TØI report 1682/2019

Erik Figenbaum

Institute of Transport Economics
Norwegian Centre for Transport Research

Charging into the future

Analysis of fast charger usage

TØI-rapport
1682/2019

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ISSN 2535-5104 Electronic
ISBN 978-82-480-2214-5 Electronic

Oslo, January, 2019

Tittel:	Lading for fremtiden – Analyse av bruk av hurtigladere	**Title:**	Charging into the future – Analysis of fast charger usage
Forfatter:	Erik Figenbaum	**Author:**	Erik Figenbaum
Dato:	01.2019	**Date:**	01.2019
TØI-rapport:	1682/2019	**TØI Report:**	1682/2019
Sider:	79	**Pages:**	79
ISSN elektronisk:	2535-5104	**ISSN:**	2535-5104
ISBN elektronisk:	978-82-480-2214-5	**ISBN Electronic:**	978-82-480-2214-5
Finansieringskilde:	Norges Forskningsråd	**Financed by:**	Norges Forskningsråd
Prosjekt:	ELAN – Electromobility Lab Norway	**Project:**	ELAN – Electromobility Lab Norway
Prosjektleder:	Erik Figenbaum	**Project Manager:**	Erik Figenbaum
Kvalitetsansvarlig:	Jardar Andersen	**Quality Manager:**	Jardar Andersen
Fagfelt:	Transportteknologi og Miljø	**Research Area:**	Transport technology and Environment
Emneord:	Elbiler Bruk av hurtigladere Effekt, tid, energi Innvirkning av klima, geografi og teknologi	**Keyword(s):**	Battery electric vehicles Fast charger usage Power, time, energy Climate, geography and technology influence

Sammendrag:

Hurtiglading gjør at elbiler kan kjøres flere km. Elbiler fikk i gjennomsnitt i 2017 ca. 4-6% av energien de bruker fra hurtigladere. Rekkevidden ble forlenget tilsvarende. Gjennomsnittlig ladeeffekt var i 2017 30,5 kW, ladetiden var 20,3 min. og det ble hurtigladet i gjennomsnitt 9,6 kWh energi. Ladetid og energi ladet følger en normaldistribusjon rundt disse verdiene. Ladeeffekten har en avvikende fordeling da mange opplever en lav ladeeffekt pga. klimaforhold og batteri- og biltekniske begrensninger. 98% av de som hurtiglader på en dag gjør det en gang, rundt 2% gjør det flere ganger. Sistnevnte er sannsynligvis på langtur med bilen. Den lave ladeeffekten kan lede til ladekøer og et behov for flere ladere.

Summary:

Fast charging enables Battery electric vehicles (BEVS) to travel more km. BEVs get about 4-6 percent of their energy from fast chargers, which thus extend km travelled equally much. The average fast charge power was 30.5 kW in 2017, although chargers can deliver 50 kW. The average time was 20.3 minutes. The average energy was 9.6 kWh. Time spent charging and charged energy follows a normal distribution around these values. The charge power deviates. A large share of users achieve low charge power during the winter because cold batteries are less capable of being charged fast. The variation is mainly due to climatic and vehicle technology issues. Most BEV users only fast charge once per day, about 2% on any given day charge more than once. The latter are likely users on long distance trips. The low charge power can lead to charge queues and a need for more chargers.

Language of report: English

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Preface

This report has been written as part of the Electromobility Lab Norway (ELAN) research project. ELAN is led by the Institute of Transport Economics and financed by the Research Council of Norway. Erik Figenbaum is the project manager of ELAN.

The main purpose of the ELAN project is enhanced and accurate knowledge on the market uptake of electric vehicles, and on the innovations and strategies required to increase the market uptake, to support Norway's ambitious national goals for the low emission society. Using state of the art research methods, the project takes advantage of the booming battery electric vehicle market in Norway.

The objective of this report has been to investigate how fast charging for Battery Electric Vehicles works in practice, for users under Norwegian traffic and climate conditions.

The report has been written by Chief Research Engineer Erik Figenbaum. The Quality assurance has been carried out by Research Director Jardar Andersen. Trude Rømming has been responsible for the final finishing of the report.

Oslo, January 2019
Institute of Transport Economics

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Analyse av bruk av hurtigladere

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Analyse av faktisk bruk av hurtigladere i to operatørers nettverk fra Januar 2016 til Februar 2018 viser at det er stor variasjon i oppnådd ladeeffekt mellom brukere, årstider, biltyper og steder. En del elbilmodellers begrensede hurtigladekapasitet, klimatiske forskjeller og variasjon i hvordan brukerne lader kan forklare hvorfor gjennomsnittseffekten blir så lav som 30,5 kW når laderne skal kunne levere 50 kW. Gjennomsnittlig ladetid var 20,3 minutter og det ble gjennomsnittlig ladet 9,6 kWh energi per ladesesjon. Utfordringen i bilene er knyttet til enkle batteritempereringssystemer som gjør at batteriene blir kalde og ikke kan ta full ladeeffekt om vinteren. Andre faktorer som påvirker i særlig grad er avstand mellom hurtigladere og risiko for ladekø på neste ladested. Disse faktorene kan få en del brukere til å lade forbi 80% ladetilstand med sterkt fallende ladeeffekt. De best utnyttede laderne befinner seg i byene der også risikoen for kø er størst. Det kan også være kø på lite brukte ladere langs hovedveiene på store utfartsdager.

Introduksjon

Elbiler må lades opp med strøm fra nettet for å kunne anvendes. Til forskjell fra en bensin- eller dieselbil, så foregår det meste av oppladingen av batteriet hjemme over natten ved å koble bilen til en spesifikk elbilkontakt, en elbil-veggladeboks eller en husholdningskontakt.

Hjemmelading, lading på arbeidsplasser og lokale og regionale offentlige ladere dekker de fleste daglige behovene. Elbileierne må ha et sted å lade når de drar på lengre turer, enten på destinasjonen eller underveis, når rekkevidden er for kort for turens lengde. Normallading (3,6 opp til 22 kW) dekker behovet på destinasjonen. Hurtigladere kan dekke følgende brukerbehov:

1. Muliggjøre lange turer
2. Muliggjøre turer til destinasjoner der lading ikke er tilgjengelig
3. Gjøre elbilbruk mer fleksibelt gjennom å muliggjøre reiseendringer i løpet av dagen
4. Gjøre brukerne tryggere slik at de kan utnytte mer av elbilens rekkevidde
5. Gi energi til brukere som har gått tom for strøm eller som glemte å lade om natten
6. I kombinasjon med gateladere, muliggjøre elbilhold i byområder der bileiere ikke har tilgang på hjemmelading

Elbilens evne til å akseptere hurtiglading og tilgang på hurtigladere i området der eierne ferdes er viktige faktorer som virker inn på hvordan elbilen vurderes opp mot andre biltyper. Lite kunnskap finnes om faktisk bruk av hurtigladere i Norge. Formålet med denne rapporten er først og fremst å forstå hvordan, hvor mye og hvor hurtigladere faktisk brukes i Norge, for å forstå hvor viktig hurtiglading er for utbredelsen av elbiler. Formålet er ikke å utvikle eller diskutere teorier om hurtiglading eller å lage en modell av markedet.

Elbilflåten

Hurtigladere (DC) kunne benyttes av 90% av elbilene i bilflåten per januar 2018. Av disse hadde 35% CCS ladestandard, 39% Chademo standard og 16% hadde Teslas proprietære system. Av CCS/Chademo bilene var 88% begrenset til 50 kW ladeeffekt, og 64% hadde passive batteri kjøle- og varmesystemer. Elbiler med passive kjøle og varmesystemer for batteriene vil ha lave temperaturer i batteriet om vinteren og risiko for høye temperaturer på varme sommerdager. Begge deler innebærer at ladeeffekten blir lavere enn den ellers kunne vært. Gjennomsnittsbatteriet i bilflåten, når en ser bort fra Tesla biler var 26 kWh nominelt, og ca. 15.5 kWh kan være praktisk tilgjengelig for effektiv hurtiglading. Det er da tatt hensyn til at lading normalt starter før batteriet er helt tomt og at det ikke er effektivt å lade etter at 80% ladetilstand er nådd.

Hurtigladingssituasjonen i Norge.

De første hurtigladerne I Norge ble bygget ut etter 2011 med offentlig støtte fra Transnova. Fra 2015 har Enova gitt støtte til et minimums hurtigladenettverk langs hovedveiene i Norge fram til 2017, med minimum to 50 kW hurtigladere hver 50 km langs hovedveiene. Enova har i 2018 hatt ett program for støtte til hurtigladere i kommuner som ikke har hurtigladere enda. Hurtigladere i byene bygges i hovedsak ut på rent kommersielle vilkår av private aktører, men enkelte kommuner/fylker gir lokal støtte til byhurtigladere.

Resultatet av disse aktivitetene og støtteprogrammene er at ladenettverket har ekspandert kraftig fram til 2017 og holdt følge med utviklingen i bilflåten fram til starten av 2018. I 2018 var det ca. 500 ladelokasjoner med ca. 1000 hurtigladere installert i Norge. Med noen få unntak var alle disse laderne dobbeltstandard CCS/Chademo ladere. Noen få ladere kan i tillegg levere 43 kW AC. I tillegg kommer omtrent 50 Tesla Supercharger lokasjoner.

Metode og datasett

Tre datasett ble anvendt i analysene i denne rapporten. Datasett 1 og datasett 2 inneholdt majoriteten av ladetransaksjoner i 2 nasjonal hurtigladenettverk fra januar 2016 til februar 2018. Datasettene er ikke direkte sammenlignbare. Datasett 1 inneholdt individuelle transaksjoner. Datasett 2 inneholdt bruksminutter per ladeplugg per hurtiglader. Total ladeaktivitet gjennom året kan ikke presenteres pga. konfidensialitet. Dataene er derfor analysert med hensyn på relative utvikling og trender eller resultater som ikke omhandler total ladeaktivitet. Datasettene inneholder ikke lading i Teslas superladere, men noen Tesla eiere kan lade fra Chademo ladere ved å anvende en adapter.

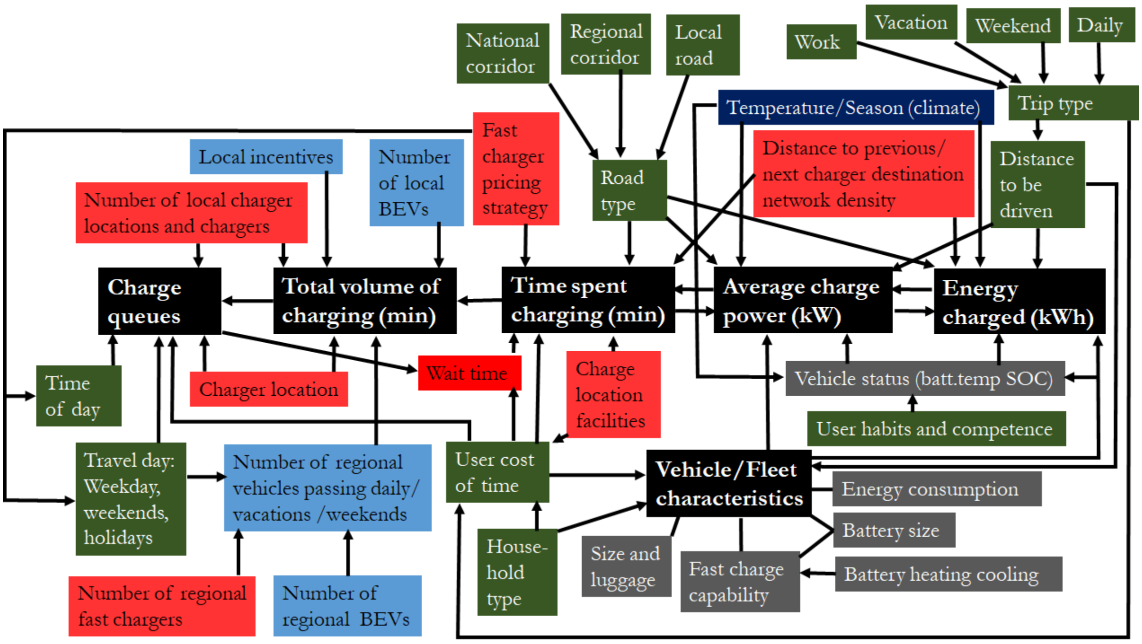
Datasett 3 inneholdt resultater fra en spørreundersøkelse gjennomført i juni 2018 blant 3659 elbileiere og 2048 bensin og dieselbileiere, vedrørende lange reiser (begge) og hurtiglading.

Resultater

Hurtiglading er et komplekst system der syv parameter innvirker på hvordan brukerne opplever hurtiglading, og på behovet for utbygging av ladere. Disse parameterne er.

1. Brukernes behov for hurtiglading og brukernes bilkjøringsvaner
2. Elbilenes tekniske karakteristika, det vil si batteristørrelse og hurtigladingskapasitet
3. Energi ladet (kWh) av hver bil
4. Gjennomsnittlig oppnådd ladeeffekt (kW) for hver bil
5. Ladetid (min) for hver bil
6. Totalt volum av lading (min), det vil si totalsummen av alle bilers lading
7. Ladekøer som bygges opp av totalt ladevolum og tid og sted ladingen pågår

Tilleggsfaktorer som innvirker på disse syv faktorene og interaksjonen mellom ulike faktorer er presentert i figur S1 som er utviklet basert på resultatene fra analysene.



Figur S1. Hurtigladelandskapet basert på analysene i denne rapporten. Mørk grønn er brukernes behov og bilbruksvaner som kan påvirke lading/valg av bil. Svart er faktorer som bestemmer brukernes interaksjon med og inntrykk av hurtigladingsinfrastrukturen. Blå er faktorer som påvirkes av den totale flåten av elbiler og av politiske beslutninger. Rødt er faktorer som ladeoperatørene påvirker. Grått er faktorer som ikke kan påvirkes etter at bilene har kommet inn i bilflåten. Kilde: Forfatteren.

Brukerbehovene er kjernen i å utvikle og tilby ett attraktivt nettverk av hurtigladere. Ut fra analyse av de anonymiserte brukerne i datasett 1, komplementert av svarene i spørreundersøkelsen ser det ut til at det er fire hovedtyper av brukere av hurtigladere; (1) tilfeldige brukere, (2) lokale og regionale brukere, (3) langdistanse reisende og (4) super brukere. Gruppe 1 lader 1-2 ganger per år og utgjør ca. 30% av brukerne. Gruppe 4 utgjør omtrent 10% av brukerne og lader i gjennomsnitt mer enn 32 ganger i løpet av ett år fra mange ulike lokasjoner i ulike fylker. I og med at det ikke er kjent hvor brukerne bor er det ikke mulig å fordele de resterende brukerne mellom gruppe 2 og 3. En ser fra spørreundersøkelsen at det er uvanlig å bare lade lokalt, de fleste som hurtiglader sier at de gjør det både på regionale og på lange reiser. I følge spørreundersøkelsen lader 8% ukentlig, 22% månedlig, 41% sjeldnere og 29% aldri. De fleste sier at hurtigladetilbudet er bra, men de er ikke like fornøyd som det eiere av Tesla elbiler er med Teslas superladernettverk.

Etterspørselen etter hurtiglading er stabil i alle fylker fra mandager til torsdager, og med økt etterspørsel i helgene med unntak av Oslo og Akershus som har nokså jevn etterspørsel alle dager. Ladere i mer rurale områder langs hoved- og motorveier kan ha store etterspørselstopper på store utfartsdager. Dette skyldes ubalanse mellom størrelsen på den lokale elbilflåten og gjennomfartstrafikken med elbiler på slike dager. En mindre andel, det vil si 18%, av brukerne som hurtiglader i løpet av en dag lader mer enn en gang. Det indikerer at de er på en lang reise.

De fleste av dagens brukere sier i spørreundersøkelsen at de er villig til å akseptere noe ladekø på dager der mange reiser samtidig, men få aksepterer mer enn 20 minutter. Opp mot 40% av brukerne sier at ladekø kan være stressende. Dette indikerer langt i fra at ladekøer er populært men heller at brukerne er realistiske og forstår at noe kø blir det på slike dager. Ladekøer oppleves oftest på lange reiser men også lokalt eller regionalt. For å unngå kø sier 50% at de vil vurdere å reise tidligere eller senere samme dag, mens få vil bytte reisedag. Et fåtall sier at ladestoppen er kjedelig. De bruker tiden til å lese e-post, bruke sosiale media, rusler en tur eller bruker fasiliteter ved ladelokasjonen, f.eks. toaletter, butikker, kiosk eller matservering. Flertallet er villige til å ta 1-3 ladestopp på lengre reiser. Sommerferien er perioden der størst andel av bileiere, både elbil-, bensin- og dieselbileiere, drar på turer over 300 km. Andelen bensin- og dieselbileiere som gjennomfører slike lange sommerreiser er 1,7 ganger høyere enn blant elbileiere.

Den gjennomsnittlige ladesesjonen i Norge i 2017 tok i overkant av 20 minutter, men det er en stor spredning mellom ulike brukere, lokasjoner og sesonger. Brukere tenderer til å lade lenger ved kjøpesentra. Gjennomsnittsbrukeren ladet 9,6 kWh energi i batteriet, hvilket er 40% mindre enn det teoretisk praktiske potensialet for hurtiglading av gjennomsnittsbilen i bilflåten. Årsaken kan være at de ikke trenger mer energi eller at de starter hurtigladingen fra ett betydelig høyere gjenværende ladenivå enn 10%. Mengden ladet energi varierte lite mellom sesongene men det kan kjøres ca. 40% færre km om vinteren pga. det høyere energiforbruket om vinteren.

Gjennomsnittlig ladeeffekt over året var 40% mindre enn ladernes teoretiske kapasitet til å lade med 50 kW. Det meste av denne forskjellen skyldes klimatiske forhold og hvordan batteriet er varmet og kjølt, samt ineffektiv bruk av hurtigladere, f.eks. lading forbi 80% ladetilstand. Det kan være brukerne har gode grunner for dette, hvis f.eks. tilbakelegging av avstanden til neste lader eller destinasjonen krever en høyere ladetilstand enn 80%. Laderne er ikke problemet de kan reelt levere opp mot 50 kW effekt.

Den lave gjennomsnittlig oppnådde ladeeffekten fører til en underutnyttelse av tilgjengelig installert effekt fra nettet. Det er da behov for flere hurtigladere på hver lokasjon for å kunne overføre en gitt mengde energi per time til biler som lader der. Kostnader overføres da fra bilprodusenten til ladenettverkoperatøren som må investere i flere hurtigladere per lokasjon og betale mer for nettilknytningen. Disse kostnadene er det brukerne som må dekke gjennom økte kostnader per kWh som lades. Når ladeeffekten blir så lav som 30 kW vil brukerne få energikostnader på nivå med dieselbiler med dagens minuttpriser for bruk av hurtigladere. De påføres også økte tidskostnader når ladingen tar lenger tid. Flere og lengre ladekøer kan også oppstå noe som reduserer brukeropplevelsen ytterligere. Mer offentlig støtte kan også bli nødvendig. Alle taper på dette, også bilprodusentene fordi brukeropplevelsen blir dårligere. Den eneste potensielle vinneren er nettselskapet som får betalt for nettilkoblingen uansett.

For hurtigladere som står langs hovedveiene er det noe mindre variasjon i minimum og maksimum gjennomsnittlig ladeffekt per måned. Årsaken er trolig en kombinasjon av to faktorer. Batteriene i bilene som ankommer disse laderne vil være litt varmere om vinteren enn de er f.eks. på byladere, fordi bilene har vært kjørt over lengre tid i høye hastigheter.

Dernest er det mulig at elbiler som brukes på slike turer oftere har store batterier som kan lades raskere.

Den største etterspørselen etter hurtiglading og den høyeste utnyttelsen av hurtigladerne er i Oslo og Akershus, noe som ikke er overraskende i og med at disse fylkene har høy andel elbiler og det største totale antallet elbiler i Norge. De lengste ladekøene finnes i disse områdene og på enkelte ladere i transportkorridorer på store utfartsdager. Ladekøer oppstår i likhet med tidspunktene for størst total etterspørsel mellom kl. 15-17 om vinteren og 14-16 om sommeren.

Antall biler per hurtiglader ble, takket være en storstilt utbygging av ladere, redusert fram til 2017. Fra 2017 og til datainnsamlingen for denne rapporten ble avsluttet i starten av 2018 så var antall elbiler per hurtiglader omtrent konstant. Videre utbygging i og rundt storbyene der det er mange elbiler er etterspørselsdrevet og bygges ut kommersielt. Det er fortsatt noen støtteprogrammer, blant annet for utbygging (Enova støtte) av ladere i kommuner som ikke allerede har hurtigladere. Den raske ekspansjonen av elbilflåten medfører et behov for videre utbygging av nye lokasjoner og ekspansjon på eksisterende lokasjoner.

Anbefalinger

Bilprodusentene bør lage biler som kan utnytte den fulle ladeeffekten som laderne kan levere over en stor del av batterienes ladetilstand, det vil si fra 0 til 80% ladetilstand. Bilprodusentene bør også se på muligheter for å fortsette med høy ladeeffekt så langt som mulig videre oppover mot 100%. Dette vil både gi brukerne en bedre brukeropplevelse fordi de får flere km ladet per minutt og kan utnytte batteriet bedre. Økonomien i ladestasjoner bedres også fordi tilkoblet ladeeffekt og investeringen utnyttes bedre.

Krav om måling av reell ladeeffekt ved ulike omgivelsestemperaturer bør tas inn i typegodkjenningskravene til nye biler.

Elbileierne trenger mer kunnskap om optimal bruk av hurtigladere. Bensin- og dieselbiler kan fylles 100% på fyllestasjoner men det er ikke effektivt å lade en elbil til 100% fra en hurtiglader. Resultatet ville blitt lav ladeeffekt, kostnader på høyde med å kjøre med dieselbil og lengre ladekøer. Det er derfor en oppgave for bilforhandlere og forbrukerorganisasjoner å lære opp forbrukerne i effektiv bruk av hurtiglading.

Produsenter av hurtigladere bør fokusere på å lage ladere som er intuitive å bruke effektivt, med klar informasjon om at ladekostnadene øker når man fortsetter å lade forbi 80% ladetilstand på batteriet. En kunne for eksempel ha en automatisk stopp på 80% med mulighet for å overstyre den ved behov. Hurtigladere må være robuste slik at brukerne kan stole på at de fungerer på den neste ladestoppen de må ta. Da blir det mindre behov for å lade ineffektivt forbi 80% ladetilstand.

Dersom tettheten av ladestasjoner langs hovedveiene økes vil det også lede til mindre behov for å måtte lade lenger enn til 80% ladetilstand. Organisasjoner som gir støtte til ladestasjoner langs hovedveier bør derfor nøye vurdere hva kravet til maksimums avstand mellom laderne bør være når anbud settes ut.

Risiko for oppbygging av ladekøer på store utfartsdager kan reduseres gjennom informasjon til brukerne om hvilke dager og tidspunkter risikoen for ladekøer er størst. Bruk av mobile ladeløsninger kan være et bidrag til reduserte køer. Det samme kan tilbud om leiebil til elbileiere som har biler med kort rekkevidde og som ønsker å kjøre på lengre turer på store utfartsdager. Det kan også være mulig å regulere ladekøene gjennom prismekanismer men det fordrer at brukerne vet hvilke dager eller tidspunkter prisene er forhøyet. En utfordring er at elbilutviklingen er ujevnt fordelt mellom storbyområder og mer rurale områder, slik at hurtigladere i rurale områder langs hovedveiene som byboere bruker for å dra på langtur utnyttes for dårlig på hverdagene. En mer balansert utvikling i den nasjonale bilflåten ville hjelpe, det samme kan en stimulering av bruk av elbiler i lokale bilflåter i slike områder.

