chapter 2.4. However, it can be difficult to fund the investment for future charging needs, since it is often few EV users in the initial phase. The purchase process and operation of EV systems can also be a challenge, since apartment associations often have limited knowledge about EV stations. To achieve a broad implementation of smart charging systems in larger housing associations, it is also necessary to understand and find good solutions to such non-technical challenges.

4.8 Smart charging systems for other means of e-transport and shared car pools

This report focuses on charging systems for personal cars. However, also charging of other means of transport is relevant for ZEN, for example charging of e-buses. There are other charging solutions available for e-buses, such as top-down pantograph – which is a fast-charging system that can be mounted on a mast or roof of a bus stop. The European Automobile Manufacturers’ Association (ACEA) gives some key recommendations for the charging of electric buses in (ACEA, 2017). Chapter 7 presents some examples of fast charging systems for busses.

Beside privately owned EVs, there are also other ownership models relevant for a ZEN. This can for example be a shared EV pool. Available cars in a shared car pool can reduce the need for privately owned cars. According to (Nenseth et al., 2012), a shared car substitutes 5-15 private cars, and members drive 1/3 less than a private car owner. Further, such EV pools can provide opportunities for the testing of new technologies. For example, an EV pool may more easily be prepared for bidirectional vehicle-to-grid (V2G) solutions than privately owned EVs. This is not further discussed in this report, but can be relevant to test in the ZEN pilots.

5 Use of batteries in a neighbourhood

5.1 Use of energy storage and batteries in ZEN

There can several advantages with storing energy in a building and neighbourhood, for example:

- to reduce the peak load by accommodating the minute–hour peaks in the daily demand curve,
- to store energy generated by renewables (e.g. solar or wind) so as to match the fluctuating supply to the changing demand,
- to allow energy plants (e.g. CHP unit) to generate energy on optimal load, independent of the demand,
- to store surplus energy generated during the day (or night), to meet demand during the night (or day),
- to take advantage of price fluctuations and reduce power tariffs,
- to have a back-up energy source during power emergencies,
- to deliver energy services to power companies,
- in areas with a lot of PV / local electricity production; Not to export more than the grid capacity.

For example, batteries can be used to reduce peak load and to increase self-consumption of solar energy in the example presented in Figure 5.1. The figure illustrates electricity imported and exported to the grid, in an area with apartments and solar cells (Sartori, 2016).

When describing the energy system, the following factors can be used (Salom et al., 2014):

- ***Load cover factor*** represents the percentage of the electrical demand covered by on-site electricity generation (self-generation)
- ***Supply cover factor***, can be defined representing the percentage of the on-site generation that is used by the building (self-consumption)
- ***The peaks above certain limit value*** indicate the part of analysed period that net export energy exceeds a certain barrier
- ***The equivalent hours of storage*** corresponds to the storage capacity expressed in hours. The physical capacity is the number of hours of storage multiplied by the power design load
- ***Generation Multiple*** is the relationship between peak export divided on peak import

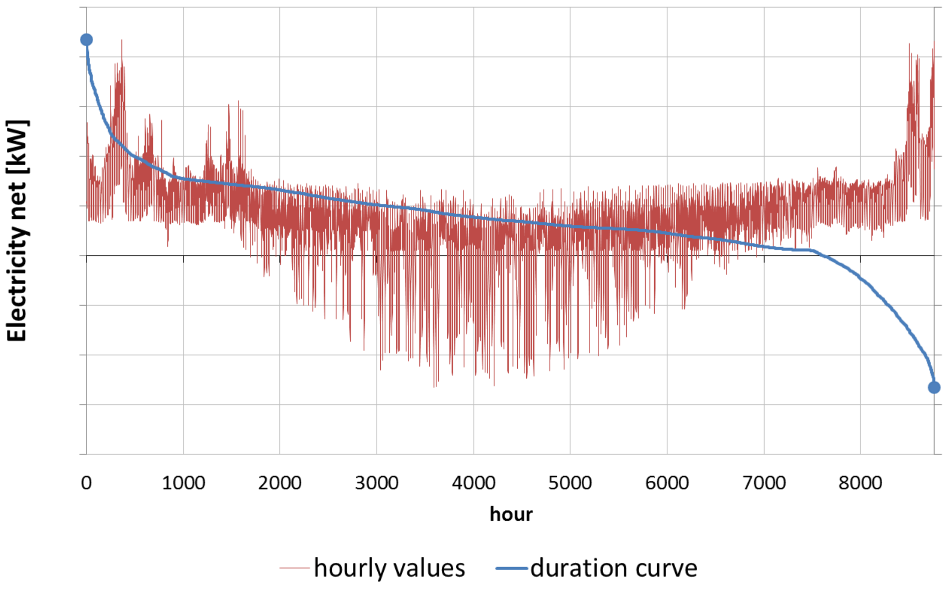


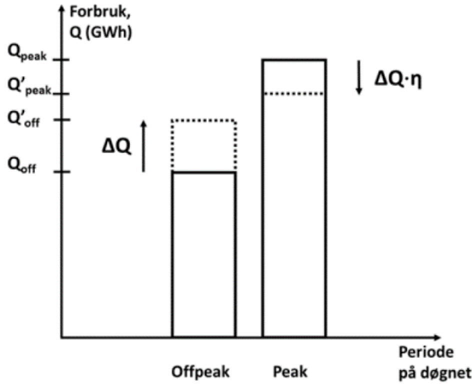
Figure 5.1 Electricity imported (above line) and exported (below line) to the grid, from an area with apartments and solar cells (Sartori, 2016)

The focus in this report is the use of batteries to store electrical energy. An electrical energy storage unit can participate in electricity market in a number of ways, depending on its energy storage and delivery characteristics (Kousksou et al., 2013). However, the production of batteries leads to environmental burdens (Ellingsen et al., 2013). This should be taken into account when planning a ZEN and when dimensioning stationary batteries. Several storage alternatives can be combined in an energy flexible neighbourhood, besides batteries. Other energy storage alternatives in a ZEN is e.g.

- Thermal energy storage, which in recent decades have demonstrated a capability to shift electrical loads from high-peak to off- peak hours (Kousksou et al., 2013). Often, there are thermal energy storage capacity available, in e.g. hot water tanks, which can be utilised in an energy flexible system.
- Using the grid as "energy storage", interacting with the large storage capacity in the hydropower reservoirs in Norway. Such energy storage has minimal environmental burden and is frequently entitled "the green battery of Europe".
- Producing hydrogen in times with energy surplus/low energy prices to use it later in a fuel cell to produce electricity and heat, e.g. for low-temperature district heating.
- Active use of the batteries in EVs: Vehicle to Grid (V2G). This is further described in Chapter 5.4.

Henden et al. (2017), draws attention to especially two areas where increased use of batteries is expected in the future; Batteries in electric cars and batteries connected to (PV) systems.

For a single household or neighbourhood, Figure 5.2 illustrates how the energy use in off-peak and peak time periods can change, with the use of batteries (Henden et al., 2017). Energy can be stored in the battery during off-peak periods, to be used during peak periods. There are energy losses in the battery and Henden et al. (2017) assume an efficiency of the battery of 0.9 in their calculations. Battery systems should therefore only store energy in the battery when it is worthwhile, eg. in terms of grid capacity, energy or costs.



Q_{off}	Energy use off-peak, without battery
Q'_{off}	Energy use off-peak, with battery
Q_{peak}	Energy use peak, without battery
Q'_{peak}	Energy use peak, with battery
ΔQ	Amount stored energy
η	Efficiency, battery

Figure 5.2 Shifting of energy use in a household, with the use of batteries (Henden et al., 2017)

Energy storage can be an advantage for the users, e.g. to reduce costs (load tariffs) and to increase self-consumption of local energy sources. Energy storage can also reduce the initial connection fee to the electricity supply network (*anleggsbidrag*), since the grid capacity can be utilized better (Skotland et al., 2016). This can for example be the case for fast charging stations, where the initial connection fee can be high compared to the income from charging services. A buffer battery can reduce the needed capacity of the grid. In a smart solution, such batteries can also sell electricity to the grid when needed.

Energy storage can also be an advantage for the grid owner, especially when there are bottlenecks in the grid or it is possible to delay grid upgrades. Batteries can contribute with flexibility in the power system, which is important when dealing with energy demand during cold winter days, demand peaks and an increasing contribution from unregulated renewable energy production (Henden et al., 2017).

