Summary

Charging into the future

Analysis of fast charger usage

TØI Report 1682/2019
Author: Erik Figenbaum
Oslo 2019 79 pages English language

Analysis of actual use of fast chargers in two charging infrastructure operator networks between January 2016 and February 2018, reveals a large spread in achieved charge power between users, seasons, vehicles and locations. The average power was as low as 30.5 kW from chargers cable of delivering 50 kW to vehicles that in theory should accept 50 kW charge power. The derating of the charge power can be explained as a combination of the limited real fast charge capability of some electric vehicle models and climatic differences and variations in how people use fast chargers, for instance users charging beyond 80% state of charge. Users do this because of long distances between chargers and the risk of charge queue in the next location. The average charge time was 20,3 minutes and the average charged energy was 9,6 kWh with much less variation between seasons than for the charge power. The best utilized chargers are in cities where the risk of queues is the largest.

Introduction

Battery electric vehicles (BEVs) have to be recharged with electricity from the grid to be able to operate. Most of that charging occurs at home, either from a traditional household socket or a specific BEV charging station. Home and on-street charging, work place charging and other local and regional public chargers, supports everyday traffic. Owners of BEVs will also have to charge somewhere during a long distance trip, either roadside or at the destination. The range is often not long enough for a round trip. Slow chargers can serve the needs at destinations, whereas fast chargers support the roadside charging during the trip. Fast charging, which is the topic of this report, can therefore serve the following purposes:

1. enable long distance driving
2. enable driving to destinations without charging infrastructure
3. make the use of BEVs more flexible, i.e. enable intraday changes to travel
4. make users confident in using more of the vehicles actual range
5. provide energy to users that run empty or forgot to charge overnight
6. together with on street slow chargers enable BEV ownership in dense cities

The vehicle's ability to accept fast charge, and the availability of fast chargers in the area users travel, are important factors in the user evaluation of BEVs versatility versus Internal Combustion Engine Vehicles (ICEVs). The actual use of fast chargers in Norway has however not been documented. The aim of this report is first and foremost to understand how, how much, and where fast chargers are used in Norway, and to understand how important fast charging is for the rate of diffusion of BEVs. The purpose is not to develop or discuss theories on fast charging or to build models of the fast charger market.

The vehicle fleet

90% of the BEVs in the fleet as of January 2018 were capable of using DC fast chargers. Of these, 35% had a Combined Charging System (CCS) charge inlet, 39% a Chademo charge inlet, and 16% the Tesla proprietary charge inlet. No fast charge use data were available from Tesla's superchargers. Of the CCS/Chademo compatible vehicles, which in most cases can use the same chargers (see next section), 88% were limited to 50 kW charge power, and 64% have a passive battery thermal management system. The use of passive thermal management leads to low battery temperatures in the winter, and potentially too hot batteries in the summer. Both of these conditions reduce the fast charge capability of batteries. The non-Tesla vehicle fleets average nominal (total) battery size was 26 kWh, of which 15.5 kWh could be efficiently fast charged when taking into account that parts of the total capacity is not available for the vehicle owner (safety margin), or inefficient to fast charge.

The fast charge scene in Norway

The first fast chargers in Norway were put into service after 2011, with support from a funding program from the public transportation sector support agency Transnova. Another program from 2015 by the public support agency Enova (that have taken over the activities of Transnova), led to the development of a rudimentary network of dual standard (CCS/Chademo) fast chargers every 50 km along all major travel corridors by the end of 2017. Today, fast chargers in cities and surrounding municipalities are built out commercially, driven by demand. A coverage oriented support program from Enova has since 2017 targeted the development of fast chargers in municipalities without fast chargers. The overall result of these support programs and commercial activities, has been a vast expansion of the network of fast chargers. From the beginning of 2017 until Q1 2018 the network of fast chargers has expanded at about the same pace as the growth in the BEV fleet.

In the beginning of 2018 there where about 500 locations with about 1000 fast chargers installed in Norway. The vast majority of these chargers are multi-standard 50 kW chargers that can be used by both Chademo and CCS equipped vehicles. A few chargers also can deliver 43 kW AC. In addition comes about 50 Tesla Supercharger locations that can only be used by Tesla vehicles.