Standardisering av hurtigladingsplugger og ladesystemer vil bli nødvendig dersom elbiler skal kunne nå sitt fulle potensial. Det er ikke egne fyllestasjoner for bensin og diesel for biler fra bestemte bilmerker, men det er det for hurtiglading. Teslas superladere tar opp plass langs hovedveiene men kan bare brukes av Tesla biler. Dette er neppe bærekraftig på sikt. Disse arealene og lokasjonene kan utnyttes langt bedre hvis alle biler kan bruke laderne som står der. Det kan dermed bli ett behov for å regulere lademarkedet for å hindre slike monopoldannelser i fremtiden.

Etterspørselen etter hurtiglading i byene vil opprettholdes selv med lengre rekkevidde fordi elbileiere fortsatt vil glemme å lade over natten, profesjonelle bruker som taxier vil trenge hurtiglading, og det vil også de som ikke kan lade hjemme og tilreisende. Hurtigladere vil også trenges langs hovedveiene. Når rekkevidden øker vil elbiler tas i bruk av brukere med mer krevende bruksmønstre, og i langt større grad for helgeutfarter og ferier. Da øker behovet for korridorladere. Det vil også være mange destinasjoner der det ikke er lademuligheter, og da trenger elbileiere korridorladere.

Institute of Transport Economics
Norwegian Centre for Transport Research

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.

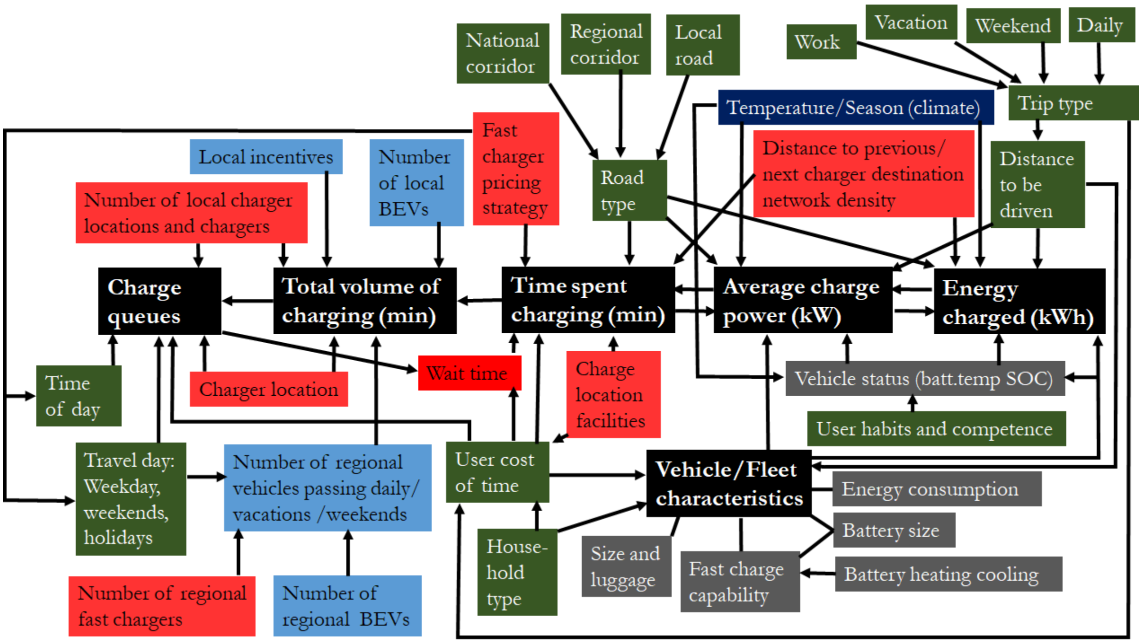


Figure S1. The fast charge landscape proposed as a result of the analysis in this report. Dark green are the user needs and habits that influence charging/vehicle choice. Black are the factors that determine the user interaction with, and perception of, fast charging infrastructure. Blue are factors 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.

1 Introduction

Battery electric vehicles (BEVs) need to be recharged with electricity from the grid to be able to operate. Differing from a gasoline or diesel car, most of that charging occurs at home, using either a traditional household socket or a BEV specific charge station or socket. In Norway, 94% of the BEV owners in 2016 charged their vehicles more or less daily at home in their own parking space (Figenbaum and Kolbenstvedt 2016). In 2018, the number was slightly lower, 92.6% (Nordbakke and Figenbaum 2019). Public slow chargers are much less used, but workplace charging is an important supplement to home charging. Home charging, work place charging and other public chargers support everyday traffic.

Owners of BEVs will have to charge somewhere during a long distance trip, either roadside or at the destination. The driving range of the vehicle is often insufficient for a round trip. Slow chargers can serve the needs for charging at destinations and fast chargers support the long distance travels. Fast chargers also complement home charging, work place and slow public chargers, and thus 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 chargers enable BEV ownership in dense parts of cities

The BEV owners are limited in their driving behavior by the technical characteristics of their vehicles, i.e. the limited range, and the longer time needed to recharge compared to filling energy on an Internal Combustion Engine Vehicle (ICEV) . The vehicles have different ability to accept fast charge. The availability of fast chargers on the route or in the area they travel is also an important factor in the user perception of BEVs versatility compared with ICEVs.

Little is however known about the actual use of fast chargers in Norway. The aim of this report is first and foremost to understand what fast charging is, by providing an overview of how, how much and where fast chargers are used in Norway. The results will indicate how important fast charging is for the diffusion of BEVs. The purpose is not to develop theories on fast charging or to model the market.

The report starts with an introduction of the technology for fast charging in chapter 2, followed by an overview of the existing fast chargers and fast charge stations in chapter 3. Chapter 4 presents the datasets used in the analysis. Chapter 5 contains the results of the analysis of fast charger usage data. Chapter 6 contains result from a user survey of BEV-owners fast charging needs, opinions about and use of fast charging. These results are discussed in chapter 7 with the conclusions in chapter 8.

2 Technology for fast charging

The fast charger system consists of the fast charger which delivers DC high power electricity through a charger mounted cable, to a vehicle that is fast charge enabled. On the vehicle the wiring directs the electricity to the batteries. The process is controlled by a communication process between the vehicle system and the charger, in which the vehicle is in charge. The battery management system controls the fast charge power so as to not damage or reduce the expected lifetime of the batteries.

Fast chargers are designed to deliver any power between zero and up to their rated maximum power. Up to 2018 fast chargers in Norway have been rated up to 50 kW power, except Tesla proprietary Superchargers rated up to 120 kW (split in two if the charging station is fully utilized). A handful of non-Tesla test chargers rated up to 120 kW have also been installed, but very few vehicles have been able to use more than 50 kW.

2.1 Vehicles

The vehicle limits the power level of the charger to make sure that the battery is not damaged, and to elongate the life of the battery. The allowed power varies with the actual battery temperature and the battery state of charge (SOC). Fast charging is slower in low ambient temperatures as the battery's chemical properties limits the speed of movement of ions through the battery materials (Jaguemont et al. 2016, Trentadue et al. 2018). The battery charge power is also limited to preserve battery life when the batteries are overheated (Keyser et al. 2017, Neubauer and Wood 2015) for instance due to high speed driving in warm weather. Charging might also be slower when the SOC is very low in cold climates, due to an increase in the battery internal resistance under such conditions (Neubauer and Wood 2014). Several subsequent fast charges combined with high speed driving, may in the summer season lead to reduced charge power in some BEV models, because the battery will gradually heat up in vehicles with passive battery climate control systems (Neubauer and Wood 2015, TU Elektrisk 2018). The opposite effect can be possible at low ambient temperatures. A gradual heating of the battery can lead to an increase in the power the battery can accept (Motoaki et al. 2018) during the charge session.

The ability to accept fast charging while limiting battery life impact depends on the type of cooling system used for the batteries (Keyser et al. 2017). Some vehicle manufacturers do not install active cooling systems for the batteries to reduce the cost of the total system. These vehicles will have a lower fast charge power capability than vehicles with a more advanced active battery liquid or air-based cooling and heating system. The average user experienced fast charge power can for these reasons be considerably less than the maximum rated power of the charger. On top of that comes the user input. If users charge beyond the 80% SOC limit, the charge power will be reduced rapidly as the SOC increases towards 100% (Fastned 2018), which also is a strategy used to be able to preserve battery life and keep the charging process safe.

The gross battery capacity of the battery in BEVs is in most cases presented in the vehicle specifications, but about 5-15% of that gross will not be made available to users (author's estimate based on test drives published on www.elbil.no and literature). The allowed range of Battery State of Charge for the customer, which is what is displayed in the instrument panel in the vehicle, is thus 5-15% less than the real Battery State of Charge. This value is often called the Customer State of Charge (CSOC). This derating of the battery capacity elongate battery life by eliminating harmful overcharge and undercharge events.

Fast charging at high power is possible up to 60-85% Customer State of Charge (CSOC) of the batteries, depending on vehicle model. Above that CSOC level, charging slows down towards the normal charging level of 3.6-7 kW. Users are unlikely to drive until zero capacity is left in the battery (Figenbaum and Kolbenstvedt 2016), especially in the winter season. If one assumes that 10% SOC is left when starting to charge, then adding in the reduction from gross to net battery capacity, and the 80-85% CSOC limit, one ends up with a practical limit for fast charging of roughly 60% of the gross battery capacity.

Figure 1 provides an overview of the BEV fleet in Norway as of 1.1.2018, and the type of charging system these vehicles have. Chademo and Combined Charing System (CCS) charge standards covers about 40% each of the total number of BEVs in the fleet, Tesla 15%, and AC fast charging about 5%. The latter is being phased out. Only about 2% of the BEV fleet (status as of 01.01.2018) cannot be fast charged. Chademo and CCS chargers normally operate at up to 50 kW charging power.

There were only 4 existing vehicle models that could accept faster charging than 50 kW for the period the data from fast chargers were collected. The Hyundai Ionic can accept up to 70 kW, the Kia Soul EV up to 100 kW. Tesla Model S and X uses the Tesla proprietary Supercharger infrastructure. In the Supercharger stations the charge power can be up to 120 kW, but two vehicles might share one charger when the station is full. Tesla vehicles can charge at regular 50 kW DC Chademo fast chargers, if an adapter is used. Only Tesla vehicles are allowed to charge at the Superchargers. Renault Zoe has a deviating charge system using 22 kW or 43 kW AC power depending on year-model. Of all BEVs in the fleet, at least 90% can be DC fast charged, of which 74% on fast chargers that are included in the data presented in this report. The use of Tesla Superchargers is not included in the material. 50 kW is the maximum charge power for 88% of non-Tesla vehicles and 64% use a passive thermal management system for the battery.

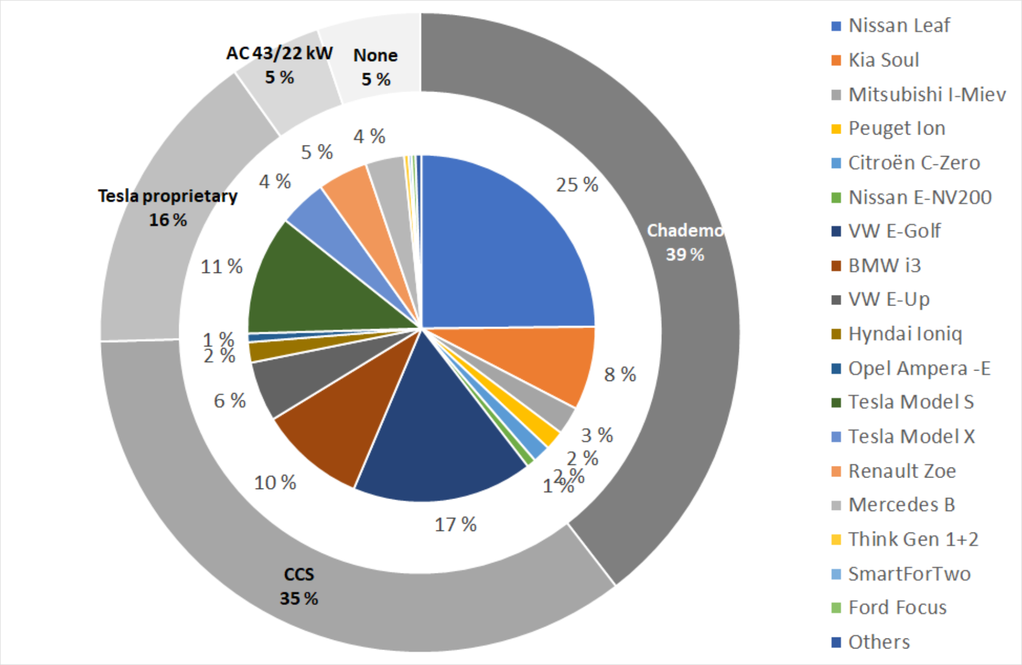


Figure 1. Vehicles and charging technology in vehicle fleet. Fleet status as of 01.01.2018. Fleet data from NPRA 2018.

Of the vehicles that would normally use fast chargers in Norway, i.e. vehicles equipped with CCS or Chademo fast charge sockets, the average gross battery size was 26 kWh as of 01.01 2018. A practical maximum of 60% of the gross battery capacity, i.e. 15.5 kWh on average, is possible to fast charge, if the charge starts when the SOC is 10%. The distribution of the CCS/Chademo equipped vehicle fleet for these two parameters is shown in Figure 2. If the users start the fast charge at a higher SOC than 10%, then the practical rechargeable energy will be less than 15.5 kWh. For instance, starting at an SOC of 30%, reduces the rechargeable energy to 12.4 kWh.

A wide distribution of charged kWh is likely across the fleet, because the fast chargers are spaced geographical unevenly, the vehicles have different battery sizes, the users may not charge up to the full 80% SOC or wait until the SOC is very low, and fast charging will be slower when the batteries are too cold or too warm. The average battery size in the fleet increases over time.

Tesla Model S and X can use the Chademo chargers with an adapter. As Tesla owners have access to the free Supercharger network, the use of other fast chargers should be rare occasions when the user drives routes that are not covered by Tesla chargers. Tesla vehicles should be distinguishable in the dataset of fast charging usage, as most have batteries ranging from 75-100 kWh, i.e. larger than any other vehicles that were on the road up to the first quarter of 2018. They are also capable of charging at close to the charger's maximum power when using 50 kW chargers.

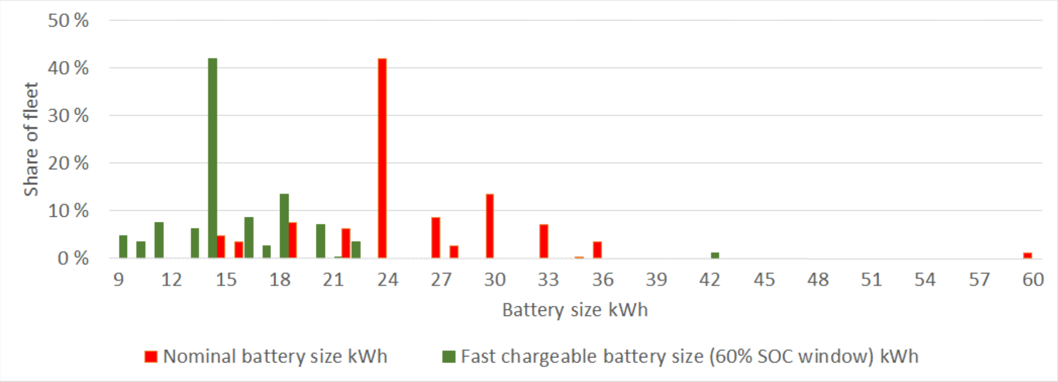
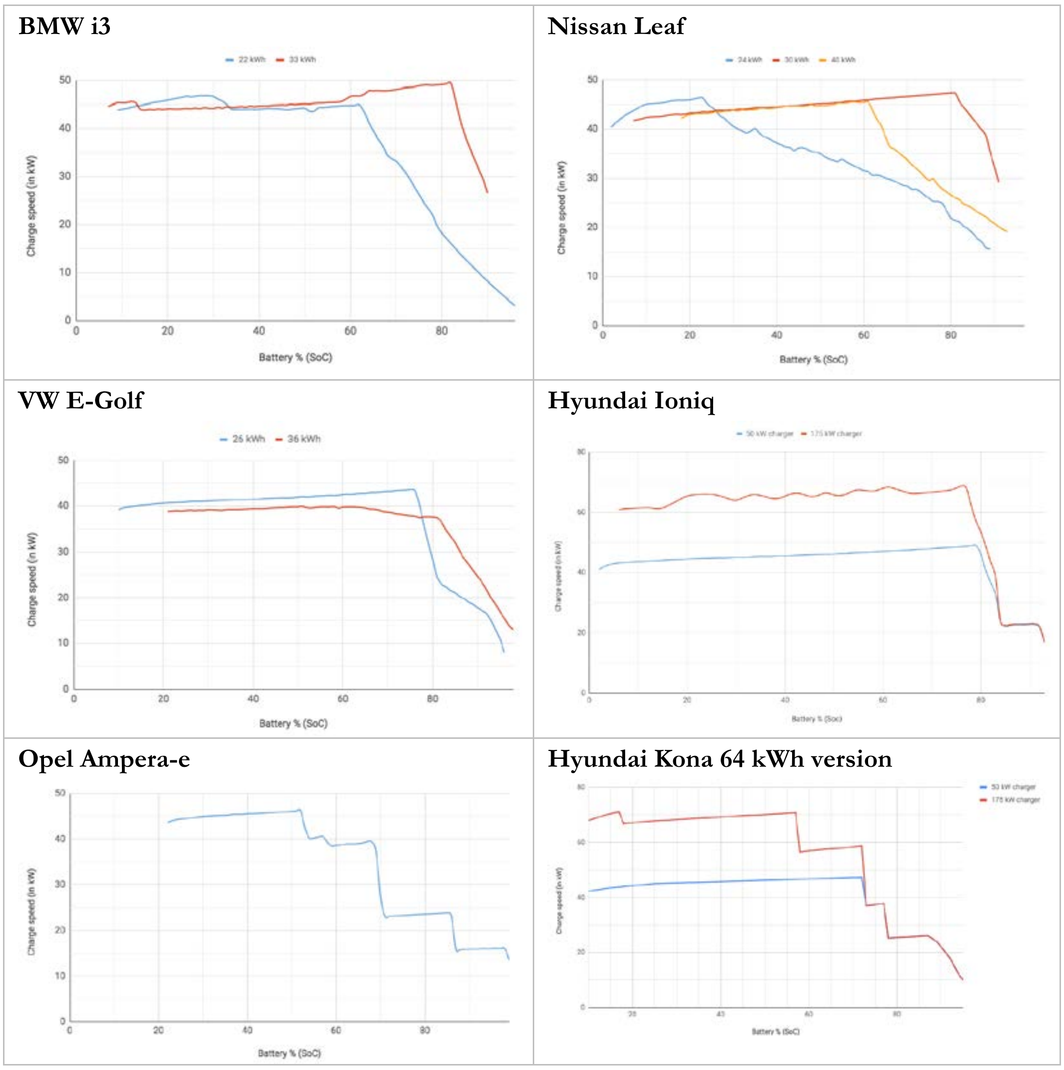


Figure 2. Nominal battery size (net for Opel Ampera-e) in kWh and estimated kWh that can be fast charged, by share of vehicles in the fleet as of 01.01.2018. Tesla vehicles not included.

Fastened in the Netherlands has presented fast charging power curves of some popular BEVs, as seen in Figure 3.


BMW i3

Nissan Leaf

VW E-Golf

Hyundai Ioniq

Opel Ampera-e

Hyundai Kona 64 kWh version

Figure 3. Charge profile of different BEVs. Data from Fastned (2018).

These curves are for summer temperatures, and shows at which SOC the vehicles start limiting the charge power, and how much and how fast the power is limited. In cold climates, less charge power will be available than shown in these figures, as the battery cannot handle the full fast charge power. Additionally, there will be a short ramp up time for the charger to reach full power, which is also not shown.

If the user charges until detecting visually that the charge goes slower on the kWh counter on the charger, the average charge power over the session will be further reduced. Users could plug in to charge and go to eat at a café or do other things that could take longer than planned. The result could be that the charge continues past 80% SOC with rapidly declining charge power as the result. Then the average charge power will also be substantially reduced. If the charge session for instance starts at 60% SOC and ends at 90% SOC in the summer, the chart from Fastned indicate that the average charge power would be below 25 kW for a 1st generation Nissan Leaf. The user would pay a high cost for these situations as they pay per minute of charge time. The chargers feature a max 80% SOC button which could be used to prevent this situation. A low average fast charge power could also be the result if the users use fast chargers to top up the charge level of the battery, i.e. starting at a high SOC and continuing beyond 80% SOC.

For a Leaf of the first generation with a 24 kWh battery starting to charge at 20% SOC, the average summer fast charge power could according to the Fastned charge curve be about 35 kW. It will be considerably less in the winter, as found by Motoaki et al. (2018), seen in Figure 4. They found a 22-36% decrease in the fast charge power at 0°C vs 25°C for Taxis in New York City, and the effect will be even larger at temperatures below 0°C.

Y. Motoaki et al. *Energy Policy 122 (2018) 162–168*

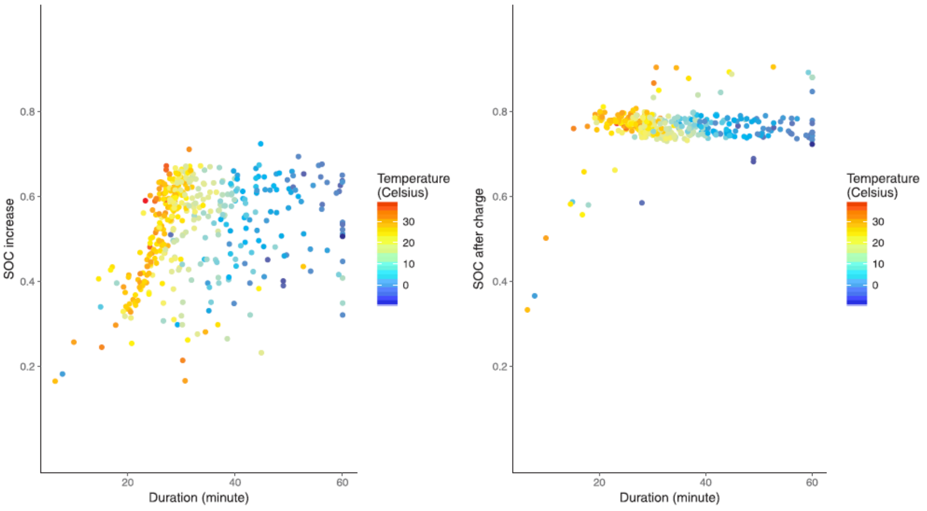


Fig. 2. Relationships of SOC, charge duration, and temperature.

Figure 4. Fast charge duration vs SOC increase at different ambient temperatures (left) and charge duration vs end SOC (right). Motoaki et al. (2018).

Trentadu et al. (2018) found that the fast charge power for a specific BEV model was reduced to 4.1-4.8 kW at -25°C and 4.3-17.6 kW at -15°C, for different fast chargers tested in a laboratory environment when starting from 25% vehicle SOC. Above 25°C the charge power was stable at the maximum achieved value of 38 and 47 kW depending on the charger they tested. The low power is only for the initial charge period. As the charge progresses the internal resistance of the battery will lead to an internal heating (Neubauer and Wood 2014), that will gradually enable the power to increase. The internal resistance is elevated at low SOC and at low temperatures, and will be maximum below about 30% SOC at -15°C (Neubauer and Wood 2014).