At the ZEN pilot area Campus Evenstad, the use of batteries is planned. On assignment from Statsbygg, Multiconsult has written a report, evaluating different battery possibilities (Holm, 2017). A public procurement for a battery bank started during the autumn 2017 (Statsbygg, 2017). There are several goals with the battery bank: 1) To store solar electricity, 2) To reduce power peaks, and 3) as a back-up energy source for critical operations at the Campus. In case of power failure on Campus, the battery will provide start-up power to the combined heat and power (CHP) unit.

5.2 Battery types and performance criteria

Battery technology is continuously being developed. Also the costs of batteries are decreasing (Henden et al., 2017), as shown in Figure 5.3. The major reason for this is the use of batteries in EVs. Successful deployment of batteries for automotive applications requires that a number of performance criteria are met (European Commission, 2016a). Figure 5.4 shows the current status and performance targets for batteries in automotive applications.

There are several types of batteries, but Lead-Acid, Nickel-Metal Hydride and Lithium-ion are shown best suited for EVs (Gjelsvik, 2015). The most commercially used battery is the Lithium-ion, and the exact chemistry varies from the different manufacturers. Lithium-ion batteries have the highest power to weight ratio of the three mentioned battery types, low self-discharge, high energy efficiency and life-time / number of cycles.

The energy capacity of batteries (kWh) is important when selecting a battery. Some other important physical properties of batteries are energy density expressed in, for example, Wh/kg or Wh/liter, life time in charge cycles, efficiency (loss of energy), maximum power during charge/discharge in kW and tolerance for temperature and other operating conditions (Henden et al., 2017). Also, the charging time and discharge time matters. Finally, safety is very important when dealing with batteries, mainly because of the thermal runaway (Gjelsvik, 2015).

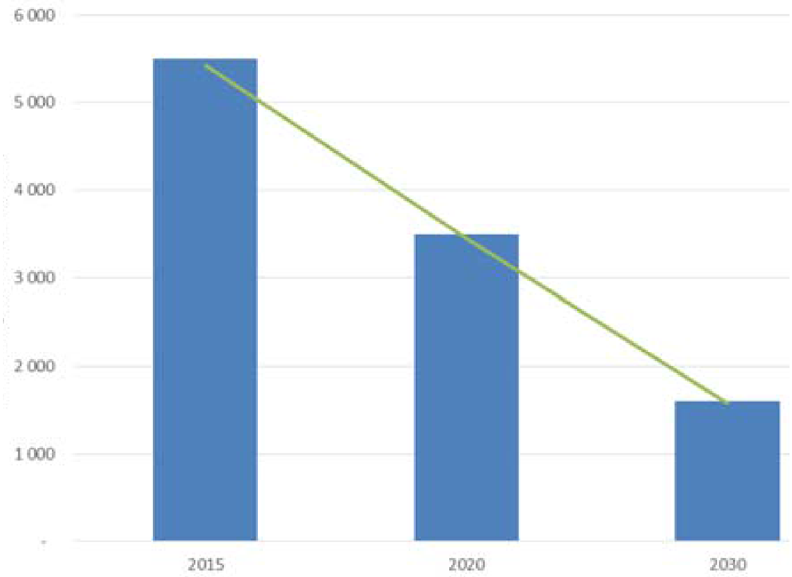
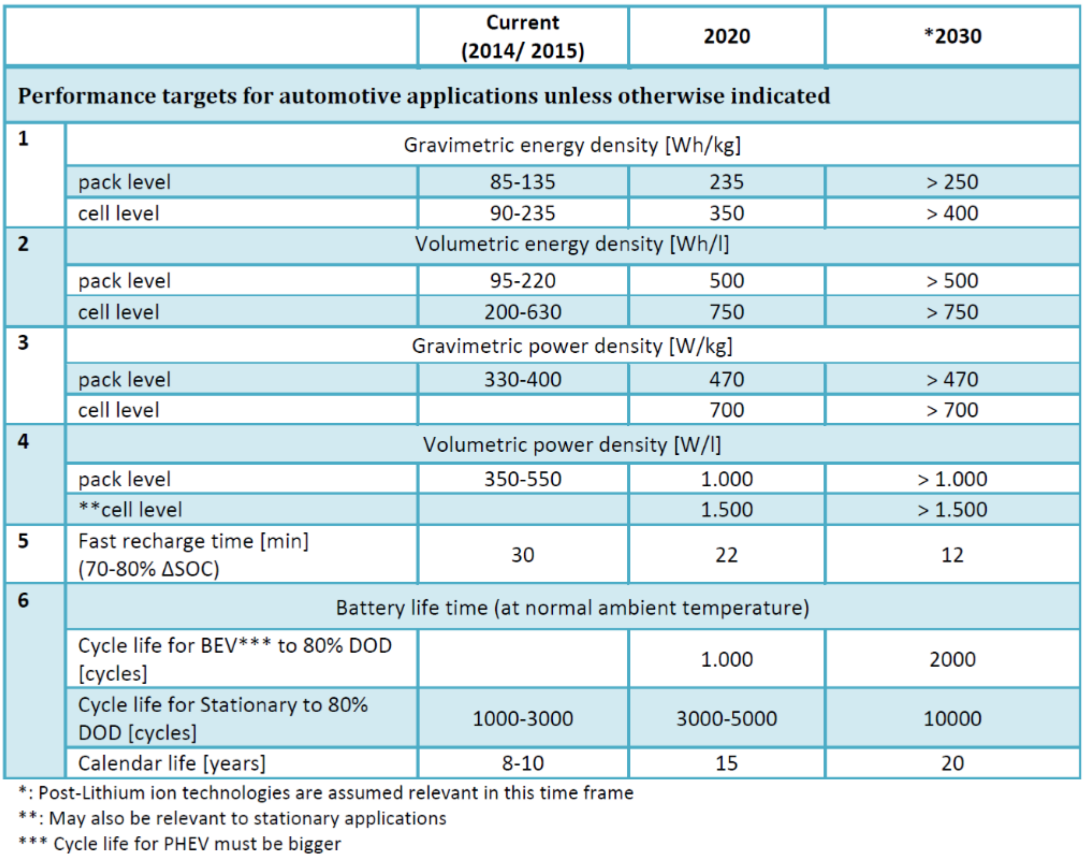


Figure 5.3 Predictions for battery investment costs (NOK/kWh) (Henden et al., 2017)



		Current (2014/ 2015)	2020	*2030
Performance targets for automotive applications unless otherwise indicated				
1	Gravimetric energy density [Wh/kg]			
	pack level	85-135	235	> 250
	cell level	90-235	350	> 400
2	Volumetric energy density [Wh/l]			
	pack level	95-220	500	> 500
	cell level	200-630	750	> 750
3	Gravimetric power density [W/kg]			
	pack level	330-400	470	> 470
	cell level		700	> 700
4	Volumetric power density [W/l]			
	pack level	350-550	1.000	> 1.000
	**cell level		1.500	> 1.500
5	Fast recharge time [min] (70-80% ΔSOC)	30	22	12
6	Battery life time (at normal ambient temperature)			
	Cycle life for BEV*** to 80% DOD [cycles]		1.000	2000
	Cycle life for Stationary to 80% DOD [cycles]	1000-3000	3000-5000	10000
	Calendar life [years]	8-10	15	20

*: Post-Lithium ion technologies are assumed relevant in this time frame
**: May also be relevant to stationary applications
*** Cycle life for PHEV must be bigger

Figure 5.4 Performance targets for batteries in automotive applications (European Commission, 2016a)

When it comes to commercially available batteries for buildings, Tesla Powerwall has received a lot of attention. Powerwall provides 14 kWh storage capacity, a continuous power of 5 kW or peak power of 7 kW. The batteries have 10-year guarantee. An alternative from Nissan is Xstorage, which either utilize second-hand Nissan Leaf batteries (4.2 kWh and 5 years guaranteed capacity) or new batteries

(6 or 7.5 kWh with 10 years guaranteed capacity) (EATON, 2017). Other examples of providers within the car-industry are Accumotive (Mercedes-Benz) and Powervault (Renault). A Norwegian provider of battery solutions is Eltek. Schneider Electric offers the battery concept EcoBlade, demonstrated in Sandbakken Miljøstasjon in Hvaler (240 kWh battery) (Schneider Electric, 2016). There are furthermore several providers of battery solutions optimized for Home-PV-Systems, like Sonnen, SolarWatt, Fenecon or Varta.