Method and datasets

In total, three datasets were used in the analysis. Dataset 1 and dataset 2 contained the majority of fast charge transactions in the networks of two operators of fast chargers in Norway between January 2016 and February 2018. These datasets are however not directly comparable. Dataset 1 contained individual charge event transactions. Dataset 2 contained the utilization rate of charge plugs per charger. The total charging activity in terms of minutes charged per year could not be calculated due to confidentiality. Dataset 3 contains results from a user survey of 3,659 BEV owners conducted in June 2018. It provides additional insights into the usage of and user experience with fast charging in Norway. The datasets do not cover Tesla's Supercharger network, but some Tesla owners use other operators' networks with the help of a Chademo adapter.

Results

Fast charging is a complex socio-technical system where seven important parameters play a big role in the final result. These parameters are:

1. User needs for charging and user driving habits
2. The BEV fleets technical characteristics, i.e. battery size, fast charge capability
3. Energy charged (kWh) by each vehicle
4. Average charge power (kW) for each vehicle
5. Time spent charging (min) by each vehicle
6. Total volume of charging (min), i.e. the sum of all vehicles charging
7. Charge queues that are built up from total charge volume and time and day of use

Additional factors that have an impact on these seven parameters, and the interactions between these parameters are presented in Figure S1.

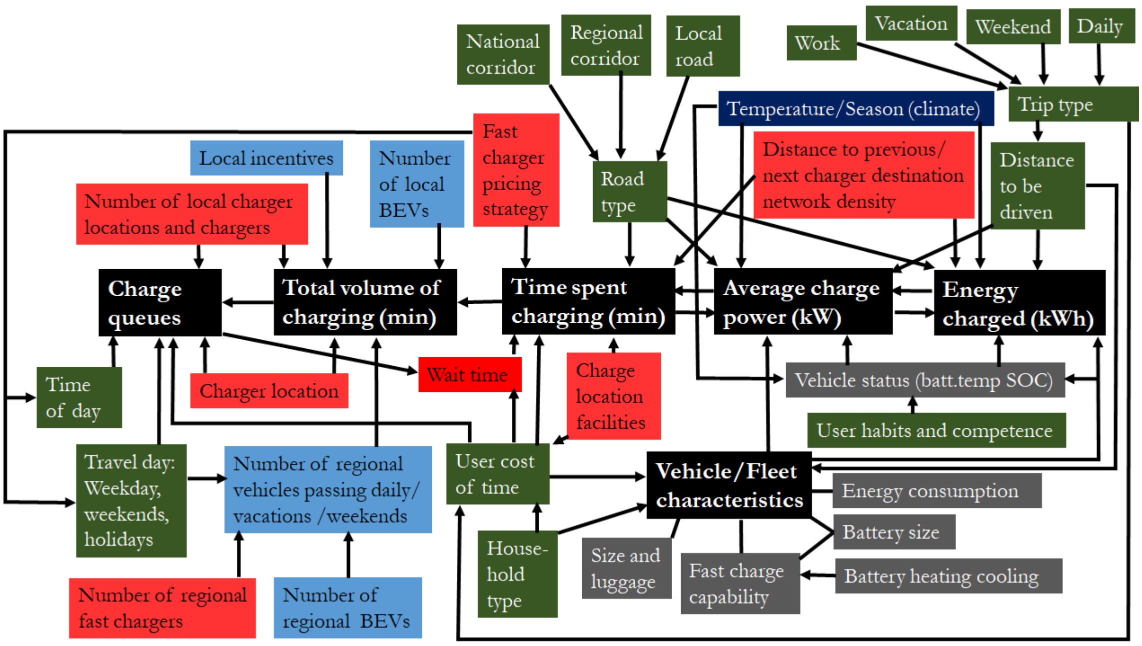

Figure S1. The fast charge landscape proposed as a result of the analysis in this report. Dark green are the user needs and habits that influence charging/vehicle choice. Black are the factors that determine the user interaction with, and perception of, fast charging infrastructure. Blue are factors influenced by the total fleet of BEVs and by political decisions. Red are factors influenced by fast charge operators. Grey are factors that cannot be influenced after the vehicles have entered the fleet. Source: Author.