The fast charge power will for some vehicles with passive battery climate control systems be reduced if the driver is on a long distance trip in the summer season and has done preceding fast charges on that trip. The battery temperature will then gradually build up (Neubauer and Wood 2015) and lead to reduced power in the subsequent fast charge events (Tu Elektrisk 2018). Such problems are less likely to occur with vehicles that have an active (air or liquid) battery climate control system.

Some BEVs cut the available power for climate controls at low ambient temperatures. This strategy can make it difficult to utilize the lowest end of the vehicle's range in the winter, especially when the weather conditions are such that heat is needed to ensure visibility through the windscreen.

Figure 5 presents an overview of the fast charge capability vs SOC of a generic BEV.

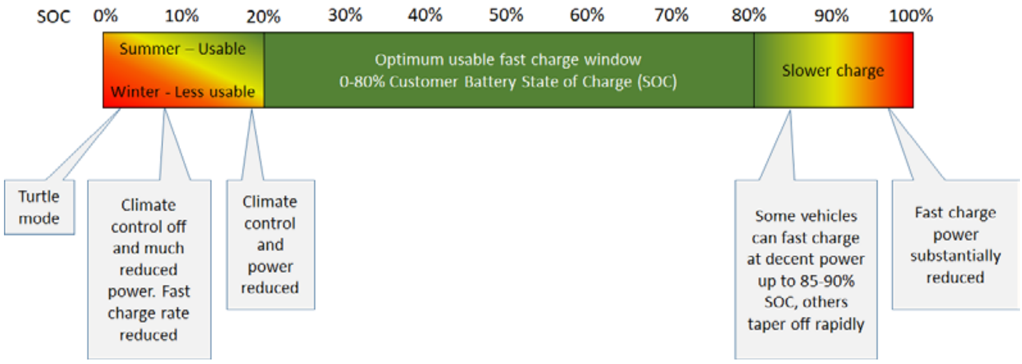


Figure 5. SOC and fast charge capability, as well as strategy for propulsion power and climate controls at low SOC of a generic BEV. Implication for user utilization of Battery SOC. Source: Author.

The fast charge capability will be reduced at very low SOCs in cold climate and at high SOCs, i.e. above 80-90% SOC. At the very low end the vehicle will first limit the power for propulsion and the output of the heater/Air conditioner when the SOC falls below a certain level. In the VW E-Golf this happens at about 20% SOC. Below 10% SOC the heating/AC system in the E-Golf is shut off and the power is further reduced.

At very high SOCs the fast charge capability will be so low that users could be better off economically using the 22 kW Type 2 slow chargers installed in parallel to fast chargers in most locations. The charge power will then be 3-3.6 kW, or 7.2 kW, or 10-11 kW, potentially up to 22 kW depending on model. Most vehicles can charge at 3.6 kW or optionally 7.2 kW, few models have more powerful on-board chargers (Figenbaum 2018). The exceptions are Tesla models that can charge at up to 16 kW. Most models have 7.2 kW chargers as options, the BMW I3 and the Mercedes B class has an 11 kW charger and the Renault Zoe a 22 kW charger. The latter two cannot use DC fast chargers.

2.2 Fast chargers

Fast chargers have since 2011 been built out across Norway with the help of public support programs from Transnova up to 2014 (Figenbaum and Kolbenstvedt 2015), and Enova after 2014 (Figenbaum 2018). In the beginning support programs from the government body Transnova was based on a first come first serve basis. The operators came up with suggested positions for the fast chargers, and if otherwise eligible for support, they would get up to 40% public funding.

The build out of fast chargers is now a mix of demand based approach and a coverage based approach. The bulk of the national support from the government entity Enova (that took over Transnova in 2015) has gone into a program to increase coverage, i.e. install fast chargers in new locations. They have issued tenders to provide fast charging every 50 km along all major travel corridors in Southern Norway and corridors of Northern Norway (ENOVA 2017), as seen in Figure 6.

Nye hurtigladestasjoner knytter Norge sammen

I 2015 og 2016 utlyser Enova utbygging av hurtigladere for elbil langs de nasjonale transportkorridorene. Alle strekningene skal være utbygget innen 1. november 2017.

UTLYSING 1 | CA. 2100 KM | 25. SEPTEMBER 2015

E18	Oslo–Grenland–Kristiansand
E39	Kristiansand–Stavanger
E16	Sandvika–Bergen
E6	Oslo–Trondheim
RV3	Kolomoen–Ulsberg
RV7	Hønefoss–Borlaug

UTLYSING 2 | CA. 2200 KM | 27. JANUAR 2016

E6/E8/RV80	Trondheim–Bodø–Tromsø
E14	Trondheim–Riksgrensen mot Sverige
E39	Stavanger–Bergen–Ålesund–Trondheim

UTLYSING 3 | CA. 2300 KM | MAI 2016

E18	Oslo–Ørje
E16/ RV2	Magnor–Kongsvinger–Kløfta
RV2	Kongsvinger–Elverum
RV35/E16	Jessheim–Hønefoss–Hokksund
RV9	Kristiansand–Haukeligrend
RV13	Jøsendal–Voss
E134	Drammen–Haugesund
RV36	Seljord–Eidanger
RV5	Lærdal–Florø
RV4	Oslo–Mjøsbrua
RV15	Otta–Måløy
E136	Dombås–Ålesund

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E6	Tromsø–Kirkenes
E10	Bjørnfjell–Å
E8	Skibotn–Riksgrensen mot Finland
E69	Olderfjord–Nordkapp
E75	Tana–Vardø
E105	Kirkenes–Riksgrensen mot Russland
RV92	Karasjok–Riksgrensen mot Finland
RV93	Alta–Riksgrensen mot Finland

Figure 6. Enova Fast charger support program for national main travel corridors. Source ENOVA (2017)

Fast chargers in cities are not supported by ENOVA. ENOVA believes that fast charging in cities is a profitable market already (Figenbaum 2018). In these areas the build out of fast chargers therefore now follows a demand based approach, where fast chargers are installed by commercial actors, sometimes in cooperation with municipalities. The latest Enova support program goes to chargers to be installed in municipalities that do not yet have fast chargers (ENOVA 2018), i.e. another coverage program approach. Some municipalities and counties also have supported the build out of fast chargers locally and regionally (Figenbaum 2018).

A typical fast charger location contains at least two multi-standard CCS/Chademo 50 kW chargers, and two AC flexi semi-fast chargers rated at 22 kW. This typical installation was the minimum requirement to get support for corridor chargers from ENOVA (ENOVA 2015). Some locations have fast chargers that are triple standard, i.e. also can deliver AC 43 kW. A few locations, mainly vehicle dealerships, offer single standard chargers, either Chademo or CCS. All new chargers installed are dual standard CCS/Chademo chargers. These multi-standard chargers can only charge one vehicle at a time, i.e. with either the CCS or the Chademo cable (or AC) with a few exceptions. All CCS/Chademo chargers in Norway are rated 50 kW maximum except a handful rated above 100 kW. Table 1 sums up the different main types of fast chargers installed in Norway.

Table 1. Main fast charger configurations used in the Norwegian market. Source: Operator data.

	Dual standard 50 kW DC	Tri standard 50 kW DC, 43 kW AC	Dual standard 50 kW DC + 22 kW AC	Single standard 50 kW DC CCS	Single standard 50 kW DC Chademo
Plugs	1. Chademo 2. CCS	1. Chademo 2. CCS 3. Type 2 43 kW AC	1. Chademo 2. CCS 3. Type 2 22 Kw	1. CCS	1. Chademo
Comment	The standard configuration used by the operators. Plugs are used one at a time.	These are older chargers, new ones are not deployed any more as 43 kW AC could only be used by one vehicle and the new version charge at 22 kW.	Some places the type 2 connector can be operated independently. In new installations, type 2 connectors are installed separately and not as part of the fast charger	Mainly used at Auto dealers selling CCS vehicles	Mainly used at Auto dealers selling Chademo vehicles. Some early single standard chargers have been redeployed

Note that as some fast chargers have a 43 kW or a 22 kW AC Type 2 plug that can be used by any vehicle, the charge power can then be 3-3.6 kW, 7.2 kW, 10-12 kW and even up to 22 kW more or less constant. As the connector is attached to the fast charger the output from this connector could be recorded as a fast charge event in the datasets analyzes in this report.

There are two main national infrastructure providers in Norway, “Fortum Charge and Drive” and “Grønn Kontakt” (in English: “Green plug”). A few smaller local operators also have fast chargers. BKK/Lyse is the largest local operator, and also has some national locations. Fortum has as seen in Figure 7, slightly more fast chargers per location, more locations and more fast chargers in total than Grønn kontakt. BKK/Lyse has much fewer locations but more chargers per location. Lyse has however a share of 20% single standard Chademo chargers in their network, whereas Fortum and Grønn kontakt mainly have deployed multi-standard CCS/Chademo chargers.

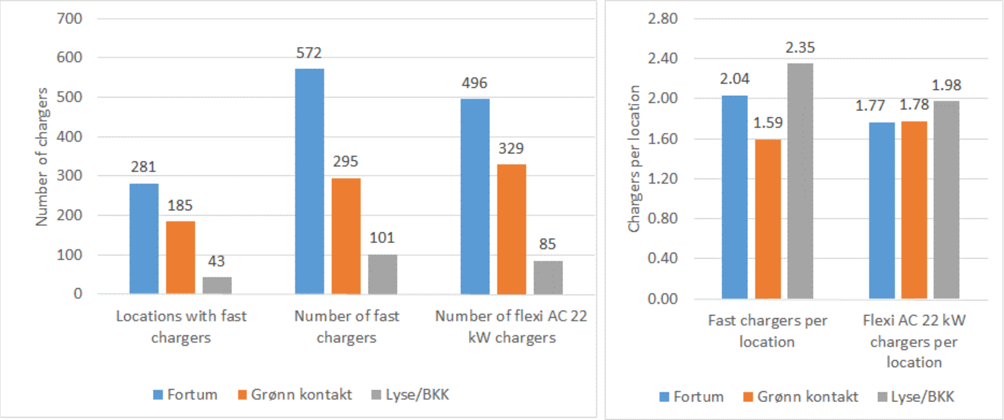

Figure 7. Number of locations, fast chargers in total and fast chargers per location, Fortum Charge and Drive (May 2018), Grønn kontakt (May 2018), Lyse/BKK. Status May 2018 (Aug 2018).

The fast charger locations in Norway have in this report been classified according to the additional functions and information presented in Table 2.

Table 2. Categories for fast chargers used in this report.

Type of function	Specification
Corridor	Major or minor transportation corridor. Chargers are mainly located roadside, but a few places with a 1-2 km detour. The possibility to support long distance driving on the main road of the corridor determines the categorization. Main corridors have E roads (E6, E18, E39 etc., in Norwegian: "Europavei") or regional R roads (R7, R22 etc., in Norwegian: "Riksvei"). Other corridors are provincial roads FV (in Norwegian: "Fylkesvei").
Major road	The name of the corridors main road
Other roads	Other corridors and roads the chargers support, for instance at corridor intersections.
City	Chargers in cities with >30000 inhabitants, Oslo, Bergen, Trondheim, Stavanger etc. The termed is used when the charger is located in dense parts of the city.
Small city	Chargers installed in cities with <30000 inhabitants
Other location	Chargers in non-city locations.
Food store	Food store chains Kiwi, Coop, Extra, Meny, Spar have installed a substantial number of chargers. Many double up as corridor chargers being located along major roads.
Shopping center	Multishop facilities, small and large
Café	Cafeterias mainly located roadside or at fuel stations doubling up as corridor chargers.
Fuel station total	Sum of chargers installed directly at fuel stations and chargers installed next to a station.
Fuel station	Chargers at a fuel station such as: CircleK, YX, Shell, Esso.
Next to fuel station	Chargers adjacent to a fuel station or across the road <100 m
Municipal, government	Chargers at schools, municipal facilities (bathing, culture) etc.
Parking	Chargers in parking facilities
Terminals	Chargers at major transportation terminals: Train stations, Airports
Vehicle dealer	VW dealers have CCS chargers. Nissan dealers have Chademo chargers.
Other enterprises	Chargers installed at Electric Utilities and in office properties etc.
Touristic	Chargers located at Hotels or various tourist facilities
Taxi	Chargers used by taxi fleets, other users cannot use them

The locations of fast charge stations have been analyzed using google maps, as the naming convention of the infrastructure providers was insufficient to identify the facilities of the charging location.

A charge location can serve several purposes. Most chargers can support driving in corridors although they in many cases have been installed for other reasons. A large share of fast chargers at food stores and cafeterias will also function as corridor chargers, because stores and cafeterias often are located at traffic intersections, and along main roads. Many fast chargers have for instance been put in place at McDonalds Restaurants located adjacent to fuel stations along major transport corridors. A main road fuel station with fast chargers may also have a café next to it or as part of the fuel station complex. These chargers will thus often be labeled corridor, café and fuel station (or adjacent to fuel station) at the same time. Charging locations that are labeled as a fuel station (i.e. Circle K, Esso, or similar) likely offers fast food, but has not been labeled as a café as it is not known exactly what the facility offers, and if there is seating available to the customers.

The main results of the categorization are shown in Figure 8. The three operator networks are rather similar. In total, 84-88% of the chargers can directly or indirectly support the driving in corridors due to their proximity to main roads. The term corridor has been widely interpreted and includes large national main road corridors as well as smaller but important corridors for long distance driving in rural areas.

The corridors can be split into European main roads (E-roads) having 60% of the corridor locations, and national main roads and provincial roads each having about 20% of the locations. That means that roughly half of all the fast charger locations are along E-roads or close enough to act as E-road corridor chargers.

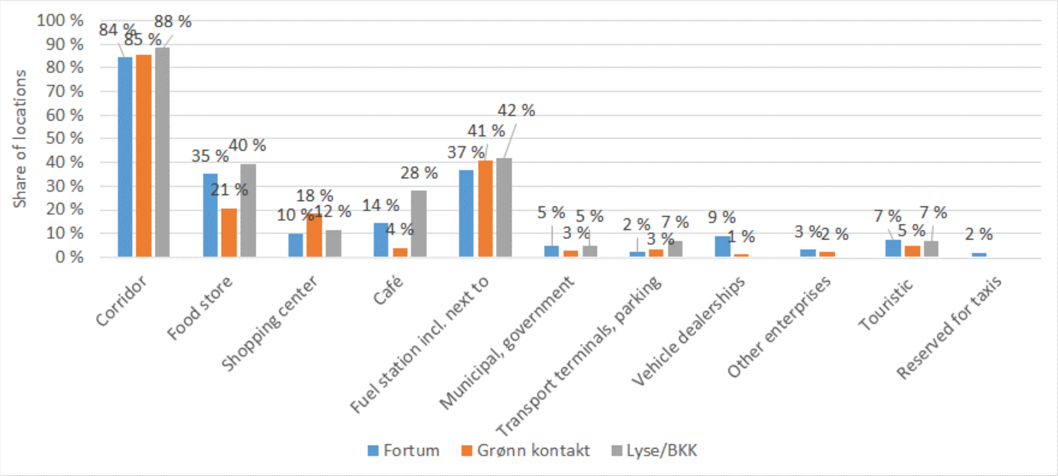

Figure 8. Share of fast charge locations by category and by operator.

The other main locations in all three networks are fuel stations (includes chargers installed next to a fuel stations), food stores, shopping centers and roadside cafés. The latter are mainly fast food chains. Fortum and BKK/Lyse has a large share of chargers next to a café, whereas Grønn kontakt has fewer café locations than the others. Grønn kontakt have now entered into a cooperation with a chain of roadside cafés (Grønn kontakt 2018), and will start installing fast chargers in these locations in the near future. These types of locations are likely popular as they already have parking facilities that can be converted to fast charging locations, and electricity is already available, although it may need to be upgraded. Peoples stop time at these facilities is fairly compatible with the charge time, and they are located where people travel. About 30% of the charger locations are in cities which partly have been put in place in cooperation with the municipality.

3 Theoretical approach

Users tend to evaluate new technologies based on how their performance relates to the existing technology it is meant to replace. Rogers' (1995) classical theory on diffusion of innovations uses the terms "relative advantage" and "compatibility" as tools to understand how the performance is evaluated against the existing technology. The new technology or innovation must be compatible with user needs, and provide users with a relative advantage over the existing technology or practice, to be taken into use.

BEVs are different from the incumbent fossil fueled vehicle technology. They have a limited range, but can be recharged at all locations where electricity is available, for instance at home. The energy transfer rate when charging a BEV is much slower than when filling fuel on an ICEV, especially from home chargers and slow public chargers, but also fast chargers are slow compared to liquid fuel dispensers.

BEV users tend to charge their BEVs at four locations (Hardman et al. 2018, Figenbaum and Kolbenstvedt 2016):

1. at or near home, usually overnight
2. at workplace or commuting locations, supporting longer distance commutes
3. at public locations, i.e. stores, shopping centers, transport terminals, parking
4. during stops in travel corridors, while travelling from origin to destination

BEV users mainly rely on recharging their vehicle slowly at home using cheap electricity, using a household socket, a dedicated power socket or a wall mounted charging station. 92.6% of Norwegian BEV owners can charge at home according to the user survey in 2018 (Nordbakke and Figenbaum 2019), down from 94% in 2016 (Figenbaum and Kolbenstvedt 2016). The speed of charge using a basic home charging connection to the grid (16A, 230V power), will be in the order of 7-15 km range per hour of charge (Figenbaum 2018). This slow charging method can also be used at destinations and public areas where electricity is available. This method of replenishing energy provides users with a huge energy cost advantage over ICEV owners in daily traffic. Running a BEV on home charged electricity reduces energy cost by up to 75% compared to running on fossil fuel. This charge method is however normally too slow to be used when on trips with a travel distance longer than the range of the vehicle.

Fast chargers decrease the range and charge time disadvantages consumers have with BEVs, and thus increase BEVs compatibility with users existing motoring practices. Fast charging can theoretically provide 3-5 km of range per minute of charge from a 50 kW fast charger under ideal circumstances (Figenbaum 2018). In reality they provide less even under optimum conditions. Depending on charger manufacturer the derating can be on the order of 6-10% (Trentadue et al. 2018), even up to 25%, although also the vehicle model heavily influence the maximum achievable power as discussed earlier in the report.

150 kW chargers will triple the number of km range available per minute of charge. The first 350 kW chargers are also under deployment although no vehicles can use them yet.

Although fast charging will never be as fast as filling energy with a liquid fuel dispenser, Figenbaum (2018) found that when the fast charge power reached 150 kW with a battery size of 40 kWh or higher, the charge time is compatible with the pauses that people nevertheless take during long distance trips. The question will then be if the infrastructure can be built out to avoid charging queues. The data analyzed in this report is however limited to an evaluation of 50 kW charging in the networks of two operators. More than 99.9% of the chargers installed when the data was collected were limited to 50 kW charging, and the vast majority of the vehicles in the fleet could not handle more than 50 kW.

Little is known about the actual usage of fast chargers and their contribution to the rate of diffusion of BEVs in the market. Fast chargers make the use of BEVs more flexible by allowing for intraday changes to travel plans and can make users more confident in exploring BEVs range capabilities by assisting users running into unforeseen problems on the go (Figenbaum and Kolbenstvedt 2016). Fast charging can enable long distance commutes for BEV owners that cannot charge at work. Fast charging on long distance trips can make it possible for users to get by with a BEV as their only household vehicle. Fast charging thus enables users to benefit from the cheap everyday home-charging that provide BEVs with a clear relative advantage over ICEVs, and users can continue their motoring practices with minimal needs for behavioral adaptation for instance on long distance trips, or when they have forgotten to charge.

Fast charging does take time and users may want to have something to do while waiting for the vehicle to finish the charge. Fast charger location attractiveness and the usage of fast chargers could therefore be influenced by the types of services that the locations can offer, such as cafés, kiosks, shops, tourist attractions etc. A behavioral adaption of travels could thus be the result of a transition to BEVs as the ability to charge must be taken into account when scheduling a trip.

As seen in chapter 3, one can expect that each fast charge session is fairly small in terms of the energy charged, and thus have a fairly short time duration. It is expected that the average charge power will be lower in the winter than in the summer, as it is known from the literature that low ambient temperatures limits the fast charge capability of batteries (as seen in section 2.1). 85% of the BEV fleet in Norway consists of compact and smaller vehicles (NPRA 2018). 72% belong to multivehicle households (Nordbakke and Figenbaum 2019). Taking these facts into consideration, and results from surveys on the characteristics of users and charging habits reviewed by Hardman et al. (2018), one can put up some hypothesis about fast charging in Norway:

1. Fast chargers are rarely used by most users, as most of the energy required will be charged at home at a much lower cost than from fast chargers.
2. People that only own a BEV use fast chargers more often than people in multivehicle households that also owns ICEVs.
3. People without charging capability at home use fast chargers more often
4. Fast chargers are mainly used for supporting local and regional traffic

5. Shorter range BEVs fast charges mainly at intra-urban locations, whereas longer range and larger BEVs fast charges at inter-urban locations.
6. Fast charging increases the electric-km driven when user's complete trips longer than the range.
7. Major travel corridor fast chargers far from cities are primarily used on peak travel days, and users charge more energy from them than from city chargers.
8. Users charge just enough to reach home/destination, not to fill up the battery, due to the huge cost difference between home and fast charging.
9. Use of fast chargers varies with the traffic flow over the year
10. Use of fast chargers is higher in the winter than in the summer due to an increased energy consumption in the winter season
11. The average fast charge power is lower in the winter than in the summer

Fast charging needs to be economically sustainable for the charge operators. A question will thus be: can a profitable fast charge infrastructure be built out to support user needs while being profitable for the infrastructure providers? Today, all fast charge operators demand a fixed price per minute of use of fast chargers. Users will therefore get varying amounts of energy for the same total price, since the charge power depends on the vehicles fast charge capabilities and the status of the battery at the start of the charge. Operators charge by the minute rather than for the energy to avoid charge queues, and to improve the profitability of fast charging. If energy was the cost unit, then more users would likely continue the charge beyond the 80% SOC point, resulting in rapidly falling energy transferred per minute of charge. The result of that would be much longer charge times per charge event, longer charge queues, and reduced operator profitability.

In this report, the following seven parameters are identified as being important when analyzing usage patterns and overall charging volumes in fast charger networks:

1. The user needs for fast charging
2. The BEV fleets technical characteristics, i.e. battery size fast charge capability
3. The energy charged, which is the utility of fast charging for the vehicle owners. It translates into kilometer added range per minute of charging.
4. The minutes spent charging, which is the utility of the fast charging for the fast charge network operator. It is directly proportional to income when users pay per minute of charge. Time is also a measure of how long people stay at the facility and potentially eat, shop or use other functions.
5. The average fast charge power achieved, is a measure of the efficiency of the charging network in delivering energy to be used by the vehicles, but of interest also for Distribution System Operators that have to deliver power to the fast chargers, and the users that use more time to get the same energy charged when the charge power is reduced.
6. The total volume of fast charging, which determines the value and the economic viability of building out a network of fast-chargers.
7. Charge queues, which could become a bigger barrier to BEV use than range anxiety now that range increases for newer BEVs, and thus limit the further diffusion of BEVs.

4 Materials and methods

Three datasets were used in the analysis of use of fast chargers in Norway. Dataset 1 and dataset 2 contains fast charge transactions from two operators of fast chargers. These datasets are not directly comparable. Dataset 1 contains individual charge event transactions. Dataset 2 contains the utilization rate of charge plugs in the network of the operator. The total charging activity in terms of minutes charged per year cannot be presented due to confidentiality reasons. Dataset 3 contains results from a user survey of BEV owners conducted in June 2018. It provides additional insights into the user experience of fast charging in Norway as well as their long distance travel patterns.