DOE global energy storage database (Sandia National Laboratories, 2017) describes energy storage projects worldwide. For example, 635 lithium-ion battery projects were described by October 2017, from small systems to 100,000 kW battery capacity. There is also a database for smaller energy storage systems connected to solar energy (IBESA, 2017). Another database is available in the Enipedi-project of the University of Delft (Enipedia, 2017).

5.3 Individual or shared batteries in a community

When planning batteries in a ZEN, it should be investigated if it is beneficial to use individual or shared batteries.

A Swedish study investigates self-consumption of residential PV power in a community of 21 single-family houses (Luthander et al., 2016). Cases with individual or shared battery energy storages for the houses were examined, as shown in Figure 5.5.

PV power curtailment was investigated as a method to reduce feed-in power to the grid, i.e. peak shaving. PV power curtailment is a method to lower the power fed in to the grid, if there is a limit for maximum feed-in power from households with PV. This will lead to production losses, and the power producer therefore has to have incentives to lower the production.

The overall conclusion of the study from (Luthander et al.), is that the self-consumption of residential PV-storage systems in a community increases by using a centralized storage unit instead of separate units in the households.

Figure 5.5 Schematic illustration of the different cases, where a community with PV production has individual or shared battery energy storage. Arrows represent power flows. (Luthander et al., 2016)

5.4 Vehicle to Grid

The term bidirectional Vehicle to Grid (V2G) covers the solution were the battery in the electric vehicle delivers power back to the source. Private vehicles are parked on average 93–96% of their lifetime, during which time each represents an idle asset (Turton and Moura, 2008).

Studies have shown that in this configuration, the EVs can participate in the energy market and provide ancillary services like frequency and voltage regulation (Mwasilu et al., 2014). Figure 5.6 illustrates how a small and large EV fleet with V2G can reduce the peak load in the energy system.

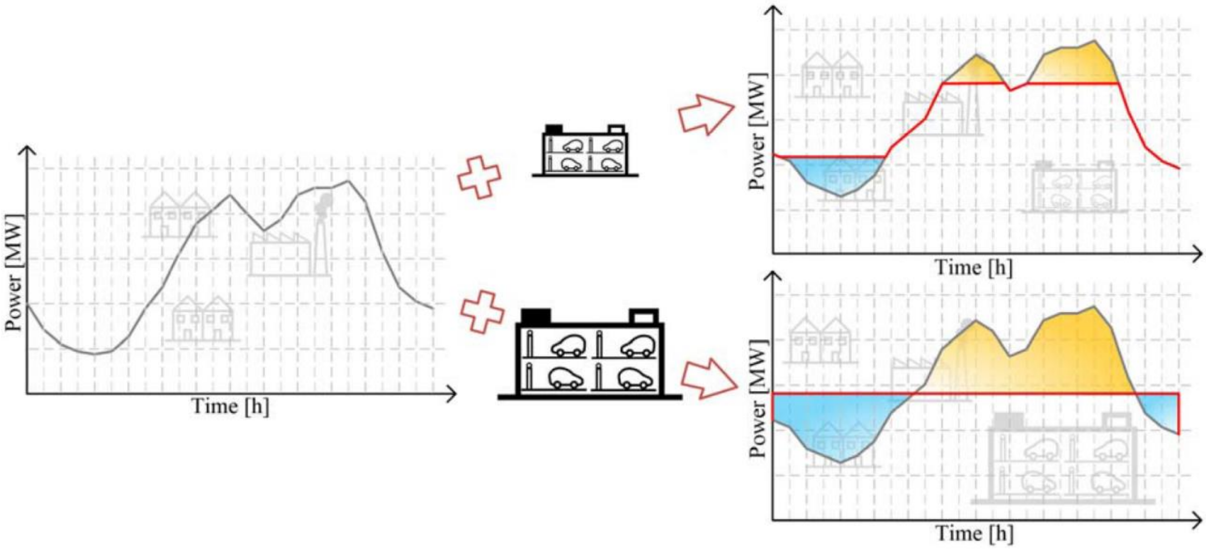


Figure 5.6 Load leveling performance in case of small and large EV fleets providing V2G (Damiano et al., 2014)

As with stationary batteries, renewable unregulated energy can be stored in the EV battery and fed back to the building or the grid during peak hours. This scenario is illustrated in Figure 5.7.

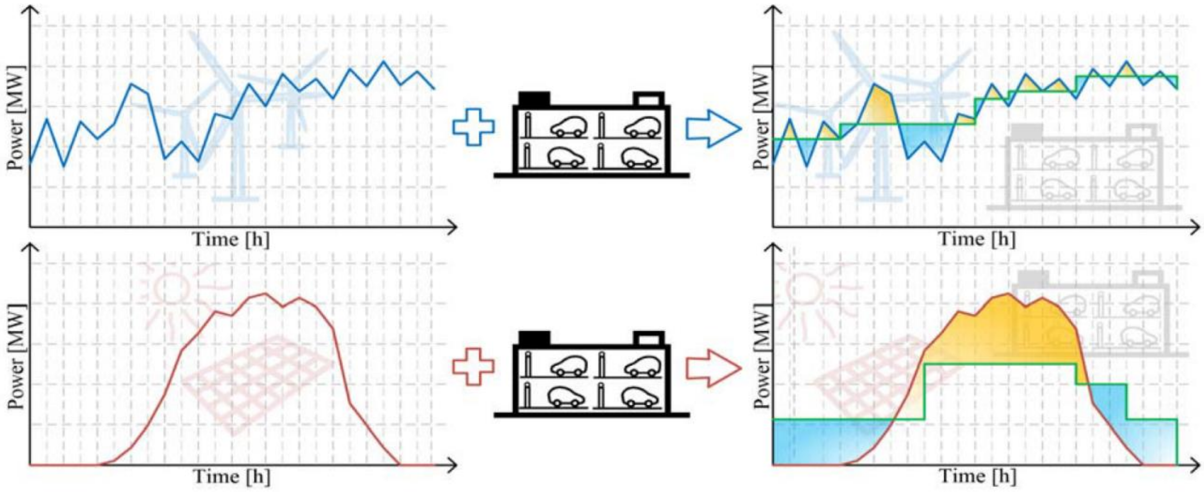


Figure 5.7 Renewable energy sources (wind and solar) exploitation by V2G (Damiano et al., 2014)

In the V2G application, the battery lifetime is highly affected due to imposing frequent charging and discharging cycles (Mwasilu et al., 2014). However, the battery life can be extended by adopting intelligent charging schemes. The use of the battery can be minimized by only allowing a few cycles per day, e.g. store solar energy during the day and discharge in the evening with high demand. Nevertheless, will the battery age faster and the car-owner will have a drawback, so this has to be compensated; Either by paying the owner for the grid-contribution or by own savings of the owner due to lower energy demand from the grid. V2G systems are only likely to change EV deployment and diffusion patterns if there are benefits associated with providing energy from parked cars (Turton and Moura, 2008) and if they are easy to use for the owners.

V2G is a rather new technology solution, still on the piloting stage. To utilize V2G, special bidirectional DC chargers are needed. Suitable software and regulations also need to be in place. However, V2G is demonstrated internationally, e.g. in Danish research projects PARKER and NIKOLA described in Chapter 6.2. Nissan, DTU and NUUVE are among the partners involved in this development. In Chapter 7.7.4 and 7.7.5, V2G projects in Denmark and the Netherlands are described. Cars from Nissan are used in the pilot projects, e.g. 10 Nissan eNV200 cars in Denmark. Also in Great Britain, Nissan plan to test 100 cars with V2G in a pilot project (TU.no, 2016).

There was also a deployment of Vehicle 2 Home (V2H) chargers from Nichicon in Japan in 2012, after the Fukushima accident (Nichicon Corporation, 2014, Corporation, 2012). They were used in combination with cars from Nissan, but are compatible with all EVs having a CHAdeMO-charger. There are also other early initiatives to develop V2H solutions in Japan, like Toyota or Hydro Quebec (Toyota, 2012).

In Norway, NVE has investigated a possible development of battery use in connection with the Norwegian power system (Henden et al., 2017). The report states that it is especially interesting to use the available battery storage capacity in the growing EV park.

By June 2016, the total battery capacity in all the EVs in Norway was around 2.5 GWh (Henden et al., 2017). In 2030, NVE assumes that a large share of Norwegian households will have an EV with battery capacity large enough to cover half of their daily energy need (Henden et al., 2017). Later, these batteries can therefore play an important part in the Norwegian power system. Based on prognoses for growth in EV use from "Nasjonal Transportplan", the total battery capacity for EVs in Norway can increase to around 100 GWh in 2030. NVE assumes that maybe 1 – 8 GW of this capacity can be available for the grid, which will be a substantial power reserve for the grid.