The user needs are the core elements of providing an attractive network of fast chargers.

There seems, based on the analysis of individual users, to be four user types of fast charging in Norway: (1) Occasional users, (2) Local and regional users, (3) Long distance drivers and (4) Super users. Occasional users charged 1-2 times per year and constituted about 30% of the users. The Super users are about 10% of the users. They charged more than 32 times per year and used many different locations in different counties. The split between the remaining two categories was not possible to calculate, as there were no information in the datasets about where these users live.

The user survey indicate however that it is very uncommon to only fast charge in the local municipality. The most common is to use fast chargers for a combination of regional and long distance trips. In the user survey, 8% said they fast charge weekly, 22% fast charge monthly, 41% rarer, while 29% said that they do not use fast chargers at all. The majority of non-Tesla BEV owners find the fast charger offer to be good, but are not quite as happy as Tesla owners are with the Supercharger network. A small subset of users fast charge more than once over a day, indicating that they are on a long distance trip. On any given day the share is about 18% of those that fast charge.

Demand for fast charging is stable in all counties Monday to Thursday, with increased demand on Friday-Sunday. The Oslo/Akershus capital region is an exception with stable demand across all weekdays. Chargers in rural areas that support travel on motorways and main roads, can have huge demand peaks on peak travel days due to the imbalance between local weekday demand and through traffic weekend demand.

Most current users (according to the survey) accept some charge queues (up to 20 minutes) on peak travel days, and they say that they accept 1-3 charge stops on the way. It does however not mean that charge queues are popular, but rather indicates a sense of realism. Charge queues are most commonly experienced on long distance trips but also locally and regionally. Few users seem to think that charging is boring, although over 40% say they are stressed by charge queues. Users read e-mails, use social media, take a stroll or use facilities at the charging station (typically a fuel station, shop or café), while charging. About 40% would be willing to consider travelling later or earlier to avoid charge queues (mainly on the same day). The summer vacation is the travel period when the highest share of users do the really long distance trips above 300 km. The share of owners of gasoline and diesel vehicles that do such long summer trips is 1.7 times higher than for BEV-owners.

The average fast charge session in Norway in 2017 took 20.5 minutes, with a large spread of charge times between different users, locations and seasons. Users tend to charge longer at shopping centers. The average energy charged was 9.6 kWh, which is about 40% less than the average practical fast chargeable energy content of the average battery in the fleet. The reasons for the lower kWh charged could be that users do not need to charge more to get to their destination, or that their effective State of charge (SOC) window is smaller, i.e. that the charge starts at higher SOCs than optimal. The average charged energy varied little between the summer and the winter seasons, yet the energy can be used to drive 40% less km in the winter than in the summer.

The average charge power was 40% less than the theoretical power capability of 50 kW fast chargers. This large reduction in the average power seems mainly to be due to the combined effects of climatic variations over the year, vehicle manufacturers' strategy to use passive battery cooling and heating systems, and that a share of users charges their vehicles inefficiently, for instance extending the fast charge session beyond 80% SOC. They could have good reasons for charging beyond 80% SOC, for instance to be able to reach the next charger or a destination.

The low average power will lead to an underutilization of the available power of fast chargers. More fast chargers will therefore be needed in each location to be able to transfer the same volume of energy per hour to the vehicles. Cost is thus transferred from the vehicle manufacturer to the charging network operators which will have to invest in more chargers in each location, and pay more than necessary for the grid power connection. These costs will in the end be transferred to users who will pay more to get the same kWh transferred into their vehicle batteries. The users cost of time will also increase as the charging process will take more time. The strategy of the automakers may thus be inefficient overall, and lead to a poorer user experience. The energy cost per km will for instance be about the same as running a vehicle on diesel when the charge power from a 50 kW charger gets as low as 30 kW. More charge queues are also likely to occur, and more public funding will be required to support the build out of the fast charger network. The economy and utility of fast charging will thus be poorer for most actors.