4.1 Dataset 1 - Fast charge user data from operator 1

Dataset 1 contains individual charge events. Each charge event is in the dataset assigned to an anonymous user ID. Each recorded event contained the start time, the charged energy, the duration of the charge, an ID for the charger used and a user ID. The data on the charge events were in a separate file from the information about each charger. The charger data had to be connected to each charge event before the analysis could be started. A database of information about each fast charger was developed containing the categorization in Table 2 and the geographical position.

There are limitations to the analysis of users. Users could for instance be using the charging networks of more than one operator. There are two user types in the dataset. Registered users use an RFID card or an app to operate the charge, they payed 2.5 NOK/min of use. SMS users (mobile phone text message payment) pay 3.0 NOK/min and send an SMS to initiate charging. The same user could use both payment methods and different RFID cards (operator plus the RFID card of the EV association). There is thus an uncertainty in the calculation of annual usage per user. In this report registered users and SMS users are all considered to be unique.

Dataset 1 does not contain the complete charging activities in the network of operator 1, but the majority of the charging is included. The dataset contain information per charge event by individual anonymous users. Nothing is known about the users, only where and when they are charging.

The dataset needed extensive filtering due to a number of very short charge durations and other types of inconsistencies. Valid data points were required to be within the maximum and minimum values shown in Table 3 for energy, time and power.

Table 3. Maximum and minimum values used for filtering data in dataset 1.

	Limit value	Unit
Min kWh	0.1	kWh
Max kWh	100	kWh
Min time Fast Charger	1	Minute
Max time Fast Charger	120	Minutes
Min Time Slow Charger at Fast Charge Station*	1	Minute
Max Time Slow Charger at Fast Charge Station*	1440	Minutes
Min Fast Charge power	1	kW
Max Fast Charge power**	60	kW
Min Slow Charge power	0.1	kW
Max Slow Charge power**	24.2	kW

*These are not intended for overnight charging

** Set above 50/22 kW to take into account the uncertainty due to only whole minutes being registered.

The time is in whole minutes and the energy charged in kWh with two decimals. There is thus some uncertainty in the results, especially for short charge durations with few kWh's. The average power was calculated by dividing the kWh with the time used. Valid charge power can be anything from 1 kW and upwards. The reason is that users could be connecting to a fast charge stations with an almost full battery, which would result in slow charging.

It is possible to continue using fast chargers after the SOC has passed the level (80-85% SOC), where the charge power rapidly is reduced to preserve battery life. The average power can thus also become very low. It would be uneconomic to continue beyond the 80% SOC-point, but some users may nevertheless do so. There could be different reasons for this behavior, for instance user misconceptions, user needing more than 80-85% SOC to reach the destination, or in situations where there is no slow charger available at the fast charge station.

The dataset contain a number of events by "System user". These events are real charging events, but the system has not been able to attribute the charge event to a customer. The operator has under these events opened the charger remotely. These events therefore represent lost potential income for the operator.

The total charging activity will not be presented in the report due to confidentiality of data.

A small share of the operators' fast chargers were equipped with AC 22 or 43 kW Type 2 charge sockets. As the unit in the dataset is the charger and not the plug, the use of these AC plugs cannot be distinguished from the use of a fast charge plug. A likely insignificant share of the charge events is related to use of these charger plugs.

4.2 Dataset 2 - Fast charge user data from operator 2

Dataset two contain charger utilization data per connector per hour from January 2016 through January 2018, i.e. each line represented the number of minutes of an hour where a charger had been in use. Each individual charge event can extend beyond one hour. The data can therefore not be split into individual charge events.

Dataset 2 contains a sub-set of the charging activities in the network of operator 2. The share of missing data is much larger than for dataset 1. The charged energy is only available for a small subset of dataset 2.

All sequences with more than 3,600 seconds recorded and data that had a recorded time exactly equal to 3,600 seconds (one hour), combined with zero recorded charge events, were removed from the dataset on advice from the operator. According to the operator these situations are due to faults in the charging recording, and it cannot be determined if the chargers have been in use or not.

In this dataset it is not straightforward to delete lines with charge events that lasted a short time. The reason is that the event could be part of a longer charging in the previous hour or an attempt to charge that failed, and it is not known which is correct. It was however decided to delete lines with less than 1 minute of activity.

4.3 Dataset 3 - User survey

This dataset provides results from a BEV user survey conducted in June 2018 among 3,659 BEV owners, mainly members of the Norwegian EV Association, as well as 2048 ICEV owners that were members of the Norwegian Automobile Federation (NAF). As all new BEV buyers receive a one-year free membership in the EV Association courtesy of the dealer, and the sample is representative in terms of models and geography, the sample is reasonably representative of BEV owners.

The survey was broad in scope and only results relevant to fast charging and long distance travel behavior is presented in this report. The dataset contains BEV user assessment of their long distance travels, where and how often they fast charge, queues, willingness to stand in charge queues, quality of the fast charge experience, what they do while fast charging, and other aspects.

The complete information about the survey design is available in Nordbakke and Figenbaum (2019).

4.4 Strengths and weaknesses of the datasets

The main advantage with datasets of actual use of fast chargers is that they contain and can provide robust results on overall usage patterns. The use of fast chargers by individual users is partly possible to analyze, but limited by the fact that it is not known where the anonymous users live or work. The trip purposes are also not known, nor the total distance being driven. The datasets are vulnerable to missing data points and communication issues, or user faults when using the chargers, for instance multiple start-up sequences etc. Users could also be using several operator networks and different payment methods within the same network. It is also not known when the user bought the vehicle. They appear in the dataset the first time they fast charge.

User surveys have several limitations, such as memory bias and potential misunderstanding of questions. Poor phrasing of questions could lead to a risk of users answering in a manner not intended. An issue can also be that the vehicle may be used by more than one user, and the respondent may not know the full household usage pattern for the vehicle. The advantage of user surveys is that they can lead to a deeper understanding on for instance the purposes of trips, or the user perception of the interaction with the charging infrastructure.

Together, these datasets of fast charger usage and the user survey, should make it possible to gain a deeper understanding of fast charging than each of the approaches can do separately.

5 Results – Data from fast chargers

The datasets used in the analysis mainly contain transactions and utility rates that made it possible to investigate differences in charged energy, time spent charging, fast charge power, geographical locations of chargers, and seasonal difference in needs for fast charging. It would be possible to calculate total charging volumes, but confidentiality agreements with the operator's means that these numbers cannot be published. Therefore, most of the data will be presented as relative variations over time, energy or other parameters. One of the data-sets used in the analysis contained anonymous user-IDs. That made it possible to investigate how much, where and when users fast charged in this operator's network. It will however only provide a partial picture of user needs, as users may also be using other charging networks or more than one payment method in the same network.

The charge events in dataset 1 is attributed to the hour of the events start time. This approach is a simplification that introduces a small non-critical inaccuracy in the load profile. Dataset 2 contained minutes of charging per hour of active operation per charge plug per charger. The datasets are thus not directly comparable.

5.1 Number of fast chargers/locations per BEV in fleet

The number of BEVs per fast charger and fast charger location is an important parameter in the utility rates for fast chargers.

At the start of 2016 the BEV fleet in Norway consisted of 69000 BEVs, which by the end of 2017 had increased to 140000 BEVs. Figure 9 shows the development in the total number of locations and fast chargers for operators 1 and 2 from 2016 to 2018, and the number of BEVs per location and charger. The BEV fleet is assumed to grow linearly by 1/12 per month of the difference in fleet sizes between years. The number of chargers and locations are found from the datasets as the month each charger and location became active. As can be seen the number of vehicles in the fleet relative to the number of fast chargers of operator 1 decreased through 2016, and remained constant through 2017. For operator 2 the rapid expansion in the number of chargers continued to the end of 2017, leading to a decrease in the number of vehicles per charger until the end of 2017. From then on the number of new fast chargers tapered off also for operator 2. Combined for the two networks there was a large decrease in the number of BEVs per location and per charger through 2016, and a fairly stable situation since January 2017 with about 330 BEVs per location and about 200 BEVs per fast charger. The same calculation could not be done for network 3, due to lack of detailed data.

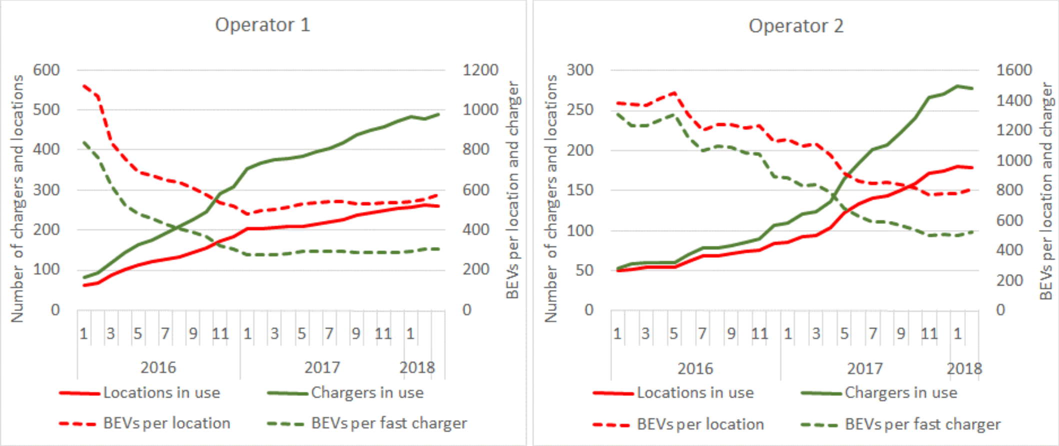

Figure 9. Number of locations and fast chargers in use per month for operator 1 and 2, and number of BEVs in the vehicle fleet per location and per fast charger. Dataset 1 and dataset 2.

The geography of the networks of two main national operators and one regional charging operator is shown in Figure 10. The number of BEVs per location and charger is much higher in Oslo and Akershus than elsewhere. Hordaland and Rogaland are other areas with high number of BEVs per charger and location. Oppland, Sogn og Fjordane, Aust-Agder, Hedmark and Nordland are examples of counties with many fast chargers and few vehicles, so the number of vehicles per charger/location is low, in particular for the first two counties.

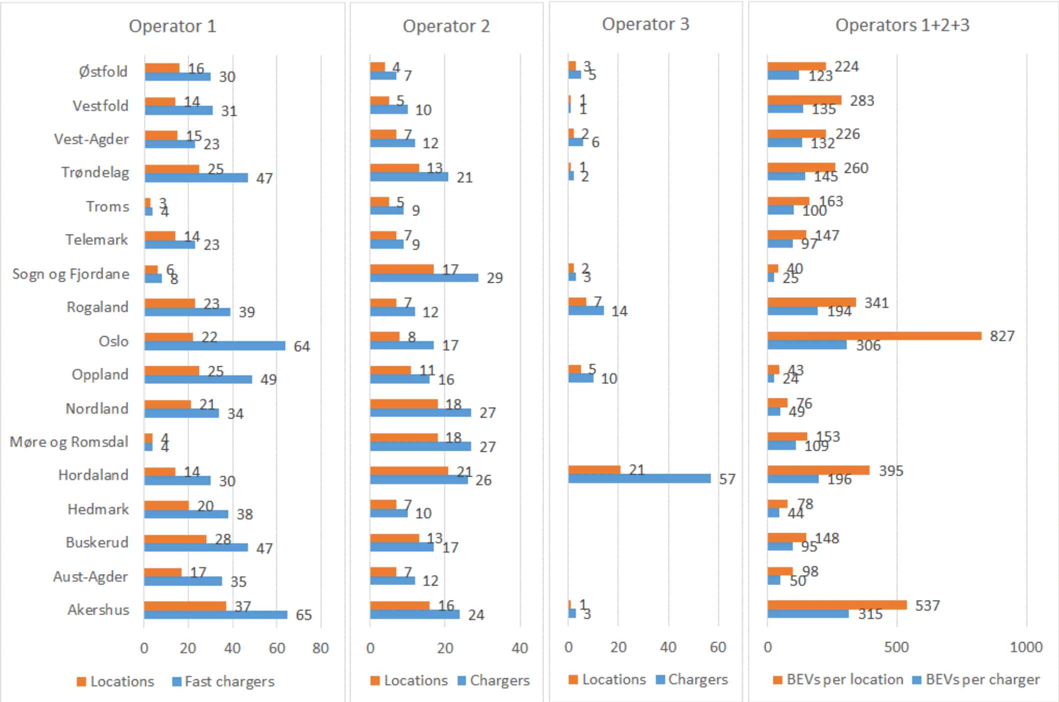

Figure 10. Geographical distribution of fast charger locations and total number of fast chargers. Vehicle fleet size status 01.01.2018, charge stations status per Q1 2018 (Q3 for operator 3).

5.2 Total annual volume of fast charging

The changes in the relative volume of fast charging between 2016 and 2017 is shown in Table 4 for operator 1. The same table contains the change in the relative number of fast charge events and minutes charged by each user group and in total, and the average relative number of fast charges per user. The dataset does not contain passive users. If they are in the dataset, they have used a fast charger at least once.

The number of users of the charging network of operator 1 increased by 70% during the period, which is faster than the increase in the fleet of BEVs. The number of fast charges per individual user increased by 15%. The volume of minutes increased slightly more than the number of fast charge events, and the volume of kWh increased faster than the volume of minutes. These facts suggest that each user charges more often, using more minutes, whereas the even larger increase in kWh per user is likely due to an increased average charge power. The increase in the number of installed fast chargers was 37% between the end of 2016 and the end of 2017 for this operator.

Table 4. Increase in use of fast chargers, number of users, total volume of fast charging minutes and kWh and per user between 2016 and 2017. Dataset 1

	Number of users of fast chargers	Number of charge events	Total volume of fast charging - Minutes	Total volume of fast charging - kWh	Number of fast charges per user	Number of minutes per user	Number of kWh per user
All valid users	+70 %	+96 %	+103 %	+112 %	+15 %	+19 %	+25 %
Registered users	+83 %	+104 %	+108 %	+122 %	+11 %	+14 %	+22 %
SMS users	+60 %	+74 %	+78 %	+86 %	+9 %	+11 %	+17 %

Dataset 2 had a high share of missing data, so it is thus not possible to know if the increase in registered charging activity for this operator is correct, but the number of valid data-points, i.e. an indication of overall activity, increased about 170-190%. The dataset contains no information on users. The increase in the number of installed fast chargers was 155% from the end of 2016 to the end of 2017 for this operator.

Figure 11 shows the regional differences in fast charging as the share of the national fast charge events that occur in each county, and the share of fast chargers located in each county, against the share of the national fleet that is registered in the county. It should be noted that some of the fast chargers were installed during 2017. Data from operator 3 which holds a strong position in Hordaland and Rogaland was not available. The data from operator 3 has in this figure been conservatively imputed as being the same per charger in each county as the lowest of the two other operators in that county.

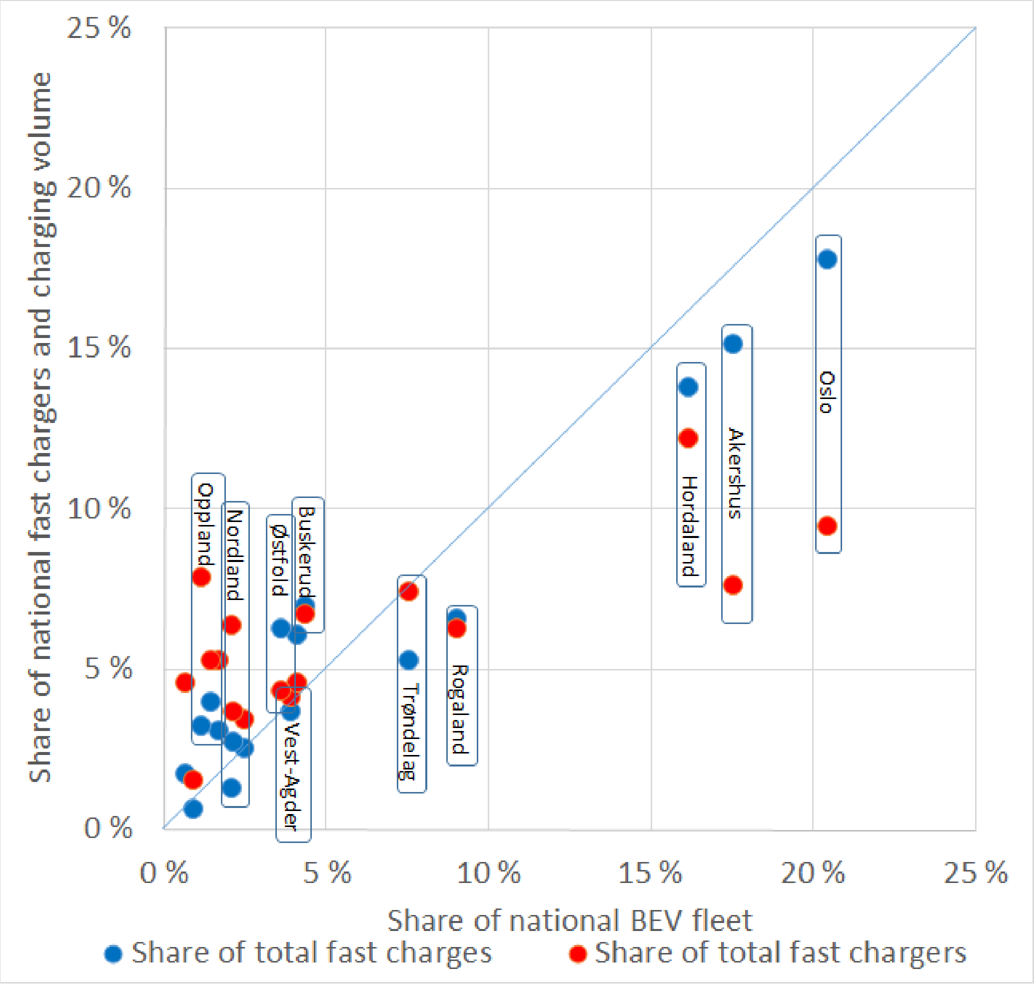

Figure 11. The counties share of the total national fast charge events and installed fast chargers (y-axis) and share of BEV fleet (mid 2017, x-axis) in 2017.

Oslo and Akershus are rather similar in terms of number of chargers, fleet size and the number of charge events. Hordaland has more chargers per user than these two . All these three counties have a high utility rate for fast chargers, as seen by the blue dots being above the red dots, and the red dots being below the line (which represents the situation when all fast chargers and all use of fast chargers is completely evenly distributed between counties). These three counties have large cities where the fast charge market is fully commercial.

Trøndelag seems to have a lower utilization of chargers whereas the situation is more balanced in Rogaland (lower than average), Buskerud (higher than average) and Vest-Agder (average). Oppland and Nordland are examples of counties with a high number of chargers built out with public support, but a low charger utilization rate.

There were no fast chargers in Finnmark in 2017, and the charge markets in Nordland, Troms, Sogn og Fjordane and Møre og Romsdal were weak.

The average fast charge power per charge event in 2017, was calculated to be 30.2 kW, whereas the average charged energy was 9.6 kWh and the average charge time 20.5 minutes, as seen in Table 5.

Table 5. Average and std.dev. of energy charged, time used and achieved power per fast charge session 2016-2017. Dataset 1.

	Energy Average (kWh)	Energy Std.dev. (kWh)	Time Average (min)	Time Average Std.dev. (min)	Power Average (kW)	Power Average Std.dev. (kW)
2016	8.85	4.90	20.13	12.16	28.72	10.06
2017	9.58	5.71	20.53	12.80	30.22	10.27
2018 Q1	9.70	6.49	23.24	15.16	27.22	10.90

The charged energy and the time spent charging are normal-distributed but skewed to the right as shown in Figure 12. The charge power follows a completely different trend, which is at the outset not surprising due to the upper limit of charge power (max 45-50 kW from 50 kW chargers). A reasonable theory would therefore be that the fast charge power would be normal distributed around 40 kW and skewed to the left. The power curve is however much more skewed to the left than expected and the shape is different from a normal distribution. Other factors such as technology constraints and sub-optimal user behavior obviously influences this result.

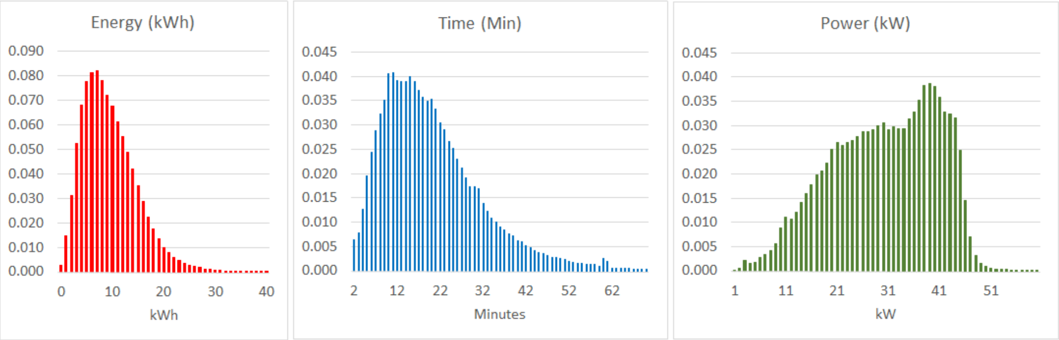

Figure 12. Normal distribution of energy charged (left) and time used charging (middle) and distribution of average charge power (right). Share of valid number of charge events on y-axis. kW, Minutes and kWh have been rounded to nearest integer. Dataset 1.

The charge power distribution curve warrants further investigations. It turns out that the power curve for the counties follows two very distinct patterns as shown in Figure 13. In counties with large cities, the curve is biased towards lower power levels. In rural counties with main roads passing through, the bias is towards a more defined and higher peak value of around 40 kW. Potential reasons are that the fleet composition of vehicles using fast chargers could differentiate between counties, or that the battery temperatures are on average lower in cities, or that users charge fewer kWh per charge event in cities.

A similar difference is also seen between seasons. A much lower share of charge events are done with a high average charge power in the winter. While batteries likely heat up while fast charging in the winter, so that the charge power increases during a charge event, the overall effect is still a much lower average charge power.