6 Research activities, smart EV charging systems

6.1 Norwegian research projects

Some main Norwegian research projects related to smart EV charging systems are listed in the table.

Project	*Goal*	*Norwegian partners*
FME ZEN, 2016-2024, FME/RCN www.ntnu.no/zen	A Norwegian Research Center on Zero Emission Neighbourhoods in Smart Cities. This report is a part of Work Package 4 "Energy Flexible Neighbourhoods". The goal for WP 4 is to develop knowledge, technologies and solutions for design and operation of energy flexible neighbourhoods.	NTNU, SINTEF, Oslo, Bergen, Trondheim, Bodø, Elverum, Steinkjer, Sør-Trøndelag fylkeskommune, Statsbygg, NVE, DiBK, Husbanken, ByBo, Elverum Tomteselskap, TOBB, Snøhetta, Reinertsen, Asplan Viak, Multiconsult, SWECO, Civitas, Futurebuilt, Hunton, Moelven, Norcem, Skanska, GK, Caverion, Nord-Trøndelag Energiverk, Numascale, Smart Grid Services Cluster, Energi Norge, Norsk Fjernvarme
FME Cineldi, 2016 – 2024, FME/RCN www.sintef.no/prosjekter/cineldi	A Norwegian Research Center for intelligent electricity distribution- to empower the future Smart Grid. Cineldi WP5 focuses on Flexible Resources. Relevant work includes PhD Salman Zaferanlouei: Integration of EVs in smart grid; MSc thesis: Sigurd Bjarghov: Utilizing EV Batteries as a Flexible Resource at End-user Level; MSc Sondre Flinstad Harbo: Agent Based Modelling and Simulation of Plug-in EVs Adoption in Norway. (Korpås, 2017)	SINTEF Energy Research, NTNU, Smart Innovation Norway and industry partners
FME MoZEES, 2016 – 2024, FME/RCN www.mozees.no	A Norwegian Research Center on Zero Emission Energy Systems with focus on battery- and hydrogen technology for transport applications.	IFE manages the centre, which has a total of 40 partners including 7 research institutions, 7 public bodies and 26 industrial partners
Smart Energi Hvaler, 2014-2016 www.smartenergihvaler.no	Smart Energi Hvaler is a pilot area, demonstrating different smart energy concept, such as smart metering (AMI), solar energy production, battery systems, EV charging and new business models.	Fredrikstad Energi, Hvaler kommune, Smart Innovation Østfold
ChargeFlex, 2015-2017, RCN ENERGIX	The main objective in ChargeFlex is increasing local network capacity 25 percent by developing software to manage the added flexibility from introducing	eSmart Systems, Værste, Sogn og Fjordane Energi, Smart Innovation Østfold, Proxll, NTNU, Fredrikstad

Project	*Goal*	*Norwegian partners*
www.esmartsystems.com/references/projects/chargeflex/	EV's, demand and response philosophy, and smart management into the equation	Energi Nett, eSmart Systems, Fortum Charge&Drive
FlexNett, 2015-2017, RCN IPN ENERGIX www.sintef.no/projectweb/flexnett	The main objective of the project is contributing to increased flexibility in the future smart distribution grid by demonstration and verification of technical and market based solutions for flexibility, on different grid levels and for different stakeholders.	BKK Nett, SINTEF, Smart Innovation Østfold, ABB, Agder Energi, Aidon, Communicate, Eidsiva Nett, ELTEK, Enfo Energy, Hafenstrøm, Hvaler kommune, NTE Nett, Odin Media, Prediktor, Skagerak Nett, Smart Grid Norway, Smartgridsenteret, Statnett
ELinGO, 2016-2018, RCN www.sintef.no/projectweb/elingo	Electrification of heavy freight transport.	Statens veivesen, SINTEF byggforsk and partners
PowerShaper, 2017 – 2019, RCN IPN ENERGIX	A realisation of a cost-effective energy storage system, for power flexibility in the grid and buildings.	Eltek
IntegER, 2017 – 2020, RCN IPN ENERGIX	The project's overall objective is to contribute with new knowledge and practical guidelines that enables energy storage (mainly electric batteries) to be used and integrated into the Norwegian distribution grid.	Skagerak Nett, SINTEF Energy Research
eCar, 2009-2012 RCN ENERGIX www.sintef.no/projectweb/ecar	The main objectives of the project was to analyze the consequences for the environment and the power sector of substituting a substantial part (30 percent) of fossil energy used in road transport with electric energy in Norway in 2020, and to form a strategy for road transport electrification.	SINTEF Energy Research, NTNU, BKK Nett AS, Eidsiva Energi AS, Miljø Innovasjon AS, Nord-Trøndelag Elektrisitetsverk og TrønderEnergi
SPESNETT, 2012-2017 RCN IPN ENERGIX	Voltage quality in Smart Grids. The project has conducted several field tests of challenging electrical appliances including three phase ground heat pumps, three phase sewage pumps and single-phase fast charging of (7kW) Tesla Model S.	Energi Norge, Sintef, Luleå Universitet, Agder Energi, BKK, Eidsiva, Hafslund, Helgeland kraft, Istad Nett, Lyse Elnett, NTE, Skagerak Nett, Statnett, Trønder Energi and NVE

In addition, there are Norwegian participants in some of the European research projects, as described in Chapter 6.2.

6.2 European research projects

Some examples of relevant European research projects are listed in the table, with description of Norwegian participation, if any.

Project	*Goal*	*Norwegian partners*
INVADE, 2017-2020, H2020, Smart system of renewable energy storage based on INtegrated EVs and bAtteries to empower mobile, Distributed and centralised Energy storage in the distribution grid http://h2020invade.eu	INVADE will deliver a cloud-based flexibility management system integrated with EVs and battery storages at mobile, distributed and centralized levels. The goal is to change the way energy is used, stored and generated by utilizing renewable energy more effectively, optimizing the supply of electricity and making services more end-user centric.	Coordinated by Smart Innovation Norway. eSmart Systems AS, Schneider Electric Norge AS; Lyse and NTNU are Norwegian partners in consortium. Stavanger is a pilot site.
SEEV4City, 2014-2020, InterReg, Smart, clean Energy and Electric Vehicles for the City www.northsearegion.eu/seev4-city	All SEEV4-City Operational Pilots are aimed at combining electromobility and renewable energies.	Oslo is a pilot city, with the site Vulkan. See also Chapter 7.2.
FREVUE, 2013-2017, FP7, Freight Electric Vehicles in Urban Europe http://frevue.eu	FREVUE aims to prove that the current generation of electric vans and trucks can offer a viable alternative to diesel vehicles, particularly when combined with state of the art urban logistics applications, innovative logistics management software, and with well-designed (local) policy.	Oslo is a demonstrator city, cooperating with the local postal company Bring to introduce electric freight vehicles in its fleet and its distribution operations. Pre-booking of Fortum fast charging stations is tested.
ELECTRIFIC, 2016-2019, H2020, Enabling seamless electromobility through smart vehicle-grid integration http://electrific.eu/	ELECTRIFIC will develop novel technologies and theoretical understanding that enable highly attractive and sustainable electro-mobility through smart vehicle-grid integration. The technologies will be developed at three layers – the grid, the EV and the user.	Gfi NV (Belgium) is the leader partner. Schneider Electric, eSmart and Fredrikstad eEnergi Nett (FEN) are Norwegian partners in consortium.
EMPOWER, 2015-2017, H2020, Local Electricity Retain Markets For Prosumer Smart Grid Power Services http://empowerh2020.eu	The EMPOWER concept aims to encourage and enable the active participation of citizens that consume and produce energy in the electrical system. The project has three pilots, including Hvaler in Norway. (Ottesen, 2017)	Coordinated by Smart Innovation Norway. At Hvaler there are two sites: Norderhaug and Sandbakken miljøstasjon.
CoSSMic, 2013-2016, FP7,	CoSSMic aims at enabling higher rates for self-consumption (>50%) of decentralised renewable	SINTEF is the coordinator. UiO and