Motorway chargers tend to have a lower variation between the max and min power achieved over the year (per month). The reason can be a combination of the batteries being warmer in the winter because the vehicle has been driven at higher speeds for some time, so the charge power will be less reduced than in other locations, or vehicles that embark on long distance trips can have larger batteries enabling faster charging.

The highest demand for and utilization of fast chargers, is found in the counties of Oslo and Akershus, which is not surprising as these counties have the largest BEV fleets. The longest charge queues are also found in these areas, and on some corridor chargers on peak travel days. Charge queue peaks typically occur in the afternoon rush hours, i.e. between 15-17 in the winter and 14-16 in the summer.

Expansion of the fast charger networks decreased the number of vehicles per fast charger up to 2017. The situation was then stable until the beginning of 2018, when the data collection for this report ended. The expansion of fast chargers in Norway is now demand driven in cities with large number of BEVs, and coverage oriented through public support in travel corridors and low demand areas with few BEVs in the local fleet.

The continuing rapid increase in the national BEV fleet leads to a need for continued expansion of the fast charger networks, both in new and existing locations.

Recommendations

A number of recommendations can be made based on the results.

Vehicle producers should build vehicles capable of fast charging close to the full power chargers can deliver over a wide SOC-range. Increasing the charge power will require more advanced battery management systems. An ability to charge at a high power beyond 80% SOC will make the usable SOC window larger, and should be explored. Users can then charge more efficiently and chargers can be spaced wider apart. Measurements of the charge speed at different ambient temperatures should be part of the vehicle homologation regulations.

BEV owners need knowledge on the optimum use of fast chargers. ICEVs can be refilled to 100% at fuel stations, but that is not an efficient way to use a fast charger. It would lead to low charge power, high costs and charge queues. BEV dealers and consumer groups should educate BEV owners about efficient use of fast chargers.

Charging equipment producers should make fast chargers intuitive to use with clear information about the real cost of charging beyond 80% SOC, and recommended efficient use. Chargers could for instance have an automatic stop at 80% SOC, but allow a manual override. Fast chargers need to be robust so that users can trust that it works when arriving at a station, and thus avoid the inefficient charging users do as a precaution in case the next charger does not work.

Increasing the density of fast chargers along major routes will lead to less needs to charge beyond 80% SOC. Support agencies should therefore carefully consider requirements for charger spacing in tenders for fast charger support.

The risk of charge queues on peak travel days can be reduced through information to users about which days and times the risk of queues is the biggest. The use of mobile charging units (the peak demand can be in different locations summer and winter) could also be taken into use to reduce the peak travel queues as well as schemes that allow shorter range BEV owners to rent vehicles to do long distance driving in the most demanding travel periods. Demand oriented pricing schemes on peak travel days could also be taken into use to reduce peak travel days' charge queues.

Governments needs to understand the huge variability in the demand for fast chargers in different regions and travel corridors, to be able to set up appropriate incentive programs for chargers that mainly support long distance travel.

National support programs are still needed for typical corridor chargers in remote areas that mainly are used on peak travel days. These chargers enable travel between cities and regions. Governments should promote a more balanced roll-out of BEVs across a country, so that local weekday use can support chargers that are also used for corridor travel in weekends and vacations. A measure could for instance be to stimulate local fleets to use BEVs.

Standardization of fast charging connectors will be required for BEVs to reach their full potential. Tesla's proprietary network is an example of a solution that, while being effective in supporting BEV development in the early days of market diffusion, may be a hindrance for further expansion. Tesla Superchargers take up spaces and locations that could have been used more efficiently if all vehicles had access. Authorities may need to consider regulations of the charge market to stop further development of such proprietary solutions.

The demand for city fast chargers is not likely to be reduced as they serve users that have forgotten to charge overnight, professional users such as taxi drivers and craftsmen, as well as those that cannot charge at home. Fast chargers will still be needed along highways even after BEVs gets longer range. Longer range BEVs will enable BEV ownership in single vehicle households. The general driving pattern of vehicles could then be adopted by BEV owners. These vehicles will thus likely also be used for weekend and long distance vacation trips leading to a need for more corridor chargers.