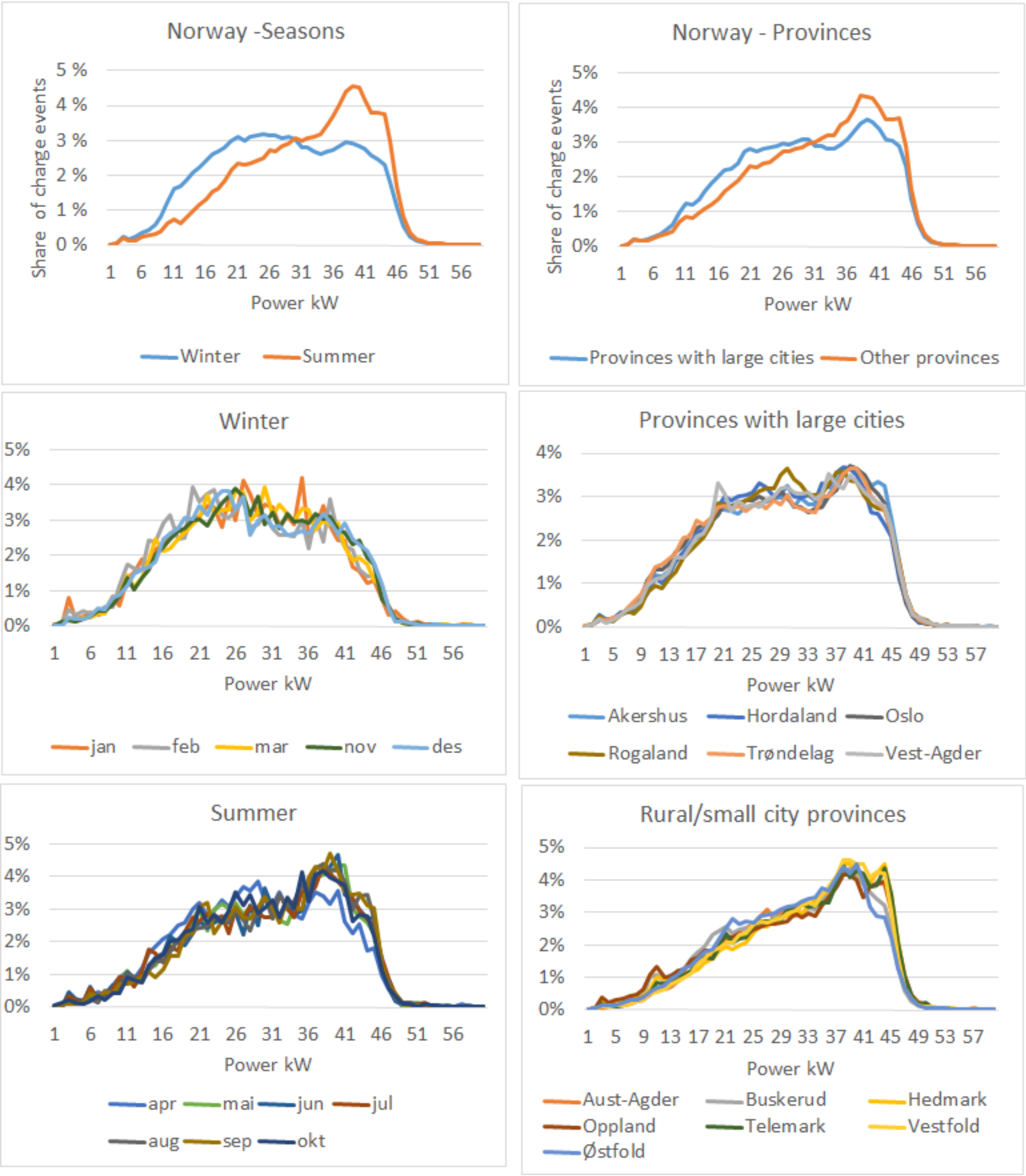

Figure 13. Distribution of fast charge power for summer and winter seasons (left), and two types of counties, those with major cities and rural counties with large main roads (right). kW was rounded to the nearest integer. Y-axis is the share of the total annual charge events. Dataset 1.

The distribution of the average charged energy, the average time spent charging and the average charge power per session and per user, is shown in Figure 14.

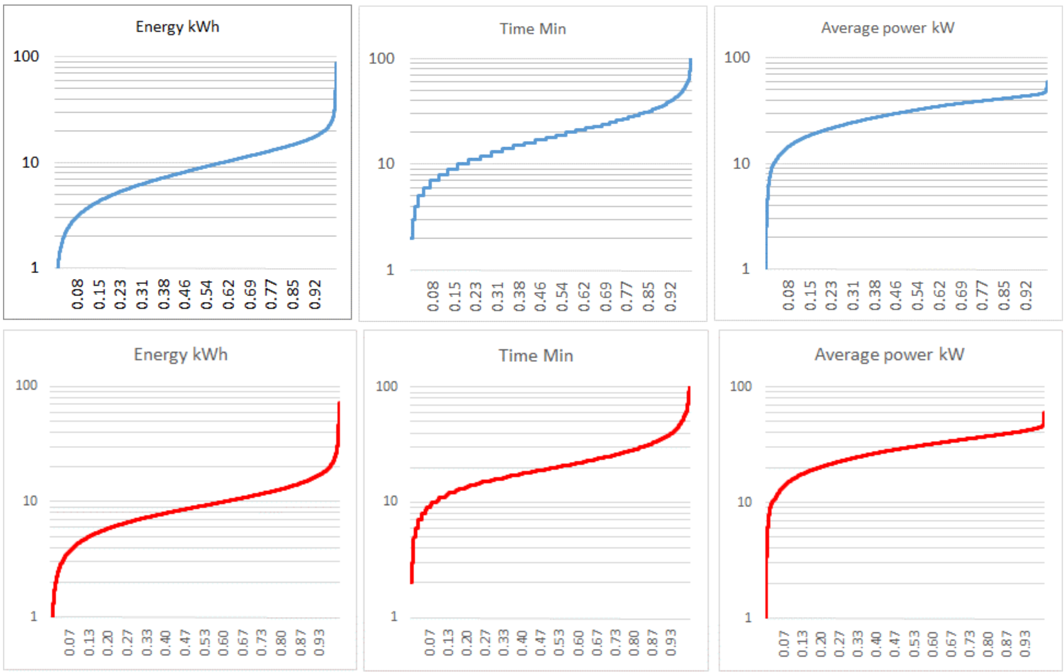

Figure 14. Distribution of volume, time and power (y-axis) over all fast charge sessions in increasing order of share of users (x-axis) (top), and distribution of each users' (bottom) average volume, average time and average power (Y-axis), in increasing order of share of users (x -axis)[1]*. 2017. Dataset 1. Log scale.*

The average fast charge power of only 30.2 kW (as seen in Table 5), is perhaps the most surprising result in this report. It turns out that only 20% of the fast charge sessions have a higher average charge power than 40.1 kW. The median is 31.1 kW. When averaging each user's fast charge events over a year, 20% achieved an average power above 37.4 kW, as seen in Table 6. The median is 29.4 kW.

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[1] Power levels above 50 kW is a result of only whole minutes being available in the dataset, or users charging at one of the few chargers capable of higher charging power, or registration faults.

Table 6. Energy, time and power percentiles and median for charge sessions and users in 2017. Dataset 1

		Energy kWh	Time Minutes	Power kW
Average all charge sessions	10 percentile	3.47	8	15.8
	20 percentile	4.91	10	20.5
	Median	8.66	18	31.1
	80 percentile	13.6	29	40.1
	90 percentile	16.5	36	43.1
Users average	10 percentile	4.43	10.8	16.0
	20 percentile	5.86	13.5	20.3
	Median	8.92	19.8	29.4
	80 percentile	12.8	28.5	37.4
	90 percentile	15.6	35.3	40.4

The dataset was as seen in Figure 15 split into the periods January-March and June-August 2017, to look at the most typical winter and summer months for any seasonal differences. The influence of temperature is clearly seen in the huge difference in the charge power, whereas time and kWh varies little between seasons. The difference in average power between the median values summer and winter is 6.63 kW. For the average value the difference in 4.75 kW. The difference in median and average kWh charged is 1.2 kWh. There is no difference in the median charge times but the average charge time is 1.3 minutes longer in the winter.

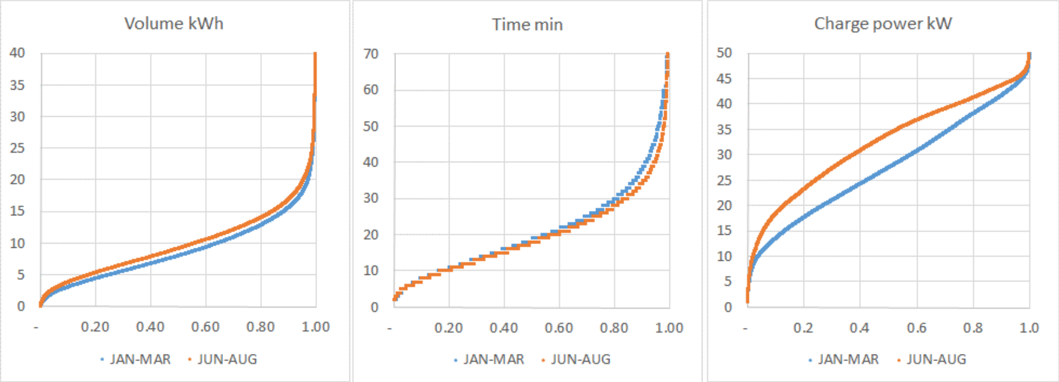

Figure 15. Distribution of charging energy (kWh), Time (min) and Power (kW) winter (Jan-Mar) and summer (Jun-Aug) 2017. kWh, Minutes, kW on y-axis, share of charge events on x-axis. Dataset 1.

The 30.2 kW average charge power at first sight seems to be much lower than expected given that a fast charger can deliver 50 kW peak power. The ramp up and ramp down of the power when initiating and ending the fast charge event means however that the full 50 kW power can never be achieved. The available power from the charger can also be reduced somewhat on hot summer days due to the electronics heating up[2]. Other reasons are linked to use of the type 2 charge outlet on

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[2] Information from fast charge operator.

some chargers, and the differences between vehicles' fast charge capabilities as seen in Figure 3. A very important additional aspect is the limitation in the ability to fast charge some vehicle types in the winter. The seasonal differences in fast charging are explored in the next section.

Some further observations:

- Charging more than 20 kWh energy is rarely done, which is expected given the fleet composition found in chapter 2.1.
- Users charging more than 30 kWh energy into their vehicle can be an Opel Ampera-a, or Tesla owners using an adapter to charge from Chademo plugs.
- Users charging less than 1 kWh and fast charges that last only a few minutes are likely to be due to tests or demonstrations of how fast charging works, or faults in the charging process.
- Fast charge power below about 20 kW could be users who starts the fast charge at a high SOC and continues charging beyond 80% SOC, or users that attempt to charge a very cold battery, or users that do not understand the technology and plugs in to charge when the SOC is high, or users of the Type 2 plug on the fast charger.
- Very long charge durations are likely vehicles with large batteries, or users charging far beyond 80% SOC, or users who have plugged in and gone to do other things, or users that use a type 2 plug on a fast charger.
- The charge power will be the highest for vehicles that are capable of fast charging at a higher power than the 50 kW chargers can deliver, i.e. Tesla Model S/X, Hyundai Ioniq or Kia Soul BEVs.
- Very short charge durations could also lead to high power due to the fact that only whole minutes are registered in the dataset.

Figure 16 explores further if it is possible to identify vehicle types or user types from the charge data. The chart plots all users' average charge power versus the average energy they have fast charged. It can thus be used to explore the more extreme users. Users in the upper right hand side of the chart have to be Tesla owners as they have a large battery that is capable of charging at or close to 50 kW. Users in the right hand side (above 30 kWh charged energy) with charge power less than 40 Kw, have a large battery but it cannot be charged as fast as a Tesla. These could be Opel Ampera-e vehicles. In the lower left part of the chart one can see likely users of the Type 2 connector on the fast chargers as "lines of datapoints" at about 3.5 kW and 11 kW. These users might have vehicles not capable of fast charging, such as the Mercedes B-Class, Smart vehicles, or Tesla BEVs, so they charge their vehicles using on-board chargers. It could also be other vehicle types for which the users tops up the battery towards 100% SOC after the fast charge has finished, or users waiting for a free fast charger.

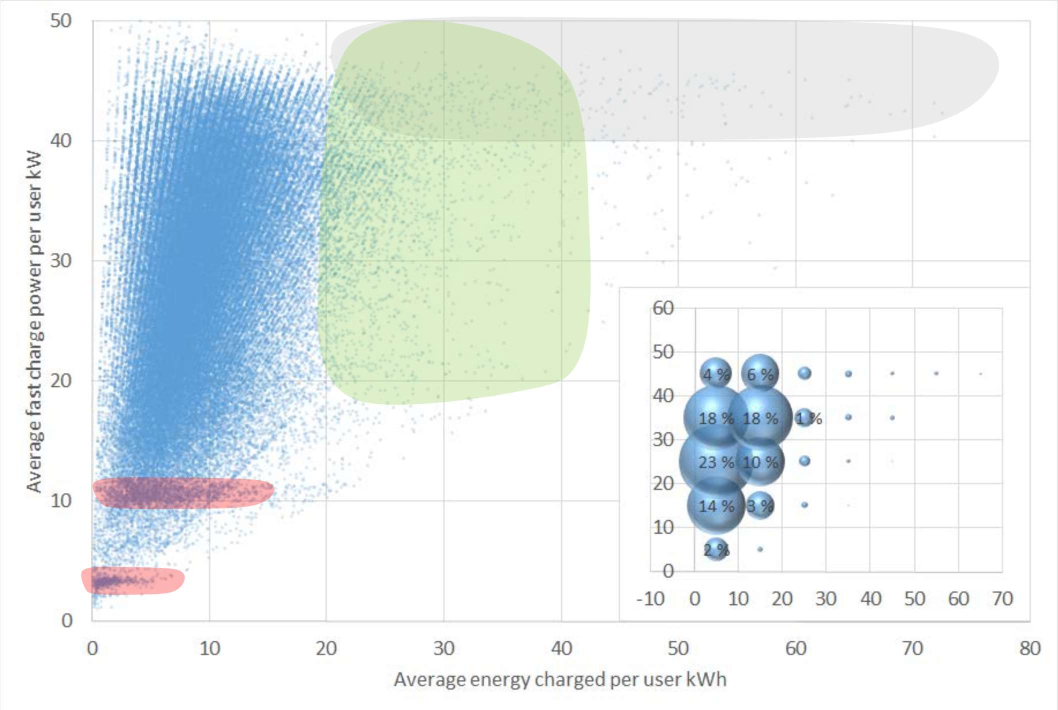

Figure 16. Average fast charge power in kW as a function of average energy charged in kWh per user[1] in 2017. The Bubble chart in the lower right corner show the share of users within each quadrate of the main chart. Grey area are likely Tesla owners. Green area, could be Opel Ampera-e owners. Red areas marks likely 22 kW AC plug users (charging with their on-board charger at 3.7 or 11 kW). Dataset 1.

5.3 Seasonal effects on fast charging

Seasons have several impacts on fast charging. Temperature impacts the charge power that the batteries can accept. The ambient temperature and seasonal driving conditions differences influences the driving resistance of the vehicle (dry/wet/snow covered roads, winter tyres, air density), and thus the energy consumption. The energy used to heat the cabin comes in addition (it is much higher than the energy used for cooling in the summer). The energy used per km is thus much higher in the winter than in the summer, which should have an impact on the demand for fast charging.

The total traffic flow and distances driven by the vehicles also varies between normal workdays, holidays and vacations. Dataset 1 and 2 can be used to analyze these seasonal differences.

Average power, time and energy charged

The average fast charge power is higher in the summer than in the winter, as seen in Figure 17, but the differences were smaller in 2017 than in 2016. The average charged energy was slightly higher in 2017 compared to 2016. The seasonal variation in average time was reduced between 2016 and 2017. The charge power has increased over time, likely a consequence of the introduction of new vehicle models with improved fast charge acceptance, and new battery options in existing models.

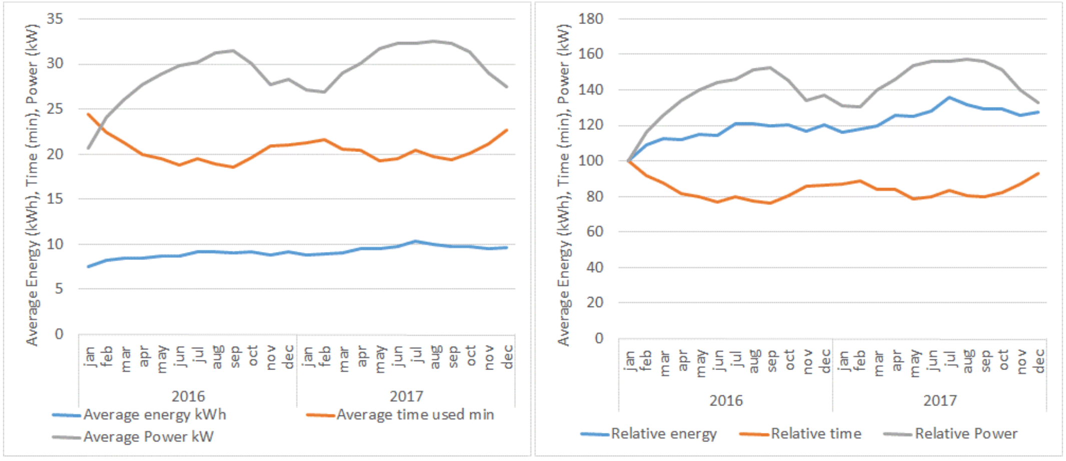

Figure 17. Average energy charged, average time used, average charge power by month 2016-17 (left), and relative to January 2016 (right). Dataset 1.

Share of total charge events and average power by energy charged by month

Figure 18 shows the distribution of fast charged energy in kWh by month and for the total year of 2017, together with the practical fast charge potential of the fleet. For the share of charge events, the distribution is skewed to the right (left figure). The variation between months is small. The variation in charge power between months is much larger, as clearly seen in the figure. The reason is the reduced ability of batteries to accept full fast charge power when they are cold during the winter season.

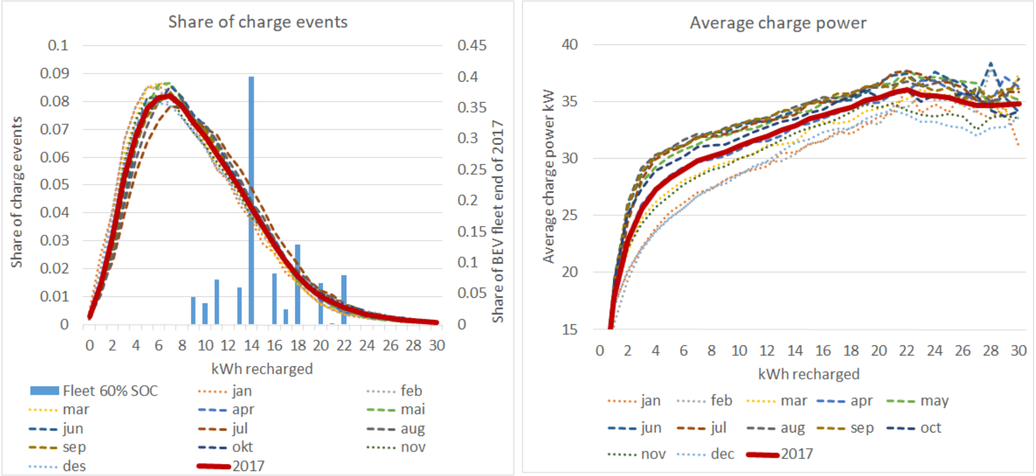

Figure 18. Distribution of charge events by kWh recharged per month, and distribution of BEV fleet with a 60% SOC fast charge window(left). Distribution of average charge power by kWh charged (right). 2017. Dataset 1.

Apparently the differences between winter months and summer months is small when it comes to how much energy people charge, which is counterintuitive. The expectation would be for the winter months to have a larger share of users charging more energy than in the summer, to be able to accomplish the same driving distance. However, the energy consumption is 50% higher in the winter, whereas the charged energy is slightly higher in the summer. The fact that the charge power increases with more kWh being recharged is due partially to the likelihood of the vehicle having a larger battery, as well as a potential heating of cold batteries while charging in the winter. The latter can be seen as the steeper increase in charge power with increasingly more kWh charged in the winter months.

Range capability difference summer and winter

In Figure 19 the charged energy has been recalibrated to the number of km that can be driven with the energy recharged, assuming that the energy consumption in the winter (February) is 50% higher than in the summer (August) under Norwegian conditions (Figenbaum 2018).

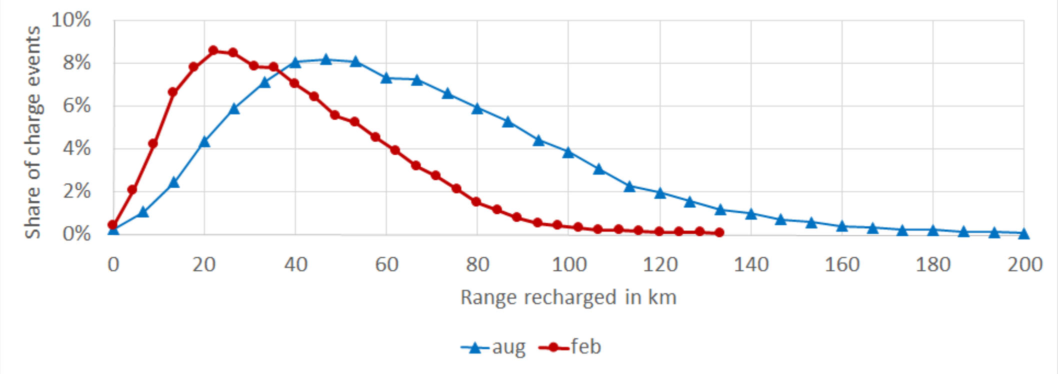

Figure 19. Energy charged recalibrated into range capability by share of charge events, August and February 2017. Dataset 1.

The difference between summer (August) and winter (February) is striking. One can however not know if the difference between winter and summer reflects a difference in trip types, or is merely a result of BEV owners fast charging to a specific SOC level regardless of energy needs. The former seems more likely as the cost of energy per kWh is about 4 times higher when fast charging than when charging at home. It also takes more time to charge in the winter than in the summer as seen by the variation in fast charge power between seasons.

Influence of ambient temperature (winter/summer) on the fast charge power

The average ambient temperature significantly influences the charge power, as seen in Figure 20 were the average charge power of users in December is compared to the average charge power in August. The reason for the difference is that batteries cannot be charged equally fast at low winter temperatures as at summer temperatures. The difference goes down the more kWh being recharged.

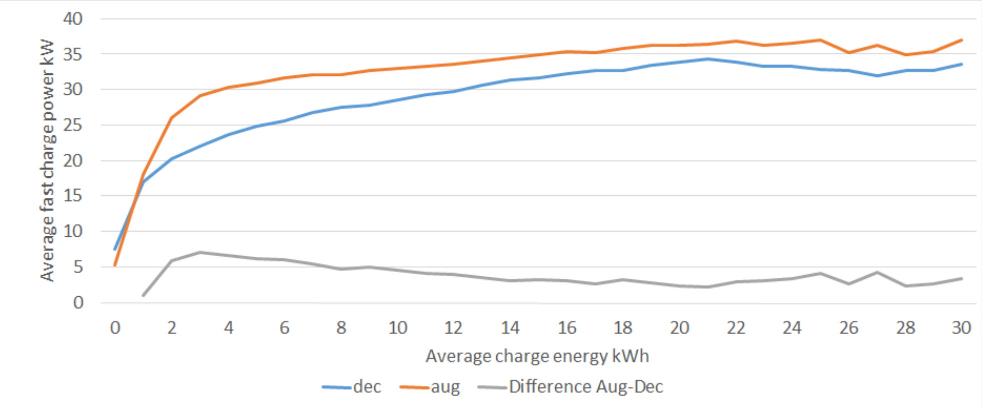

Figure 20. Average fast charge power (kW) versus average energy charged (kWh) for August and December, and the difference in charge power between August and December. 2017. Dataset 1.

If a user fast charges 4 kWh, the average power will in December be 24% lower than the power in August (the fleet composition can be regarded as stable for such short time frames). The difference decreases to 15% for users charging 8 kWh. The reason could be a combination of more advanced battery climate control systems in larger vehicles, and a gradual heating of the battery while charging. The difference stabilizes at 2-3 kW, and the average user will even in December achieve an average fast charge power above 30 kW when charging more than 12 kWh energy.