Project	*Goal*	*Norwegian partners*
Collaborating Smart Solar-powered Micro-grids http://cossmic.eu	energy production by coordinating the energy production, consumption, and use of storage units of the buildings in a neighbourhood.	NTNU are the Norwegian partners in the consortium.
Storage4Grid, 2016-2019, H2020, www.storage4grid.eu/pages/index.html	Storage4Grid aims at boosting the uptake of storage technologies between the distribution grid level and the end-user level, by developing a novel, holistic methodology for modelling, planning, integrating, operating and evaluating distributed Energy Storage Systems. The Storage4Grid methodology encompasses storage at user premises and storage at substation level, Electrical Vehicles, innovative energy metering and energy routing technologies.	No Norwegian partners. Istituto Superiore Mario Boella (Italy) is the leader partner.
Parker, 2016-2018, Danish research project www.parker-project.com	The objective of the project, Parker, is to validate that series-produced electric vehicles as part of an operational vehicle fleet can support the power grid by becoming a vertically integrated resource, providing seamless support to the power grid both locally and system-wide.	Nissan, Mitsubishi Corporation, Mitsubishi Motors Corporation, PSA ID, NUVVE, Frederiksberg Forsyning A/S, Insero A/S, Enel and DTU Electrical Engineering (PowerLabDK)
NIKOLA, 2013-2016, Danish research project, Intelligent electric vehicle integration www.nikola.droppages.com	With sufficient control and communication it is possible to influence the timing, rate and direction of the power and energy exchanged between the EV battery and the grid. This ability can be used in a set of "services" that bring value to the power system, the EV owner and society in general. Nikola seeks to thoroughly investigate such services, to explore the technologies that can enable them and finally to demonstrate them through both simulations and in-field testing.	NUVVE, EURISCO, SEAS-NVE, DTU
COTEVOS, FP7, 2014-2017, Concepts, capacities and Methods for Testing EV Systems and their Interoperability within the Smart Grids http://cotevos.eu	The aim of COTEVOS is to establish the optimal structure and capacities to test the conformance, interoperability and performance of all systems making up the infrastructure for the charge of Electrical Vehicles (EV).	11 partners from 9 countries. TECNALIA is the coordinator. Denmark/DTU is a partner.

6.3 National Smart Grid Laboratory

A National Smart Grid Laboratory is built in Trondheim, by NTNU and SINTEF, as shown in Figure 6.1. The laboratory will be capable of combining laboratory tests with real-time simulations, like a smart home management system (intelligent smart meters, controlling of components, in-house energy management), micro-grids or the battery test system. More details can be found on (Sintef.no, 2014, NTNU.no, 2017)

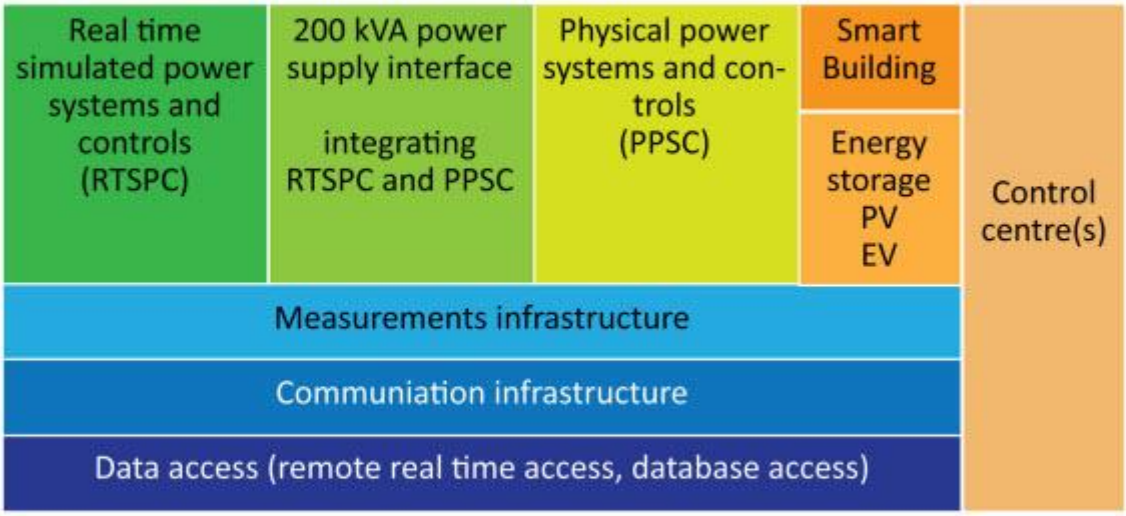


Figure 6.1 Concept of the National Smart Grid laboratory in Trondheim (Sintef.no, 2014).

The laboratory consists of six parts, where EV charging energy storage infrastructure is one of these. The construction of the EV infrastructure is starting in 2017, with Jon Suul or Kjell Sand as a contact person. Figure 6.2 shows the six parts of the infrastructure.

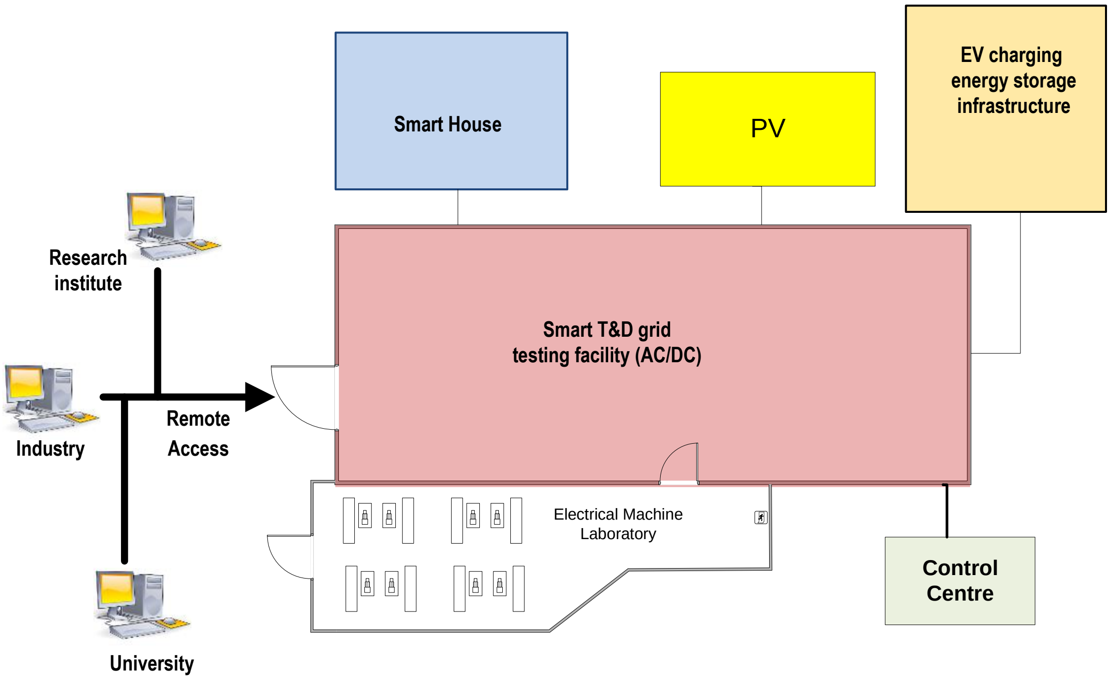


Figure 6.2 Schematics of the National Smart Grid laboratory

7 Examples of EV charging systems

7.1 Publicly available charging stations

As described in Chapter 4.2, there are more than 2000 fast and semi-fast charging stations registered in Norway, by May 2017. These are either owned by public authorities, which many places offer up to semi fast charging services free of charge, and private companies, which often offer semi-fast or fast charging services for a fee.

7.1.1 Charging stations owned by public authorities

Several municipalities in Norway offer charging services for EV users. Oslo, Bergen and Trondheim are examples of this.

Oslo municipality is the largest public owner of charging stations, providing charging services and EV parking free of charge. By March 2017, Oslo has about 1150 charging points, and in total 1300 charging points will be available by the end of 2017 (City of Oslo, 2017b, City of Oslo, 2017a). Typically, the charging stations is Type 2 and offer 3.6 kW power (230V 1 phase max 16A). The company Salto Ladestasjoner has delivered many of the current charging stations, with Mennekes charging columns. Technical specifications for new procurements are described in a new tender, dated May 2017 (City of Oslo, 2017a). The charging garages Vulkan and Akershus Fortress are described further in Chapter 7.2 and 7.3. Oslo is cooperating with private companies, for example to establish fast-charging stations in the city.