A reduction in the battery capabilities to accept fast charge in the winter is also clearly seen in the scatter plot in Figure 21 of the average fast charge power for users that fast charged both in January and in August, compared with a similar plot for August and July. The plot indicates a general reduced battery charge power acceptability in the winter across the BEV fleet. The energy charged and the time used for charging varies less systematic, although a tendency is for users to spend longer time charging in January.

Although the clear tendency for the majority of users is faster charging in August than in January, a large share of users also experiences the opposite, which could be related to batteries having heated up on hot summer days, which again would lead to a reduction in the power accepted by the vehicle. Other reasons could be differences in the battery SOC when starting and ending the charge.

Vehicles with more advanced climate control of the battery should not charge at significantly different power levels in the summer or winter, and are likely to be the vehicles that are close to the center line and in the upper part of the diagram.

Users of fast charging would actually have wanted faster charging in the winter than in the summer due to the increased energy consumption. To get 50 km range the average user would on average have to fast charge 14 minutes in the summer and 23 minutes in the winter. User will be able to drive 100 km between fast charges in the summer and about 70 in the winter (assuming the 60% SOC window that can be fast charged). Long distance driving with a short range BEV would therefore be rather impractical in the winter due to the added travel time when charging (Figenbaum and Kolbenstvedt 2015), and the risk of charge queues associated with multiple charge events. Over a year the saved energy cost in daily traffic could however make up for the added time cost on long distances, or users could also use some of the saved energy cost in daily traffic to rent an ICEV for long distance trips (Figenbaum 2018).

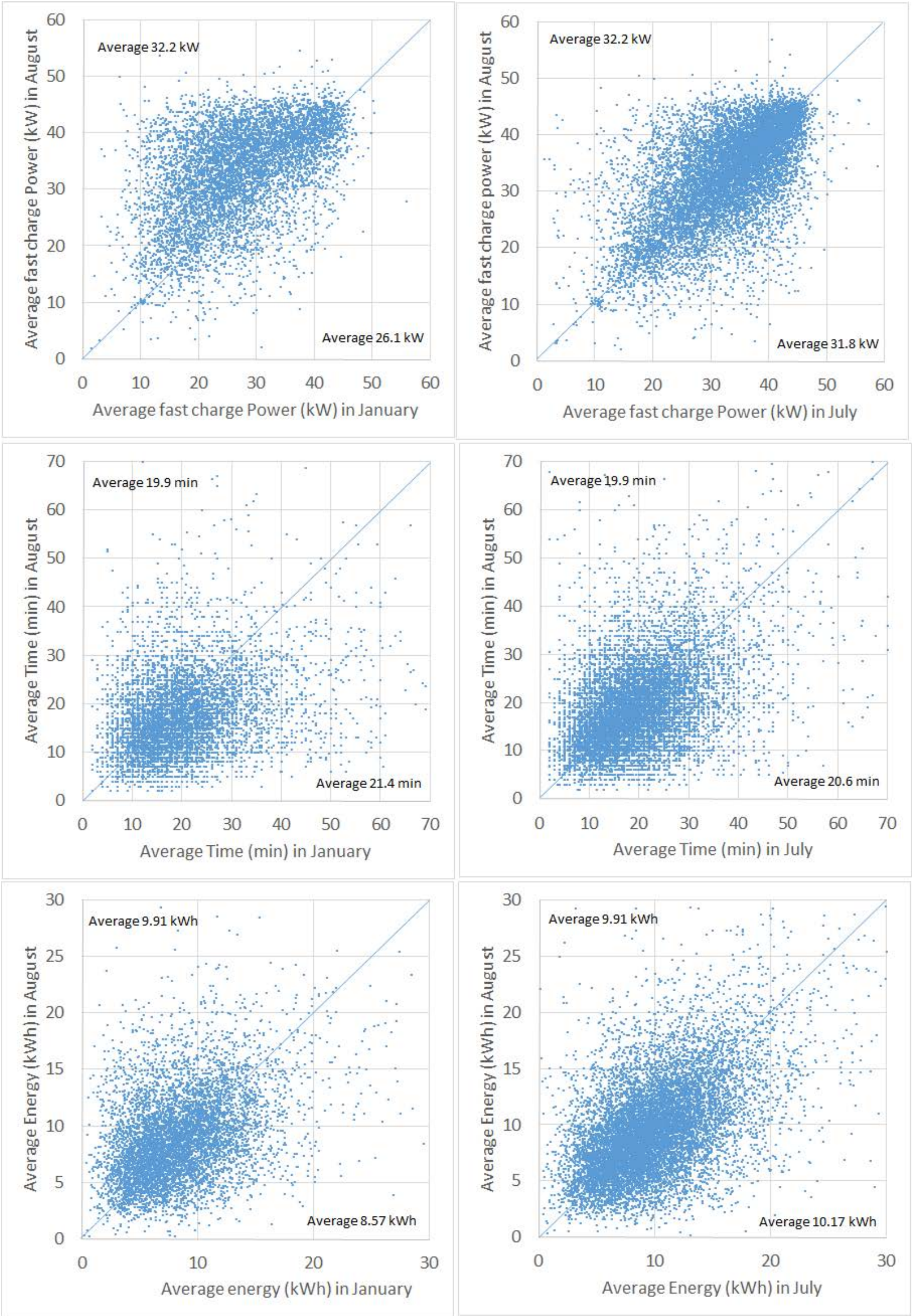

Figure 21. Scatter plots of users average fast charge Power (kW), Time (min) and Energy (kWh) for January vs August, and July vs August. 2017. Dataset 1.

5.4 Geographical variation in seasonal charging effects

The counties in Norway are very different in terms of population density, climate, and the size of cities as seen in appendix 1. These variations could influence the average charge time (min), the average charged kWh and the average charge power (kW) for users that use fast chargers. The main factors involved in such variations are likely due to differences in driving distances, distances to the next charging station, the presence of cities, and differences in ambient temperatures.

Table 7 reveals that users in counties with large cities charge less energy per charge event, and the average charge power is lower than elsewhere (apart from Nordland). Rural counties and counties with large roads with through-traffic have longer charge durations, more energy is charged and the average power is higher, as seen for Hedmark, Telemark, Vestfold and Oppland. Nordland has the longest charge times, and the average power is low. It is the county furthest north, with a tough climate, long driving distances, and mainly local users. The overall number of users is also smaller than for the other counties.

Table 7. Average charged energy (kWh), average time (minutes), average Power (kW) per county. 2017.

	Average Energy kWh	Average Duration Minutes	Average Power kW	Major cities
Akershus	9,2	20,0	29,9	Surrounds Oslo
Aust-Agder	10,1	20,0	32,2	
Buskerud	10,2	21,5	30,7	
Hedmark	11,2	22,1	32,2	
Hordaland	9,2	20,6	29,4	Bergen
Nordland	10,3	24,2	27,9	
Oppland	10,4	21,6	31,0	
Oslo	9,4	20,8	29,4	Oslo
Rogaland	9,1	19,9	29,9	Stavanger
Telemark	10,5	20,7	32,2	
Trøndelag	8,9	20,0	29,2	Trondheim
Vest-Agder	8,9	19,7	29,6	Kristiansand
Vestfold	10,3	20,3	32,3	
Østfold	9,8	20,1	31,0	
Norway	9,6	20,5	30,2	

Figure 22 shows the variation in the average values for energy charged, time used and power achieved between January 2016 and March 2018. The longest charge times, the smallest energy charged and the lowest charge power is seen in the winter months in all counties, i.e. Jan-Mar and Nov-Dec, as expected based on the overall results for the whole of Norway. The reasons for this has been explained in earlier sections as the batteries' inability to accept high power when cold. Another reason can be that users are not able to utilize as much of the range before having to charge as they can do in the summer.

The overall trend is that the average charged energy is increasing in all counties, which also is not surprising as the average battery size in the fleet has increased since January 2016. The charged energy reaches peaks in the summer vacation periods, likely users on long distance trips, and the charge time increases in some counties for this reason. The monthly data shows that users in Oslo and Akershus charge less kWh, use less time and achieve a low average power compared with users in other counties. Users in rural provinces such as Oppland and Hedmark charge more kWh, at a higher power, especially in the summer, than users in cities.

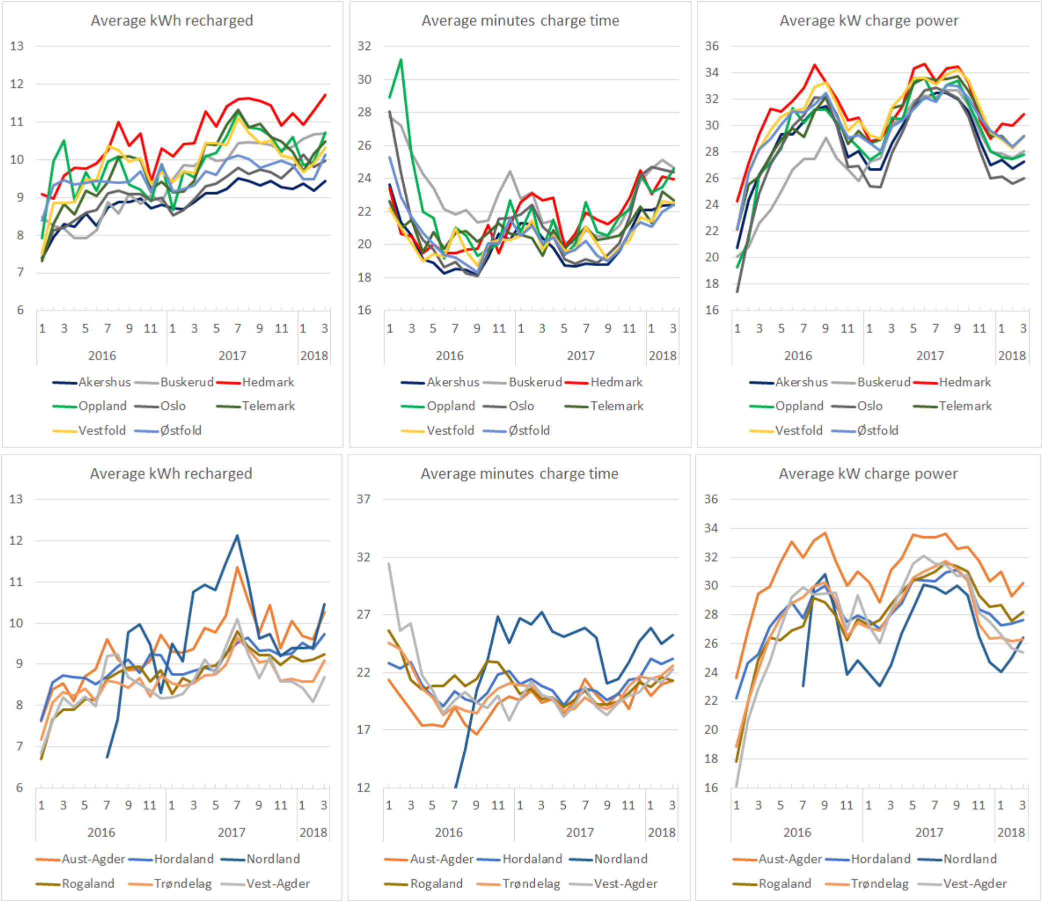

Figure 22. Geographical and monthly variation in average fast charge event characteristics. Dataset 1.

Dataset 2 provide a similar picture for charge time and variation in charge power, as seen in Figure 23, but a larger variation for kWh charged. The kWh charged was only available for a smaller subset of that dataset. The dataset is centered around the charging activity per plug per hour in use, not charge events, and is thus not directly comparable to dataset 1. For instance, the charged kWh is the average kWh delivered per hour the charge plug was in use. Since charge sessions can stretch out between whole hours, the result deviate somewhat from dataset 1. The variation between months and the overall trend between years is however possible to compare with dataset 1, and is rather similar in multiple counties.

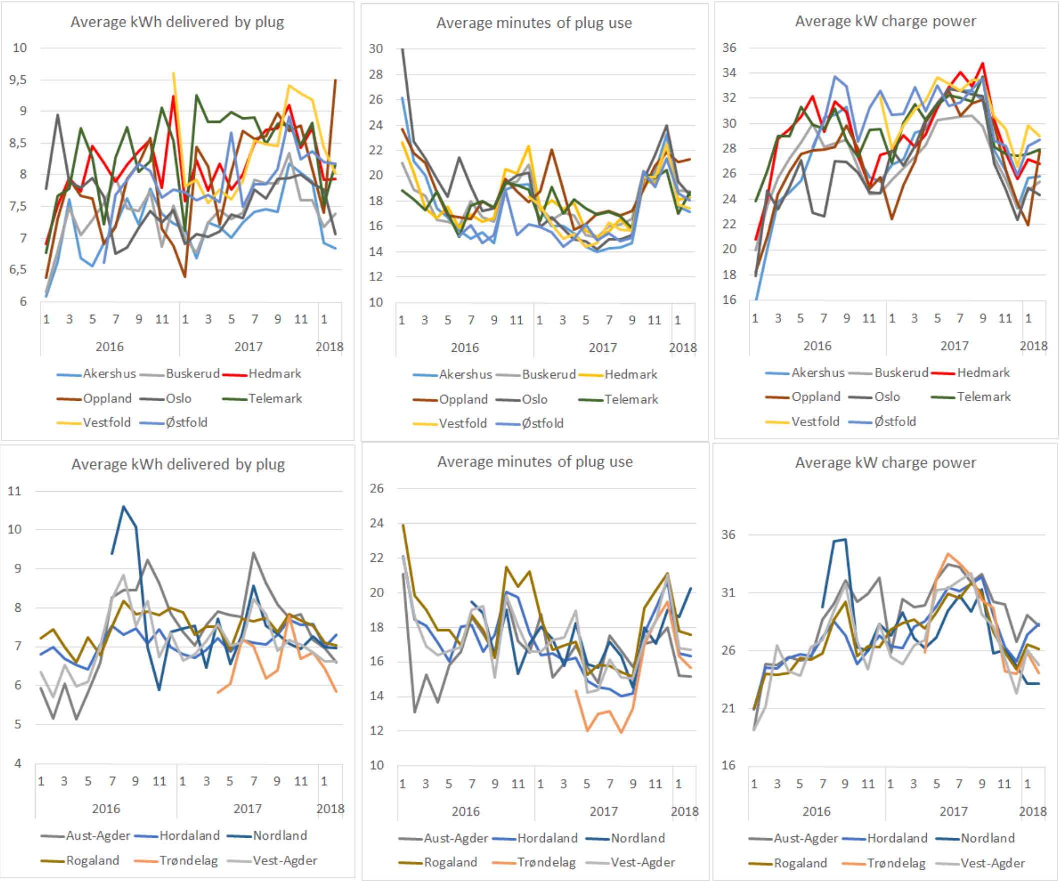

Figure 23. Geographical and monthly variation in average fast charge plug usage. Dataset 2.

5.5 Week number /weekday/vacation demand variation

The demand effects of holidays can be more clearly seen when the months are broken down into week by week plots of average power, time used and energy charged, as seen for some counties in Figure 24.

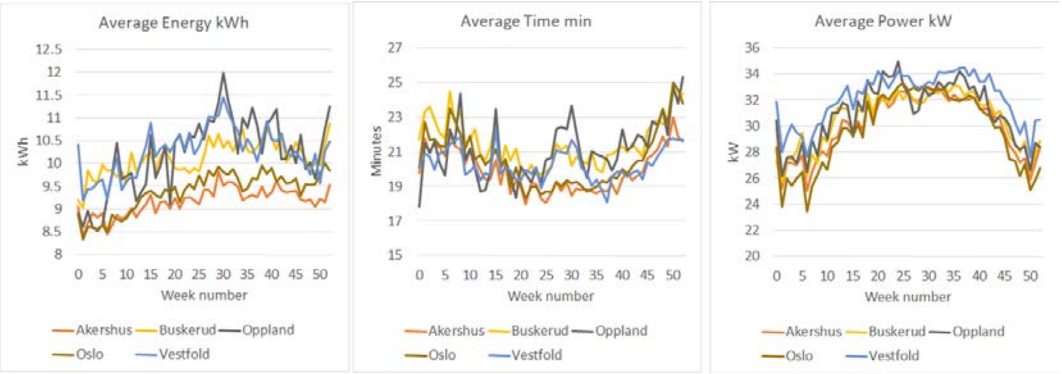

Figure 24. Weekly variation in fast charge energy, time and average power. Dataset 1.

The effect of holidays is seen in an increased average energy charged in the main summer vacation weeks (28-30), and in the peaks in weeks 8 (winter school holiday), 15 (Easter vacation) and 40 (Fall school holiday) for Oppland. Oppland is a typical winter vacation destination also attracting summer visits, whereas Vestfold is a more typical summer travel corridor. The average power is lower in Oppland in the peaks summer holiday weeks than the weeks before and after, which could be due to a potential battery heating effect in long distance high speed driving. Another reason could be differences in the fleet mix between seasons.

The total volume of minutes and kWh charged increases rapidly over the years due to the fast growth in the number of chargers and the vehicle fleet. Yet, a seasonal effect in the demand for fast charging can be seen for the relative variations in the number of fast charges per week and day of week, as seen in Figure 25 and Figure 26.

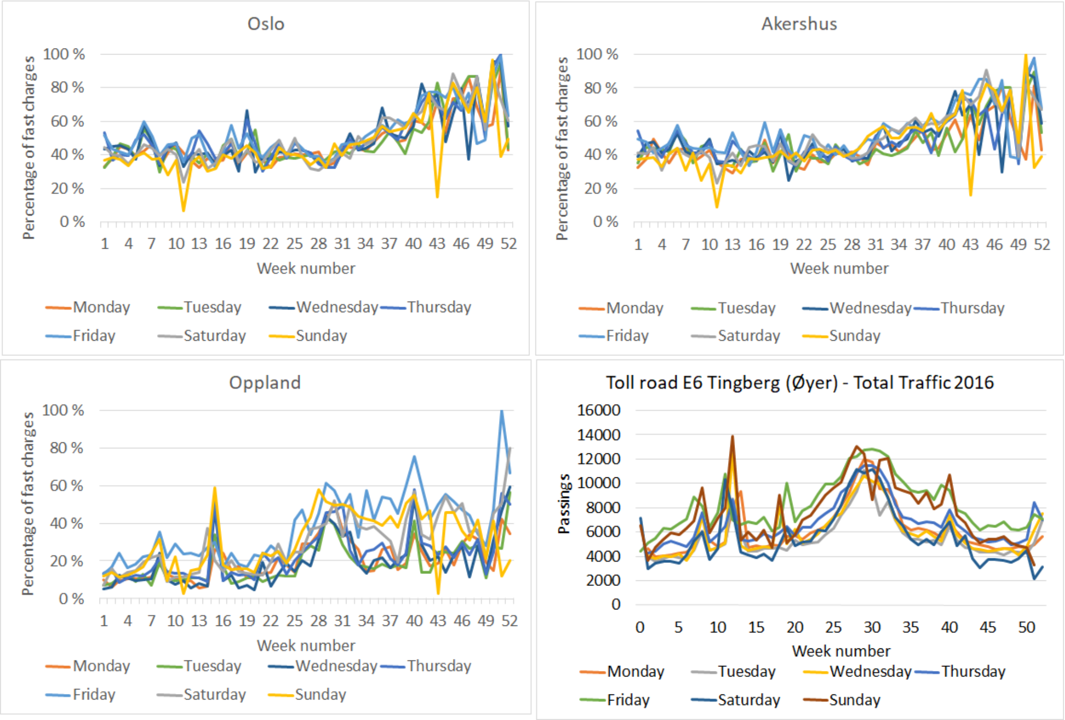

Figure 25. Development of charge volume over 2017 for three counties. Max value over year set to 100%. Dataset 1. Total LDV traffic flow (number of light vehicles) through a toll gate in the middle of Oppland province 2016 (Lower right, data not available for 2017). Source of toll road data: Toll road company.

The Easter, week 15 (week 12 in 2016), is seen as large spikes in the use of fast chargers in Oppland (shown in both figures, data from both operators) and in Hordaland. The same is true for week 40 which is a week with school vacation in many counties. The summer vacation weeks 28-32 can also be distinguished. Compared to toll road data from 2016 that shows the number of vehicles passing on the E6 main road in the province per day of week and week, the demand in the weekend traffic at fast chargers is higher in the fall than the toll road traffic pattern from 2016 should imply. Each BEV could however be needing more than one charge stop in Oppland to get to their destination, and the overall market could have increased. In Oslo and Akershus the variability of the demand is small over the year, apart from the general increase in the overall demand. The variability seen in these counties seems not to be due to vacations, as the demand is lowest in the summer vacation period.

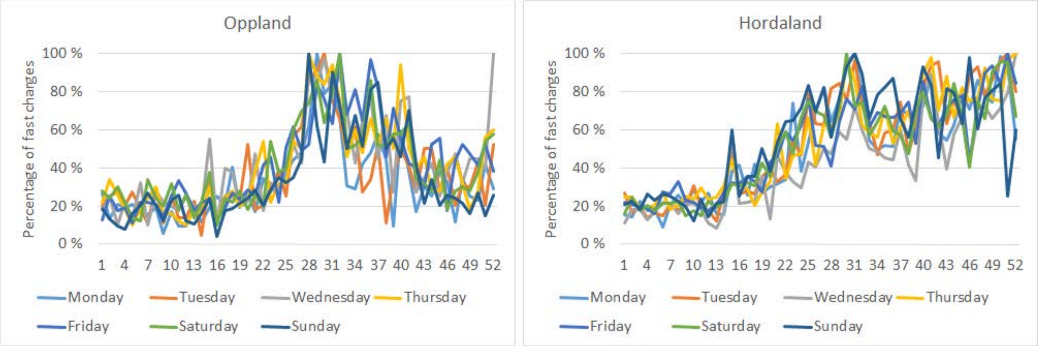

Figure 26. Variation of charge volume in 2017 for 2 counties. Max value over year was set to 100%. Dataset 2.

A large variation between counties in the fast charge demand between days of the week, could be related to variations in the daily traffic and weekend traffic flows. The demand for fast charging is in all counties fairly stable Mondays-Thursdays as seen in Figure 27. For Oslo and Akershus the demand is about the same also in weekends, which indicate that the users are mainly local, or there is a balance between local users on workdays and through traffic users in weekends.

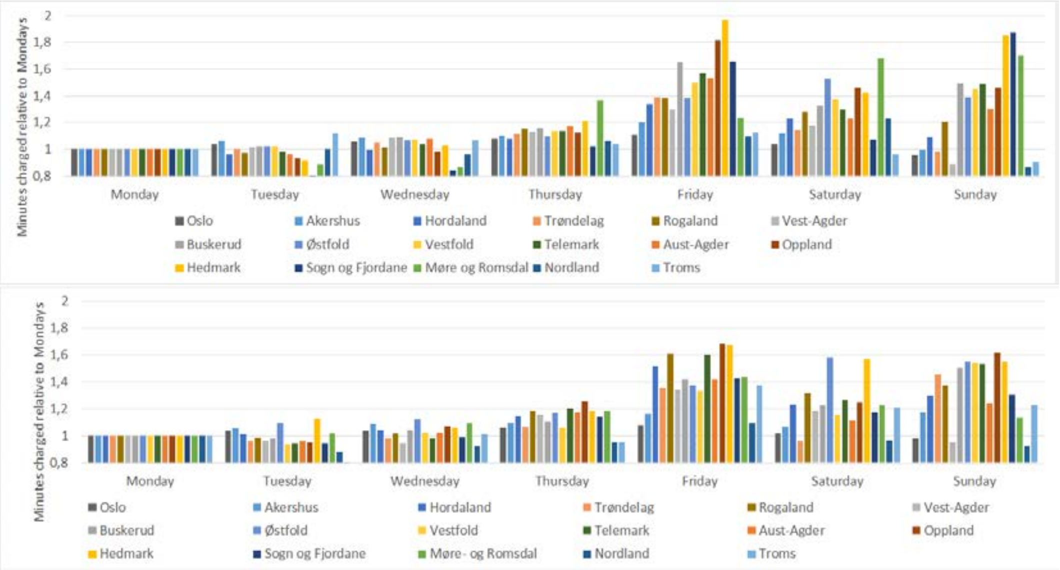

Figure 27. Minutes fast charged by province relative to Mondays. 2017. Dataset 1 and Dataset 2.