As part of the FREVUE project, the City of Oslo tripled the number of quick chargers in the city in 2016. The three largest sites in Oslo are now operating a total of 11 fast chargers and 22 semi-quick chargers. The three sites are located at the Munch Museum parking, at the “Margarinfabrikken” in Bjølsen and in Skøyen.
All sites offer a pre-booking system, which allows freight operators using electric vehicles, to reduce the waiting time and the uncertainty related to the availability of the public chargers. The charging station located on the Munch Museum parking uses a solar panel solution, while the one in Skøyen is also prepared for the new generation super quick DC chargers of more than 150 kW and can easily be upgraded as soon as the new protocols are approved. (FREVUE project, 2017)

In **Bergen**, the municipality offer charging services for a fee at seven locations (Bergen municipality, 2017). The fee structure varies between day and night time.

Also, **Trondheim** has a number of charging stations in the city. EV-drivers need to pay ordinary parking fees for parking in Trondheim, while the charging is included in the parking fee. Outside the city center there is no parking fee at the chargers.

7.1.2 Commercial fast charging stations

When it comes to private companies, Fortum Charge&Drive, Grønn Kontakt and Tesla are examples, representing the companies with a highest share of charging stations in Norway. As mentioned in Chapter 4.2, the companies had about 130, 75 and 31 fast charging stations accordingly - by August 2016 (elbil.no, 2016a). This number is increasing, and Fortum Charge&Drive had about 350 fast charging points by April 2017, divided on 170 locations in Norway (Sletvold, 2017). Grønn kontakt is planning to open 100 new fast charging stations in Norway in 2017 (Grønn kontakt, 2017).

From Fortum Charge&Drive and Grønn Kontakt, customers can buy charging services for a fee. The charging service has a cost per minute (often 2.5 NOK/min for <50kW chargers). Super charging of the Tesla cars are often included in the car investment, up to 400 kWh annually. After using 400 kWh annually, the charging has a fee – according to the energy used (kWh) (Tesla, 2017). All the three companies have an App with information about their charging stations.

Since Tesla has longer driver range, they have a smaller number of charging stations, but there are normally more charging points per charging station. For example, in Nebbenes by Eidsvoll, the large fast charging station has in total 28 charging points, where 20 are from Tesla and 8 from Fortum. This charging station is stated to be the largest fast charging station in the world (TU.no, 2017c).

7.2 Smart EV charging systems at Vulkan garage and Akershus Fortress garage (Oslo)

The increased use of EVs in Norway call for new and innovative solutions for charging infrastructure. An example of such solutions is the commercial charging station Vulkan in Oslo, with the possibility of charging 100 EVs. The charging station is already testing new business models, and it will from summer 2017 have a dynamic management of the power use, a battery package and also be prepared for vehicle to grid solutions (V2G). The garage is also prepared for the next generation fast chargers of 150 kW. It will later also be possible to book charging parking places. (Fortum Charge & Drive, 2017, Grønn Byggallianse, 2017).

During the daytime, dynamic charging services are available for a fee. The dynamic load management provides power from 3.6 to 22 kW, where all the charging points are managed individually. The charging power is chosen on a local screen or an App, where there are different fees for the different power options. Charging is free during the night-time (from 17 to 09 (11) o'clock), with 3.6 kW. The battery package of 50 kWh will be used as a buffer and to manage peak loads, to avoid upgrading of the grid in the area. (Grønn Byggallianse, 2017)

Aspelin Ramm is the owner and developer of the Vulkan area, and Oslo municipality and Fortum (operator) are partners in the development of the smart charging system. The investment is partly financed by the EU project SEEV4-City.

Under Akershus Fortress in Oslo, a garage for EVs opened in June 2017. The opening of the garage was delayed, partly because of fire safety measures. There are 86 charging stations in the garage, where EVs can park without costs for up to 10 hours (elbil.no, 2017a, elbil.no, 2015). The garage has a main switch of 600 amps, which is divided into nine groups; most with 80 amp power supply. Each group can charge 10 EVs, with about 2.7 to 3.3 kW. There is a smart load sharing in the garage, where 12 amp power supply is the lowest charging speed, while 16 amp power supply is the theoretical maximum. The technology is delivered by Sønnico AS.

Oslo has an app for the two garages (EL Oslo kommune), which communicates with technology in the garage. The App is used as an entry card for the garages.

7.3 Large fast charging system at Danmarksplass (Bergen)

At Danmarksplass in Bergen, Bergen municipality and BKK have installed 14 fast charging stations and 8 semi-fast chargers. The technology is delivered by ABB. When built in January 2015, this was the largest fast charging station worldwide, according to Vest24 (2015). The charging station has a combination of CHAdeMO (50 kW DC), Combo (50 kW DC) and Type 2 chargers (22 kW AC semi fast). The system is dimensioned, so all the 14 fast charging stations can offer 50 kW (22kW) simultaneously. It is planned that the semi-fast chargers will be replaced with new fast charging points of 150 kW in 2018 to 2020 (Askeland, 2017). BKK has good experiences from the charging station, which has a central location and is frequently in use.

7.4 Public concept study: Forus Parkering (Stavanger)

Forus Parkering is a parking garage by Stavanger in Norway, with capacity for about 1550 cars. During autumn 2017, Forus Parkering received funding from Enova for a public concept study. The study will map the possibilities for further develop the garage to become a mobility hub for EVs and electric busses. Part of the electricity needed will be generated by PV and wind mills locally. The study will be made public by Enova, so also others can benefit from the experiences. (TU.no, 2017d, Forus Parkering, 2017)

7.5 Smart solutions for apartment buildings

As described in Chapter 4.7, EV owners in flats and apartments cannot necessarily charge at home.

Norsk elbilforening, OBOS, Oslo and Transnova published in 2014 a manual for housing associations, on how to establish a charging station for the residents (Norsk elbilforening et al., 2014). However, the manual only focus on single charging points, not smart solutions and load sharing. The need for smart solutions is higher now than in 2014, since there are a higher number of EVs.

The large cooperative building association OBOS, confirms the need for EV charging in apartments (Grønn Byggallianse, 2017). OBOS has been working with EV charging for several years. Beside OBOS, also others are working on charging systems for apartment buildings such as BKK in Bergen and Oslo municipality.

Some examples of solutions commercially available for apartment buildings are listed below. The list is not comprehensive.

The Norwegian company ZAPTEC (zaptec.com) states that the ZapCharger Pro solution utilizes the available electric capacity to its fullest, sharing the power dynamically across several charging stations. Balancing technology makes it possible to charge over 100 electric vehicles in 24 hours, on a single 63A circuit. Up to 22kW of power is available on every single charging station. The load balancing is across all 3 power phases, to avoid lopsided loads. All the chargers communicate through ZapCloud (Microsoft Azure based cloud solution), with a supplementary dashboard, reporting tools, statistics, etc. ZAPTEC has installed their system in some larger apartment buildings and garages, eg. by Bekkestua, where there are 51 charging points in a garage with 100 parking places.