Oppland, Hedmark, Buskerud and Telemark have much higher demand on Fridays and Sundays than on Mondays, indicating a high share of weekend traffic from other counties. Østfold is the only province having the highest demand on Saturdays. Vest-Agder and Trøndelag have less demand on Sundays than on Mondays. Vestfold and Vest-Agder also have a fairly high demand on Fridays and Sundays. A large variation between local daily use and induced weekend use from elsewhere leads to a risk of either weekend charge queues, i.e. chargers are built out for local day to day use only, or low profitability, i.e. chargers are dimensioned for weekend and vacation traffic.

A strategy at the national level should be to achieve a better balance between local demand and through traffic demand. The current situation is that the share of BEVs is low in regions with large shares of through traffic, thus elevating the issue. Measures to increase BEV ownership in these regions would make the fast charger infrastructure better utilized and thus more profitable. A measure could for instance be to stimulate professional fleet usage.

5.6 Share of users charging more than once per day

Users doing more than one fast charge on one day are on long distance trips or driving extensively locally. The number of fast charge sessions per day can be split into users charging once, users charging twice, and users charging more than two times. The share that the latter two groups constitute in percentage of those charging on a given day is seen in Figure 28.

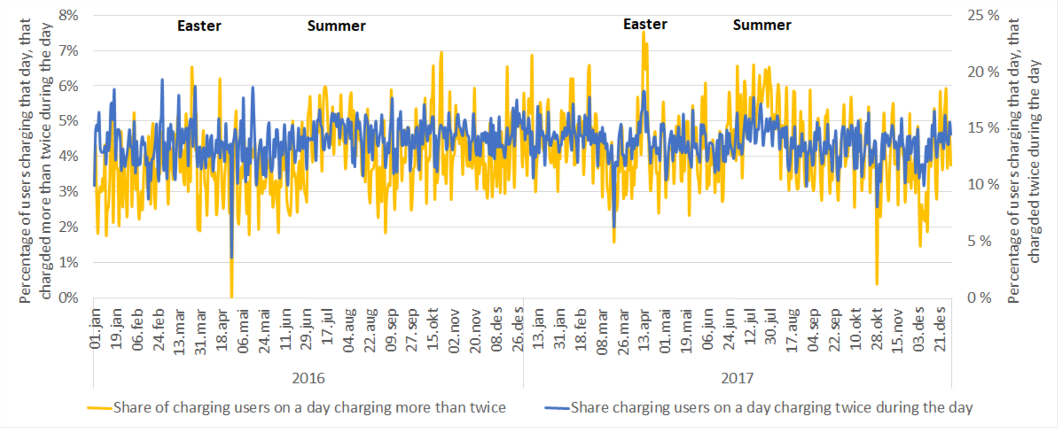

Figure 28. Share of users fast charging on a given day that fast charges twice and more than twice in the same operator network. Dataset 1.

These shares have been stable over the years with variations due to vacation periods. The share of users that charge multiple times per day goes up in vacation times, especially the share charging more than twice. This shows that there is indeed a small share of users doing quite long distance trips/travels also with shorter range BEVs during vacation periods.

The total number of users at any one point in time cannot be known in this dataset. If one considers all users that charged sometime during 2017 to be active users, then about 2.3% of active users fast charged on a given day at the end of 2017. Of these, 1.9% did it once, 0.3% twice and 0.1% more than two times in one operators network. Users can charge in multiple networks so this number only gives an indication of the overall situation. The situation is anyway likely to be very different for the next generation of longer range vehicles that are gradually introduced into the BEV fleet.

5.7 Intra-day variation in demand

The demand varies substantially over the day as seen in Figure 29. In most counties across both datasets, the peak hours of use on is between 15-17 in the afternoon, i.e. when people drive home from work. The peak hours during weekends can deviate somewhat from the general picture in some counties. Oslo and Akershus have very little variation in the afternoon peak between weekdays and weekends. In the other counties the peak is much higher in the weekend traffic (Friday-Sunday), and in most cases highest on Fridays and Sundays, as seen by the examples of Buskerud and Oppland. As the fast charge markets are more local in Hordaland and Rogaland their overall peaks are also associated with weekends, although less pronounced. The Saturday and Sunday demand for fast charging starts later in the morning than on weekdays. Some counties have a small peak in the morning traffic in the timeframe 07-08, which could be users that forgot to charge overnight. The Friday peak can potentially be a bigger challenge than the Sunday peak, when it comes to the willingness to accept charge queues. People are on Fridays heading for their weekend destinations in the same time period as the regular afternoon rush hour traffic. There is therefore a risk that the overall queues will be larger. Users could also be less willing to accept queues outbound than homebound.

A small difference between weekdays and weekends can be a proxy for primarily local induced demand, or that the local demand on workdays is balanced against local and induced (from other counties) weekend traffic, as for instance is likely for Oslo and Akershus. A large difference is an indication of long distance driving occurring in the province during weekends combined with low local demand on weekdays. Typical counties here are Buskerud, Hedmark (not shown in figure), Oppland and Telemark (not shown in figure). Hordaland, Rogaland and Trøndelag (not shown in figure) has the same weekday/weekend pattern, but as seen elsewhere in the report, the demand is mainly from drivers living in these counties.

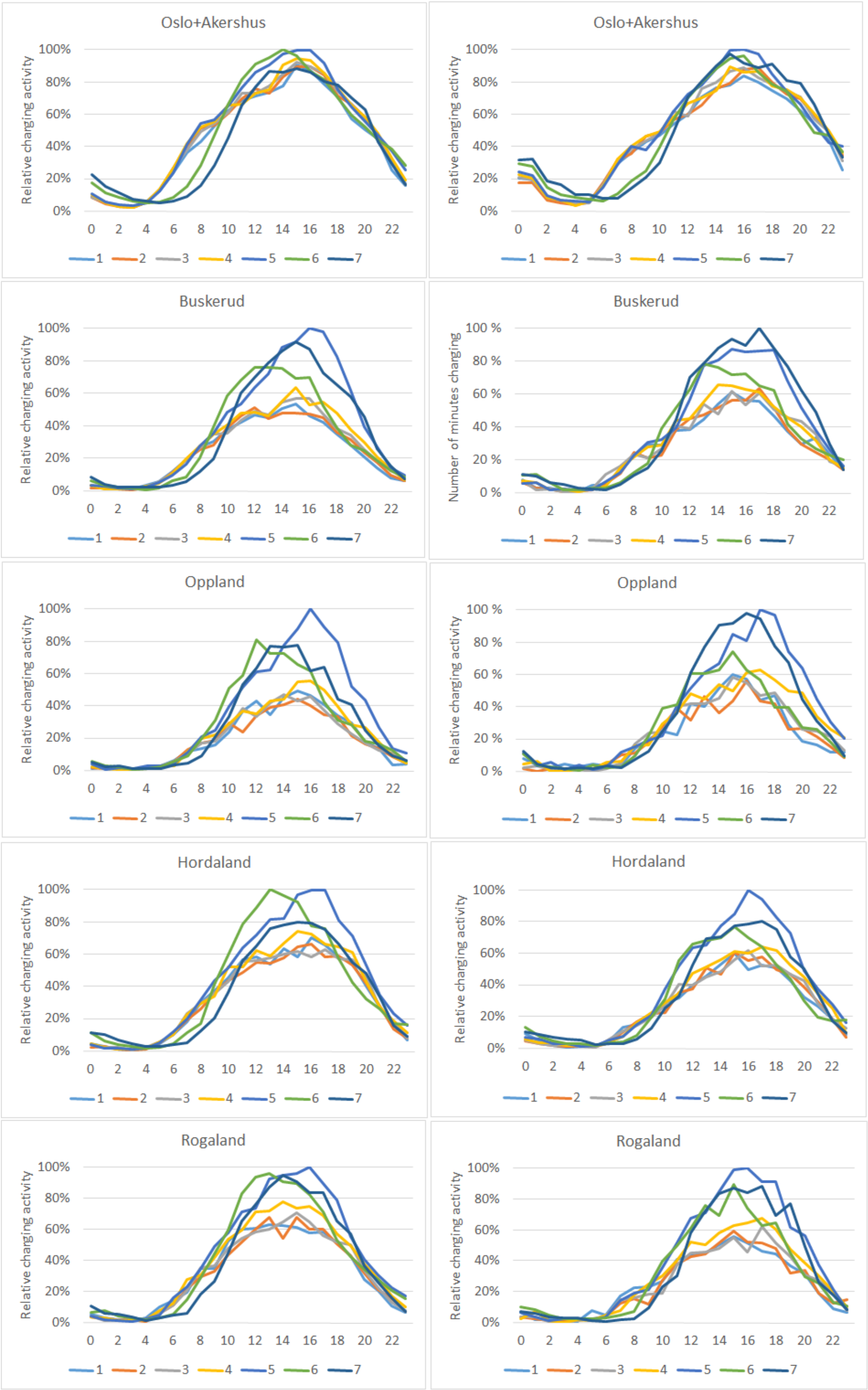

Figure 29. Average intraday (00-24) fast charge demand variation (minutes), Mondays-Sundays (day 1-7) per province. 2017. Datasets 1 (left) and dataset 2 (right). In each province the maximum data point has been set to 100%. In dataset 1 the minutes of charge has been attributed to the hour the event started, whereas in dataset 2 the charge minutes per hour per charger is the basis.

5.8 Demand variations due to charge site "Attractions"

The use of fast chargers could vary between locations. Chargers have been put up at fuel stations, next to fuel stations, at roadside Cafés, food stores etc. Any systematic differences in use of chargers between locations is interesting from an economic point of view. Income is proportional to charge times. So if users charge longer in certain locations, those charge operators will potentially make more money.

As shown in Figure 30, the differences in average charge time, average kWh charged and average charge power is small between fast chargers at Cafés, Fuel stations, Food stores and other types of shopping facilities (Centers, and specialist supermarkets), but they vary substantially across the counties. Shopping centre charge times are longer than the average charge time in all counties, but the average power tends to be lower, which could be an indication that people stay longer in the shopping facility than it takes to charge to 80% SOC.

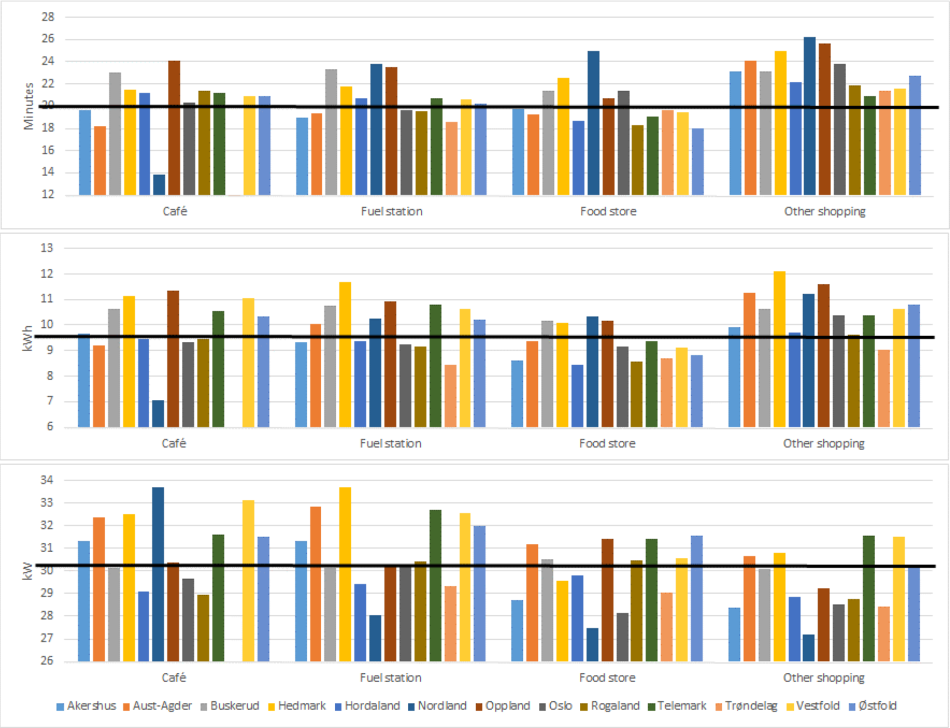

Figure 30. Variation in minutes and kWh charged, and power between 4 different location types.

The highest charge power is seen at chargers located at fuel stations or cafes (that typically are close to fuel stations). Food stores tend to be the locations with the least kWh charged. The variation between counties is in general large, so location within counties must also play a crucial role.

There are likely differences between weekdays for different locations. Shopping centers and auto-dealers are for instance not open on Sundays. Fuel stations should be more attractive in weekend traffic etc. The general picture is that the need for fast charging is lowest Mondays-Wednesdays in all locations, as seen in Figure 31. The use increases into the weekend, with Fridays and Sundays the days with the biggest demand, apart from in facilities that are closed on Saturdays and/or Sundays. Auto dealers is an example of the latter with less uses both days, shopping centers closed on Sundays is another. Fuel stations have the highest demand for fast charging Friday-Sundays. Food stores, fuel stations, shopping Centers and Cafés all have the highest demand on Fridays. Food stores have a higher demand on Sundays than on Mondays-Wednesdays, indicating that they also serve as corridor chargers supporting long distance travel. Even Shopping centers have a similar demand on Sundays as on Mondays, indicating that they also serve users travelling in corridors.

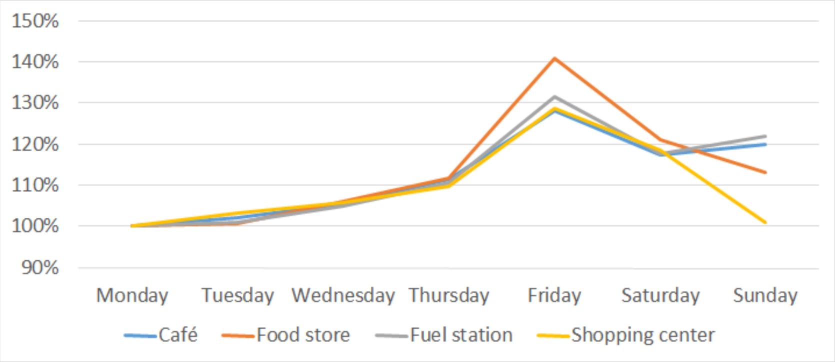

Figure 31. Variation in charge demand between weekdays and location types.

5.9 Fast charging variation – road types

Differences in average speed between different road types could lead to differences in average charge power or charged kWh. High travel speed could lead to hotter batteries that are less willing to accept high power charging, as well as a need to charge more energy due to the high energy consumption when driving on high speed roads. In addition, specific types of vehicles with longer range or faster charging capability could be over-represented in long distance driving. Further on, users could be more prone to do long distance trips in the summer than in the winter, leading to a difference across seasons, or to long distance trips on different roads in different months of the year. As seen in Figure 32 and Figure 33, there are clear indications of variations in charging behavior between road types.

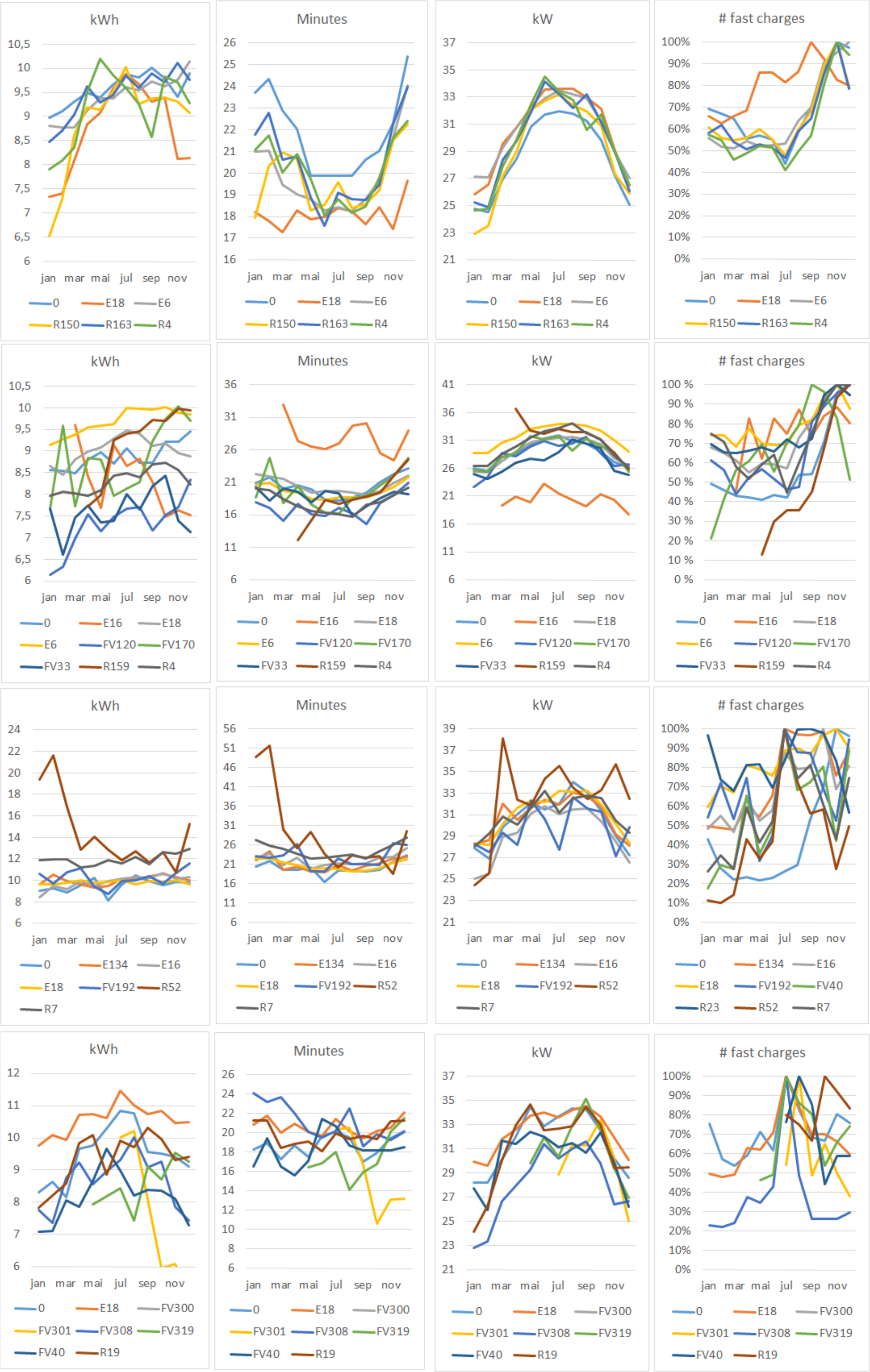

Figure 32. Top to bottom: Oslo, Akershus, Buskerud, Vestfold. Left to right: Energy (kWh), time (minutes), power (kW), development of number of fast charges.

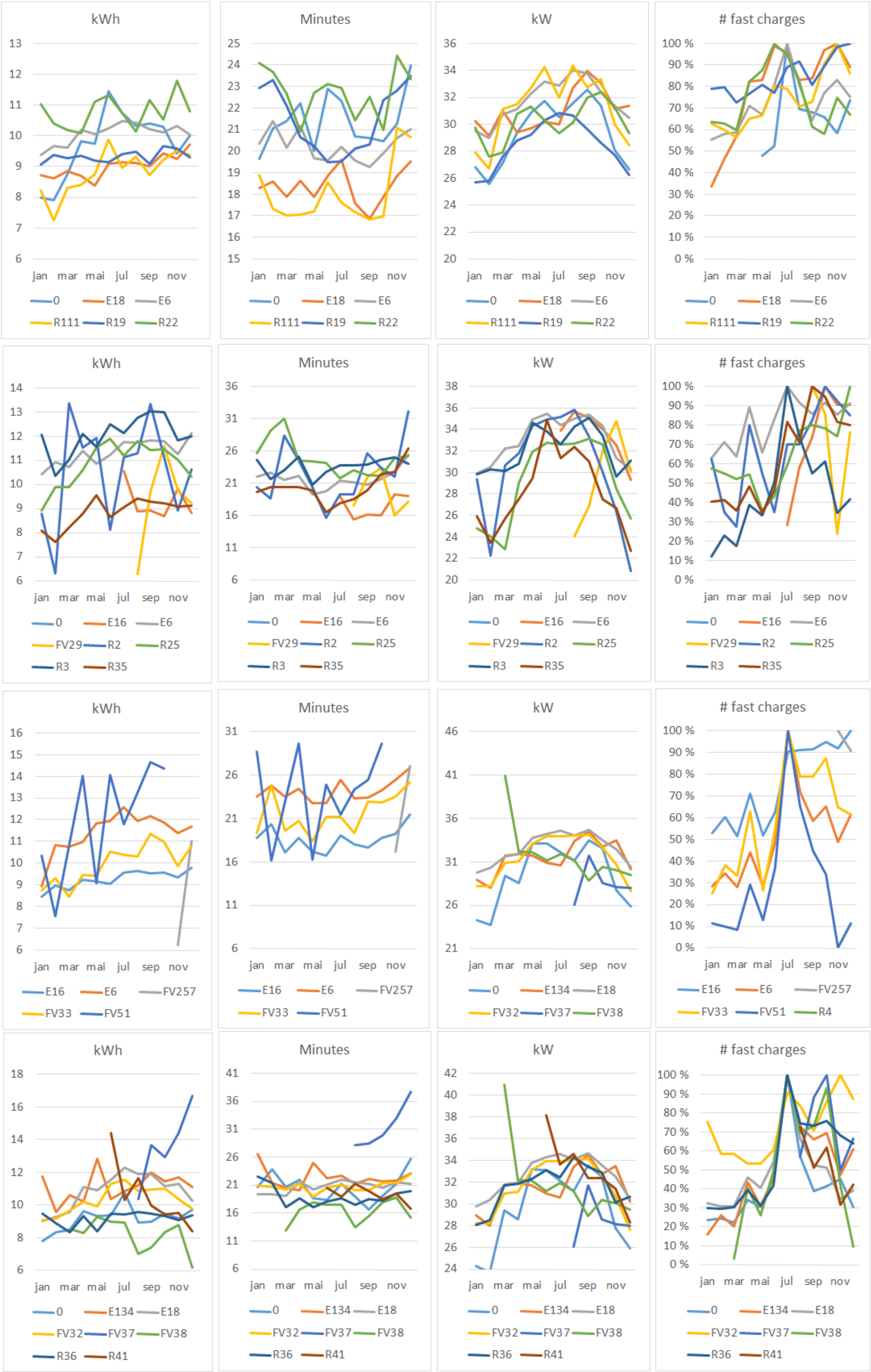

Figure 33. Top to bottom: Østfold, Hedmark, Oppland, Telemark. Left to right: Energy (kWh), time (minutes), power (kW), development of number of fast charges.