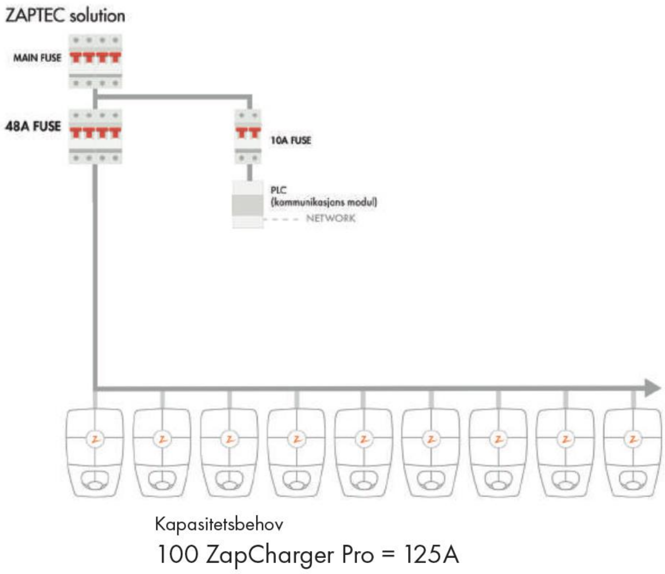
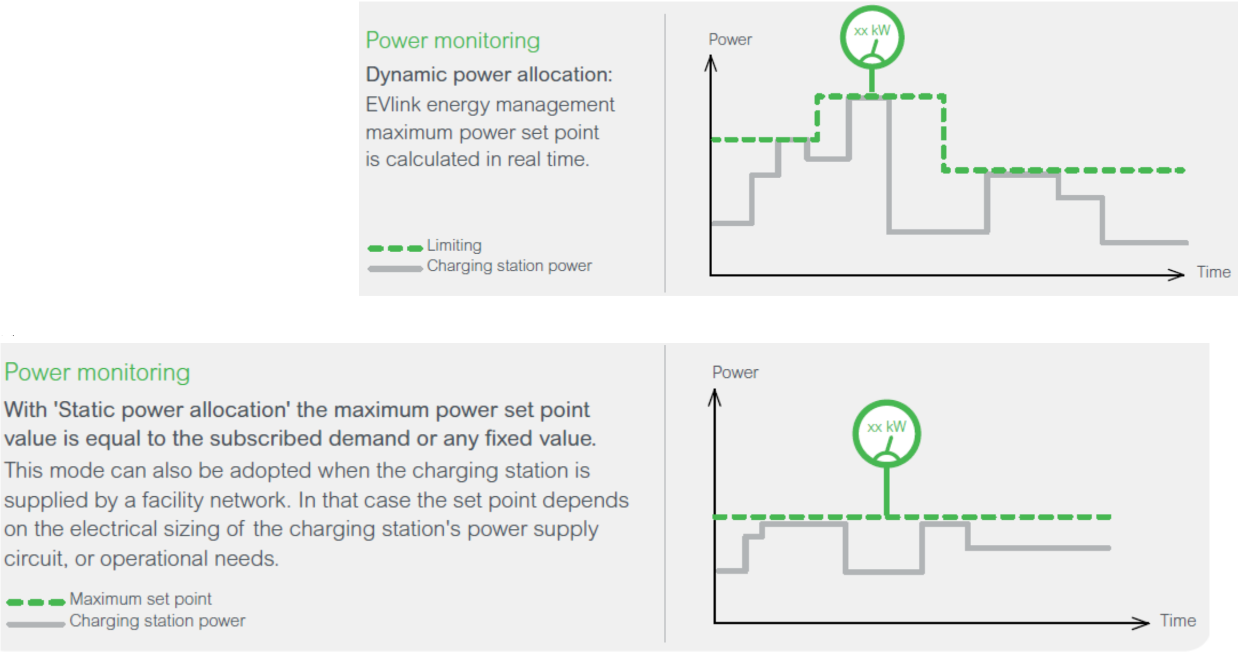


Figure 7.1 Illustration of a ZAPTEC solution with power balancing technology (ZAPTEC, 2017)

Schneider Electric (schneider-electric.no) offers an EVlink Smart Wallbox with energy metering capabilities. With a commissioning tool, e.g. the following parameter settings can be configured: Maximum authorized charging current per charge point; the energy management functionalities load shedding and deferred start; balancing the charging powers for charging stations with two charge points, etc. Up to 24 socket outlets can be connected to a cloud supervision. The maximum power of the charging station can be set remotely by an external system, either as a permanent value or dynamically, e.g. using a Building Management System. A dynamical system is tested in an apartment block in Oslo, where the current available for EVs was between 63 A and 200 A, depending on the other electricity use in the apartment (Grønn Byggallianse, 2017).



Power monitoring

Dynamic power allocation:
EVlink energy management maximum power set point is calculated in real time.

Power monitoring

With 'Static power allocation' the maximum power set point value is equal to the subscribed demand or any fixed value.
This mode can also be adopted when the charging station is supplied by a facility network. In that case the set point depends on the electrical sizing of the charging station's power supply circuit, or operational needs.

Figure 7.2 Dynamic power allocation (top) and static power allocation (bottom), possible in the EVlink energy management system (Schneider Electric, 2017)

Ensto (ensto.com, norcharge.com) provides Chago Cloud services with e.g. dynamic load charging between the charging stations.

MOVEL (movel.no) is a Norwegian company, offering assistance to housing associations for development and operation of EV chargers. The chargers are delivered by Ensto. The individual users can choose from three different subscription packages based on annual power consumption and mileage. Movel takes care of safety issues, optimal distribution of available power between the EVs and payment for the charging. MOVEL has a pilot project in Elvefaret Borettslag in Oslo, where 210 parking places are prepared for charging (Elvefaret Borettslag, 2017). Initially, 45 chargers are installed.

CHARGE AMPS (charge-amps.com) is a simpler home-charging solution. However, it has a cloud service (my.charge.space) where users can see how much they have charged the car, time the charging and control the charging remotely. My.charge.space is an open protocol, which can communicate with different solutions, allowing integration with 3rd parties such as payment services.

ETREL (etrel.com) provides charging stations for charging of one or two vehicles. The chargers offer connection to an Ocean cloud management system, with interface for EV charging operators (with e.g. billing and booking services), service providers and end-users.

7.6 Charging stations with solar cells

"Salto Power" at Sjølyst in Oslo was piloting charging stations with solar cells from 2014.

In 2017, Circle K Økern in Oslo will install solar cells, and the energy will partly cover the energy needed in the fast charging station (TU.no, 2017b). Solar cells are also planned on Circle K Kjeller close to Lillestrøm.

Solarcharge 2020 is a project within the ERA-Net Smart Grids Plus initiative, combining charging stations with solar cells. Systems for solar charging will be built in full scale in Uppsala and in Tromsø, Norway (Solelia, 2016).

Tesla has ambitions internationally, to have nearly all their supercharge stations powered by local solar cells and battery systems (TU.no, 2017c).

7.7 Smart charging systems internationally

Smart charging systems are demonstrated in several cases internationally. This chapter describes some of these systems.

7.7.1 Charging scenarios at EnergyVille in Belgium

The Flemish research association EnergyVille has a Smart Charging System concept (EnergyVille, 2017), to optimise the interaction between electrical vehicles and electricity grids. An electric vehicle might be plugged in for a whole night or day, while it may only need a couple of hours to fully charge. The EnergyVille Smart Charging System uses this flexibility to intelligently manage the charging process according to the operator preference:

- Peak shaving scenario: charge when the grid capacity is high (off-peak), or manage the simultaneous charging of several electrical vehicles in the same street or car park by spreading their demand over time.
- Renewable scenario: charge when the availability of renewable energy from sun and wind is high.
- Balancing scenario: keep demand/supply balanced.

In each scenario it is guaranteed that the electrical vehicle will be charged by the time the driver wants it to be charged, and to the level requested. EnergyVille offers its employees the use of a fleet of electric scooters for their daily commute, in order to test the Smart Charging System at EnergyVille continuously and in real-life circumstances.

7.7.2 Charging data and load shifting in the UK

The “My Electric Avenue” project in the UK aimed to assess the potential impact of a cluster of EVs may have in a local area served by one electricity substation. If users charge their EVs at the same time then the load on the local electricity network may exceed the substation capacity (ICF, 2016). The 3-year project was completed in 2015 and examined ten “electric avenue” groups or clusters of ten or more people around Britain. The trial participants were driving a Nissan Leaf for 18 months to trial a new technology, “Esprit”, which would monitor and control the electricity used when the car was being charged. This technology has been designed to avoid any potential power outages and damage to network infrastructure by temporarily curtailing high load devices (typically in this trial for 30 minutes) to reduce the overall load on a single feeder or transformer.

Another project in the UK, the Low Carbon London (LCL) trials, involved both residential and commercial vehicle fleets, as well as charging data collected from Source London public charging stations (Aunedi et al., 2014). The EV data collected in the LCL trial covered three broad areas: (i) metered EV charging data for 72 residential and 54 commercial charging points; (ii) data on charging events collected at 491 public charging points; and (iii) vehicle logger data capturing driving and charging behaviour for 30 EVs. Some project results are described in Chapter 4.5 and details are available in (Aunedi et al., 2014).

7.7.3 User responses in Germany

In Germany, a project aimed to investigate users' real-life experiences with a smart charging system and their evaluation of it (Schmalfuß et al., 2015). In a 5-month field trial, 10 EV drivers compared conventional EV charging with smart charging. Via smartphone application, users could modify settings which determined the charging process (e.g., departure times). Results showed that the users were motivated and positive about using such a smart charging system.

7.7.4 V2G units at the utility Frederiksberg Forsyning in Copenhagen

The Frederiksburg Pilot is a real-world test of ten Nissan eNV200 cars and ten Enel V2G charger stations. California-based Nuvve is the provider of the platform that controls the power flow to and from the cars. The V2G units are located at the headquarters of the utility Frederiksberg Forsyning in Copenhagen.

When the e-NV200s are not in use, they can be plugged in to the charger stations on site and can receive energy from and provide energy back to the national grid on demand. The total capacity made available by the ten kilowatts Enel V2G chargers amounts to approximately 100 kilowatts (NUVVE, 2017). The Technical University of Denmark (DTU) investigates the services the EVs can provide to the grid operator; Frequency regulation or power (Andersen, 2017). Frequency regulation is illustrated in Figure 7.3.

By participating in this initial project, the Danish grid operator Energinet.dk is keen to apply the findings from the commercial implementation of the V2G hub, to adapt the national network in order to better integrate EVs and provide ancillary services to stabilize the grid.

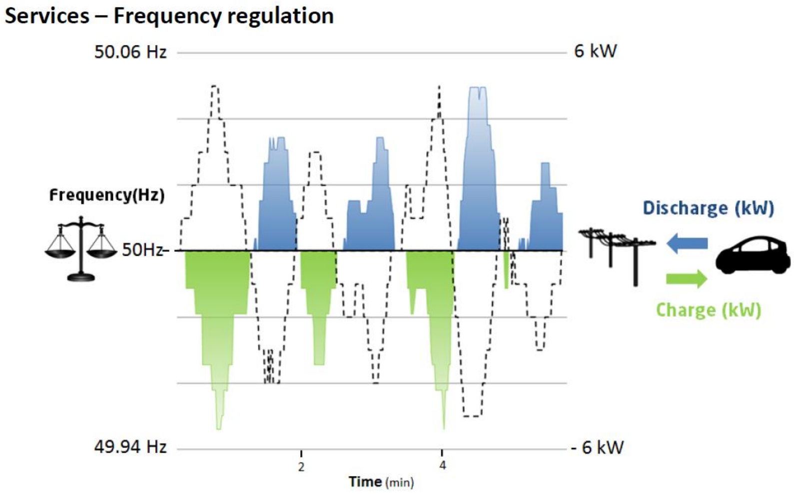


Figure 7.3 EVs provide frequency regulation as a service to the grid operator in the Frederiksburg V2G Pilot (Andersen, 2017)

7.7.5 Energy storage in EV batteries at Amsterdam Arena and V2G in the Netherlands

In 2016, Amsterdam ArenA agreed with Nissan, Eaton and The Mobility House to provide back-up power from second life Nissan LEAF batteries (Amsterdam ArenA, 2016). The xStorage Buildings system aim to draw energy from the grid, providing businesses with more control, better value and a more sustainable choice for their energy consumption.

Using 280 Nissan LEAF batteries, the system will have four Megawatts of power storage capacity, which in November 2016 was stated to be the largest energy storage system powered by second-life batteries used by a commercial business in Europe. As well as providing vital back-up power services to the ArenA, xStorage Buildings also enables the Amsterdam ArenA to power the surrounding neighbourhood when necessary and protect the grid.

There are also other interesting projects in the Netherlands, such as the Amsterdam Vehicle2Grid project (Resourcefully, 2017). This project aims to investigate the contribution of smart energy storage to sustainable urban development. Since April 2014, an Electric Vehicle participates actively in the electricity system, storing surplus of production during the day and providing this stored energy by night to a household in Amsterdam. After two years of running, the household has increased the energy independence from 34 to 65% with V2G, and there has been a solid decline in energy exchange with the electricity network with 45% less compared to the situation without V2G.

Another V2G project is the LomboXnet in Utrecht (Renault, 2016). Phase one of the project will involve setting up 1,000 smart solar-charge stations, powered by 10,000 photovoltaic panels in the Utrecht region. Infrastructure installation will run side by side with development of a car-share service of electric cars, powered by renewable energy, for Utrecht residents. Phase two of the project will proceed with the partners developing a vehicle-to-grid ecosystem, with the network of solar chargers capable of both charging the electric cars and of feeding energy stored in the batteries of parked cars onto the grid to meet demand peaks.

7.7.6 Fast charging of busses

Göteborg has an example of fast charging of busses, on route 55 between Lindholmen and Johanneberg (9 km). The fast charging stations has a capacity of 300 kW and a full charging takes only a few minutes. The fast-charging system used is a pantograph, where the equipment is top-down on the roof of the bus in the end-station (Siemens, 2017).

In Amsterdam, 100 new electric buses will be operated from 2018 (Heliox, 2017). Heliox will deliver the system, as a turnkey project to charge hundred VDL Citea's SLFA Electric buses. It includes the 13 MW charging infrastructure at the two depots of Schiphol Amsterdam Airport and Amsterdam/ Amstelveen, as well as two opportunity charging hubs for end of route charging. Each of the electric buses will be driven over 100,000 km per year, as this is one of the busiest bus networks in The Netherlands.

Also Ruter in Oslo is in the process of introducing electric busses. A test project started in the late autumn 2017, with six electric busses on the ordinary bus lines 74, 60 and 31 in Oslo. Unibuss, Norgesbuss and Nobina are each testing two of the electric busses each. (Ruter, 2017)

8 Opportunities for smart charging systems in ZEN pilot areas

In ZEN there are seven pilot areas: Campus Evenstad, Ydalir (Elverum), Steinkjer, Trondheim Kunnskapsaksen, Furuset, Zero Village Bergen and Bodø airport redevelopment. The energy systems in the pilot areas are further described in the pilot survey in ZEN WP4 Energy flexible neighbourhoods (Sørensen et al., 2017a).

Electric Vehicle (EV) smart charging systems can play an active role in a Zero Emission Neighbourhood, improving the energy flexibility of the area. It is therefore relevant to install smart charging systems in ZEN pilot areas, to better match the load of the energy demand in buildings and infrastructure, with local electricity generation and energy storage. Batteries in vehicles may also play a role in this, through V2G.

At Campus Evenstad some relevant activities are already initiated. This includes a study from Multiconsult, evaluating electrical energy storage at the Campus (Holm, 2017), public procurement of batteries during the autumn 2017, and an MSc thesis during the autumn 2017, focusing on load matching of EV charging, solar electricity production and batteries (Nes, 2017). A smart EV charging system at Campus Evenstad is also illustrated as a case by Sørensen et al. (2017b). In the case, their PV plant is up-scaled with a factor of four, and charging measurements from an EV pool in Trondheim is used. Further information can be found in the article.

The intention of this *state-of the art for Smart EV charging systems for ZEN*, is that the study will be helpful when planning which activities to be implemented in the pilot areas.

Examples of solutions which can be tested in the pilot areas are (both technology and user acceptance):

- Shifting EV charging and EV load sharing, taking local energy production, neighbourhood energy demand and grid capacity into consideration,
- Shifting also other loads in the energy system, such as heating, electric water boilers and white goods,
- How the self-consumption of solar electricity can be increased if it is combined with smart charging,
- Cost effective solutions for apartments with grid limitations,
- Vehicle to grid solutions, as an alternative to stationary battery solutions,
- Individual and community battery solutions, to reduce peak loads and increase self-consumption of local energy production,
- Fast charging stations with batteries, to reduce the peak loads,
- Business models with price models for different costumer groups (e.g. night prices in parking houses) and flexible EV charging services,
- EV car pools with shared cars,
- Market mechanisms to increase the use of energy flexibility – as an economically attractive alternative to grid investments,
- Quantification of the result of regulatory barriers, in terms of costs and environmental effect.

Some of the above suggestions may challenge the current legal framework in Norway, such as the possibility for installing a community battery solution or sharing local energy production between neighbours. Since the goal is to improve the overall situation, it may still be possible to test the solutions as a R&D project. This can be further investigated.

It is possible to apply for funding for testing new solutions, e.g. under the financing programme www.pilot-e.no, from Enova, Innovation Norge and the Research Council of Norway. Other Enova-programmes are also relevant, such as the programme "New technologies in the energy system".

9 Conclusion

Increased use of EVs calls for new and innovative solutions for charging infrastructure. At the same time, it is desirable to better match the energy need in buildings and infrastructure, with electricity generation and energy storage in a neighbourhood.

If energy management solutions are integrated in smart EV charging systems, such systems can improve the energy flexibility of a neighbourhood. Literature and commercial EV charging systems provide examples of smart EV charging systems, which e.g. provide dynamic load management, utilize the available grid capacity, offer a variety of charging services, and demonstrates Vehicle to Grid solutions.

Smart EV charging systems can also play a role in the pilot areas of the Research Centre on Zero Emission Neighbourhoods in Smart Cities (ZEN Centre). Piloting of new technologies and solutions will provide more knowledge about how smart EV charging systems can play a role in the neighbourhood energy management system.

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