Two parameters are of special interest, the variation between different road types and the variation between seasons. Theoretically the high speed roads should have less variation in charge power between the seasons than low speed roads, because batteries will be hotter in the winter seasons than on lower speed roads and in cities. This seems to be the case as seen in Figure 34 when comparing motorway charging stations with other stations. One would also expect the average charged energy to be higher on high speed roads compared with low speed roads, as the vehicles will have a higher energy consumption and likely drive longer distances on these roads. This assumption is not supported in the data, as seen in the same figure. It might be that either the user does not need more energy, i.e. the use of fast chargers along motorways is also mainly done to support local travel, or the distance between fast chargers is longer on the smaller main roads than along the motorways.

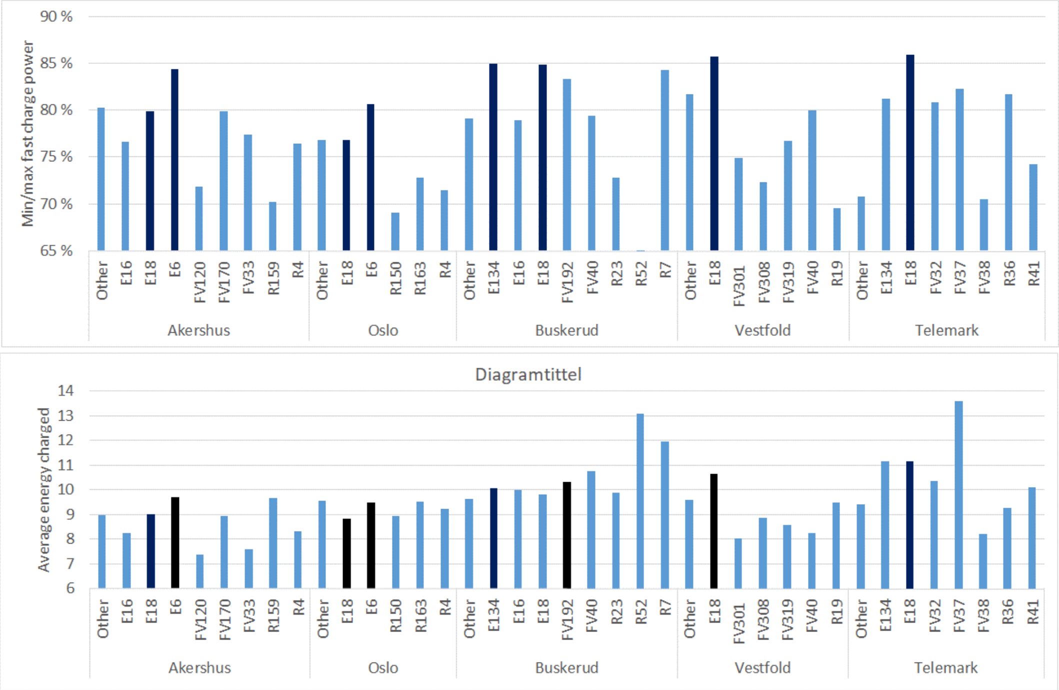

Figure 34. Variation between max and min average fast charge power per month for chargers along motorways (dark blue) and other main road types (top), average energy charged (bottom), 5 counties. E-roads: National mainroads/motorways. R roads: other national main roads. F roads: regional roads. Dataset 1.

Dataset 2 provided less conclusive data, see Figure 35. The part of this dataset that contained valid kWh data was much smaller than dataset 1 and the results are therefore uncertain. There are however some interesting similarities between the datasets. Charging along E134 has a small variation over the year in both datasets. The energy charged along R52 and R7 is the highest in Buskerud in both datasets with fairly small seasonal variation. E6 has the lowest variation within Akershus in both datasets. E18 has a much higher variation between the min/max values in dataset 2 than in dataset 1. The energy delivered is among the highest in both datasets in Vestfold and Telemark.

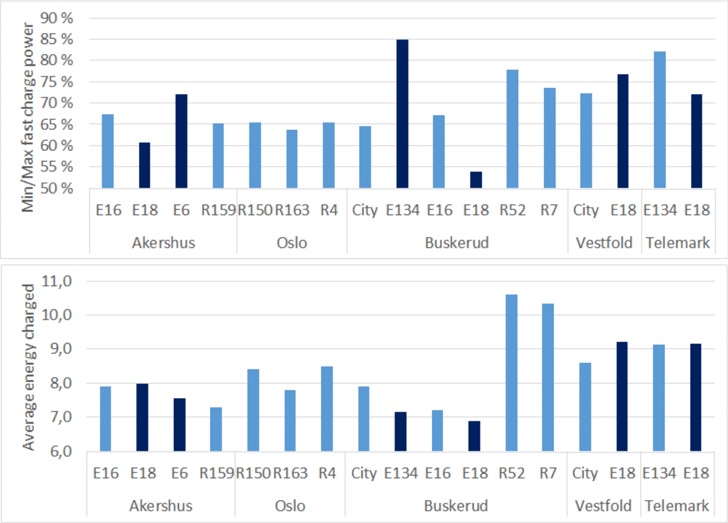

Figure 35. Variation between max and min average fast charge power per month for chargers along motorways (dark blue) and other road types (top), average energy charged (bottom), 5 counties. E-roads are national mainroads/motorways. R roads are other national main roads.. Dataset 2.

5.10 Variation in demand by individual users

Dataset 1 contained anonymous user-identification tags. It is not possible to know when the users that charged in 2017 bought their vehicles. They appear in the dataset the first time they charge, which could be much later in time than the date they started using BEVs. It is however possible to see how users that charged in both 2016 and 2017, charged in 2017. Then it is known that they were active users from 01.01.2017, and one can analyze their full 2017 year behavior. It can be assumed that these users remained BEV owners throughout the year as Figenbaum and Kolbenstvedt (2016) found that 88% will buy a BEV again, only 1% will not, with the rest undecided. The charging pattern of these users are likely to give a better understanding of how users charge over a year than if one analyzed the activity of all the users. This section therefore analyzes the charging behavior of this user group.

A large share of these users that charged in 2016 charged infrequently in 2017, as seen in Figure 36. A quarter only charged in one month, another 16% in two of the months. The median was 3 months and the average was 4 months. Only 5 percent charged in 11-12 months.

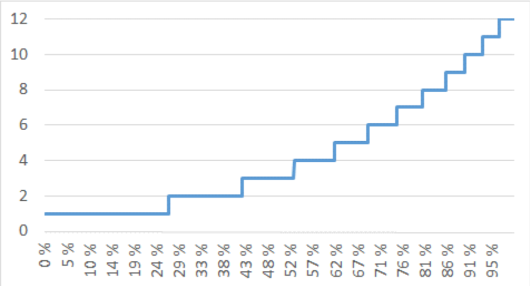

Figure 36. Number of months that users that charged both in 2016 and 2017, charged in during 2017.

Figure 37 shows the number of charge events and the number of fast chargers used in 2017 by users that also charged in 2016. The average user fast charged 13.1 times from 4.2 fast charge locations, located in 2.1 counties and 3.5 municipalities (calculated separately). About 35% charged only within one municipality, 49% only within one province, 20% charged only once, and 30% used only one fast charger location.

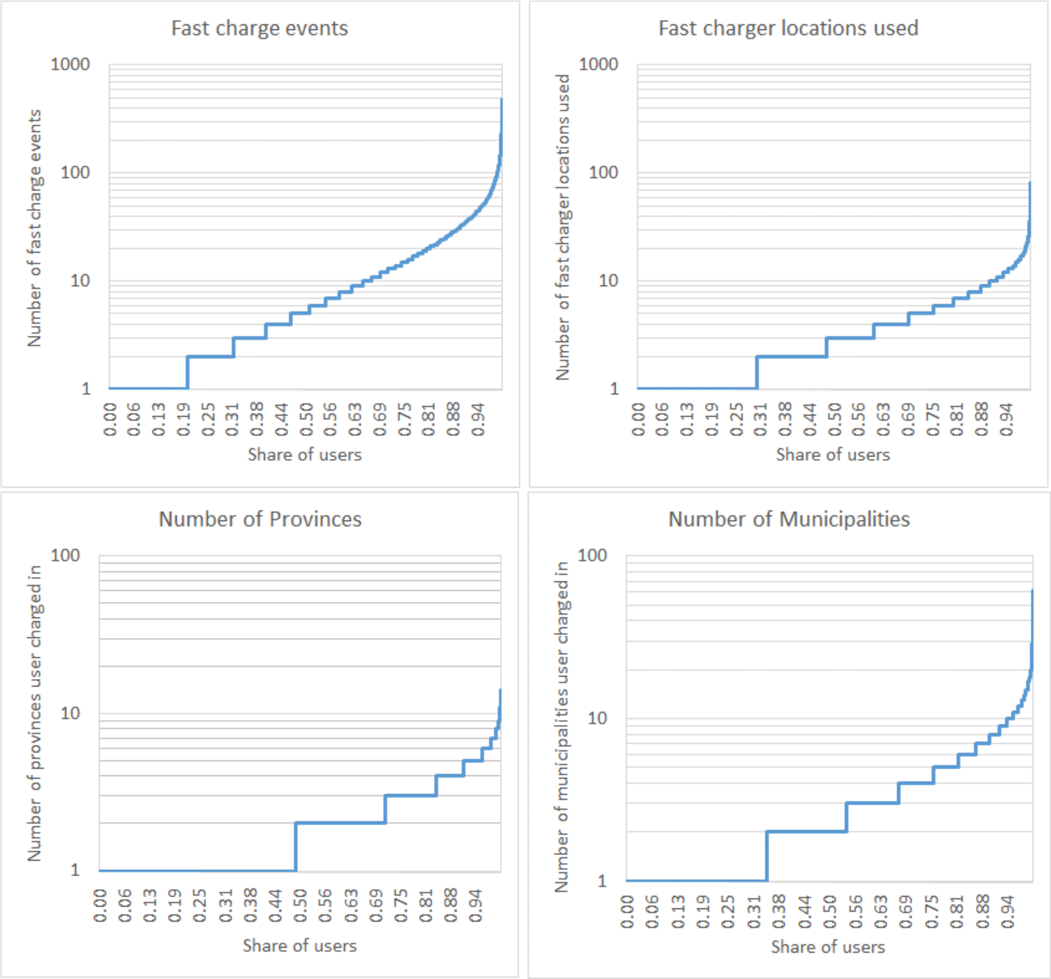

Figure 37. Number of fast charge events, fast chargers used in total, number of counties and municipalities fast chargers where used in during 2017 by users fast charging both in 2016 and 2017. Dataset 1.

Table 8 show the median values and the distribution of users. These users could however be using more than one operators network so it thus represents the lower bound of their charging activity.

The upper 5%, i.e. the 95 percentile of users, charge on average every month of the year, 48 times per year, from 13 locations in 5 counties and 14 municipalities. The average value of 13.1 fast charges per year for all users is heavily influenced by the small share of these super users, as seen by the large difference between median and average values.

Table 8. Spread of charging in 2017 for users that also charged in 2016, by number of charges, locations used, counties and municipalities charged in and months of active charging. Dataset 1

	Average	10-perc	20-perc	Median	80-perc	90-perc	95-perc	98-perc	Share rare/local
# of Charge events per year	13.1	1	1	5	18	32	48	80	20% charged once
# of Locations used	4.2	1	1	3	6	9	13	17	30% used only one charger
# of Counties charged in	2.1	1	1	2	3	4	5	7	49% charging only in one
# of Municipalities charged in	3.5	1	1	2	5	8	10	14	35% charged only in one
# of Months users charged in	4.3	1	1	3	7	10	11	12	26% charged only in one

The geographical variation in charging activity and users between counties for this user type is shown in Figure 38.

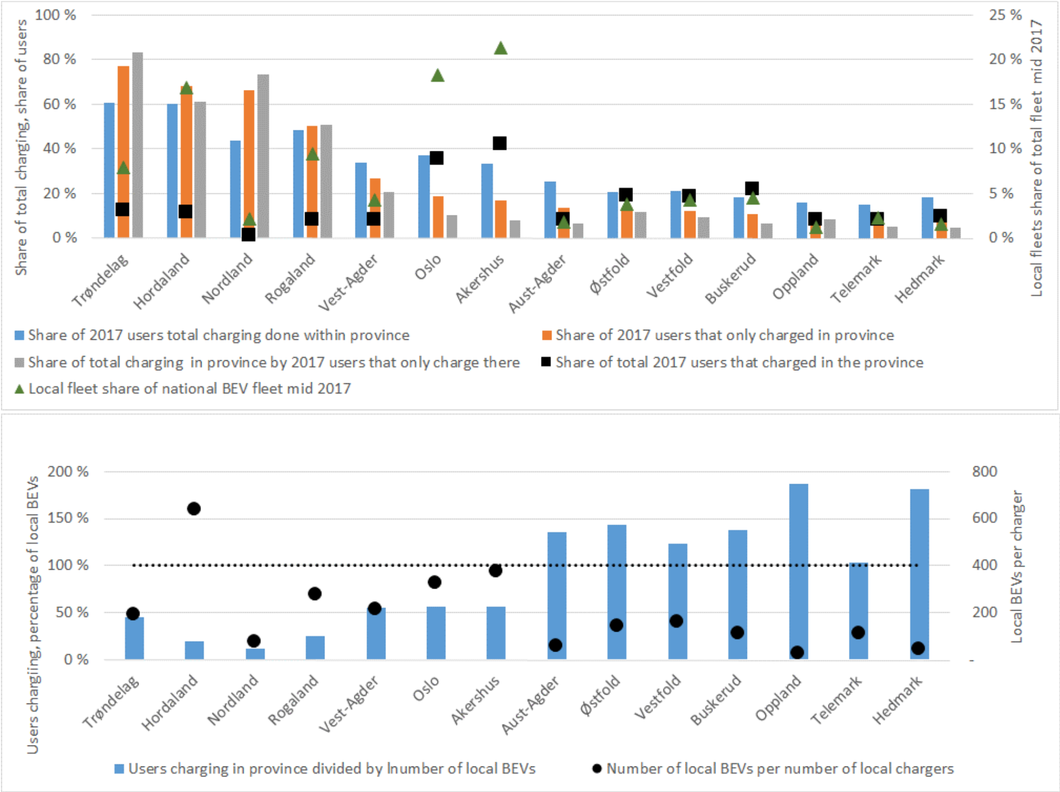

Figure 38. Share of users', i.e. those that charged within the county, total charging activity within that county, the share of these users only charging within that county, the share of the total charging activity in that county by these users, the share of total national users that live within that county, and the counties share of the national fleet (top). The number of users charging in the county divided by the number of BEVs registered in the county fleet, and the number of county registered BEVs per charger in the county (bottom). Users of chargers from the dataset are limited to those actively charging both in 2016 and 2017. Dataset 1.

An example can illustrate what the figure shows. Users that charged at least one time in Oslo during 2017 did 37% of their total charging within Oslo. 19% only charged within Oslo. For Trøndelag the shares were 61% and 77% respectively. For Trøndelag the users only charging in the province stood for 83% of the total charging. For Oslo the share was only 10%. Of all users charging during 2017, 36% charged at least one time in Oslo compared with only 12% in Trøndelag. Oslo is the home of 18% of all BEVs in Norway, whereas Trøndelag has 8% of the total fleet. When it comes to the number of local vehicles per local charger within each province in this operators network, Oslo has 325 whereas Trøndelag has 191. The share of users charging as percentage of the local fleet is 56% for Oslo and 45% for Trøndelag. It can thus be concluded that Trøndelag has, together with Hordaland, Nordland and to some extent Rogaland, mainly local users of fast chargers. Fast chargers need to be installed within these counties to cover these BEV owners' needs. This result is not surprising. BEV adoption is the highest in cities and surrounding areas (Figenbaum 2018, 2017). The geographical position of the cities within these counties is far from the borders of other counties, and their geographical extension is large (Basic data on counties is presented in appendix 1). Caution should be taken in the evaluation of the result for Hordaland because the operator has a fairly weak presence in that region.

Akershus is very much like Oslo. The more rural counties of Oppland, Hedmark and Buskerud have a large share of fast charge demand coming from users in other counties. The same goes for counties that typically have traffic coming in or passing through from other counties in vacation periods and weekends, such as Vestfold, Telemark and Buskerud.

Figure 39 shows how many other counties the users who charged at least once within the province, also charged in. The charts indicate, as Figure 38 do, that the fast charging markets in Hordaland, Trøndelag, Nordland and to some extent Rogaland, are mainly local. Users charging there rarely charge in other counties.

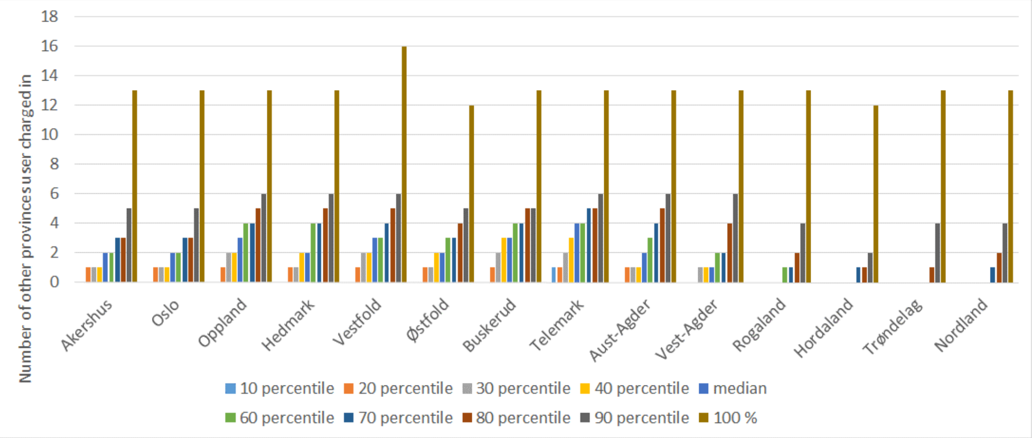

Figure 39. Spread of number of counties that users that charged in a province also charged in. Users that charged both in 2016 and in 2017.

5.11 Charge queues

Charge queues is a barrier to BEV adoption. Fast charging takes much longer time than filling liquid fuel and significantly influences the user perception of BEVs utility versus ICEVs. Charge queues are the result of large demand for charging occurring simultaneously. These charge queues have a spatial and a time dimension that can be investigated with the datasets used in this report. The question is where, when and why charge queues occur. If more than one charge session starts during an hour, it could be an indication of a potential charge queue building up.

The utilization of charging stations in the counties of Oslo and Akershus have been analyzed to find the reasons behind the development of charging queues. The results are presented in Figure 40.

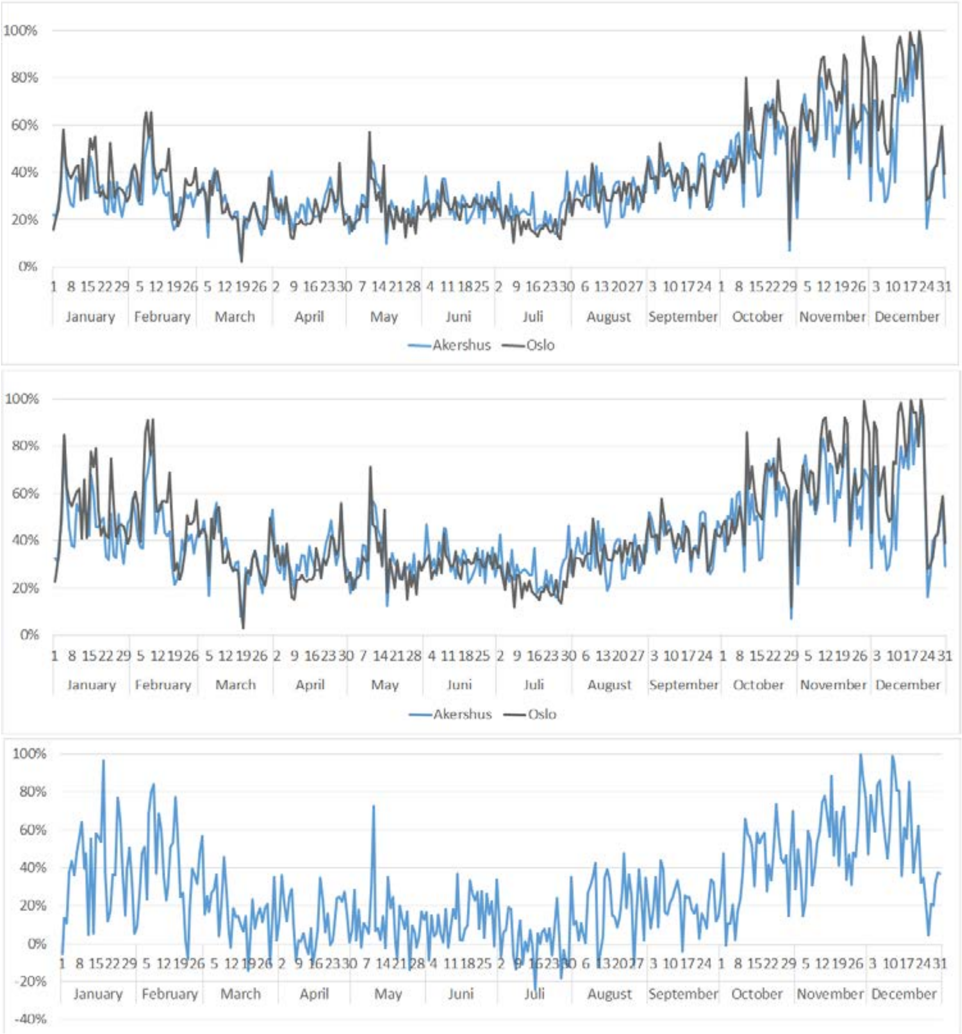

Figure 40. Annual variation in the share of the total hours of use where more than one fast charge is registered divided by the number of chargers in use (top), variation in the share of hours with more than one charge per charger without the effect of the increasing BEV fleet (middle), the difference between Oslo and Akershus in the variation in the share of hours with more than one charge per charger (bottom). In each graph 100% is set to the highest value over the year. Dataset 1.

The results suggest that there is increasing congestion at fast chargers in Oslo, due to and increased usage of fast chargers per vehicle and an increased number of BEVs in total and per charger. The increase in the winter season from October 2017 is larger than what was seen for the previous winter (January- March), which can be due to the increased cost in the toll roads from October 2017. The cost then increased from 35 NOK to 54 NOK for gasoline vehicles, and to 59 NOK for diesel vehicles. BEVs are exempted from these tolls.

There is also a large seasonal variation. This seasonal variation is much larger in Oslo than in Akershus, potentially due to long distance commuters needing a fill-up more often in the winter to be able to get back to their home base, or due to internal use in Oslo by for instance professional users such as craftsmen. The seasonal differences between Oslo and Akershus could also be attributed to BEV owners without home charging. They will likely fast charge more often in the winter than in the summer.

Hordaland with the second largest Norwegian city, Bergen, has in the dataset analyzed similar variation between seasons as seen for Oslo, but the overall level of queue potential is lower. The situation could be different for other operators. Vestfold and Østfold are also counties with some potential for queues in vacation periods. There are less queue tendencies elsewhere and the variation is more arbitrary, but often linked to national vacation periods with induced traffic from other counties.

For charging infrastructure operators, the main strategy should be to build out more capacity when the number of charge sessions per year reaches a threshold. Above this threshold the share of hours with more than one vehicle being recharged increases rapidly, leading to potential for queues to emerge. This threshold seems to be around 2000-3000 hours of registered use per year. Operators could also look at the rate of increase and the lead time for installing new capacity to find the optimum time to invest in more chargers per location or adjacent locations.

The time periods with tendencies of forming queues is from 14-16 in summer months and 15-17 in the winter month, as seen in Figure 41. This result is not surprising as these are the overall peak demand periods which coincides with the afternoon peak rush hours in the traffic flows.

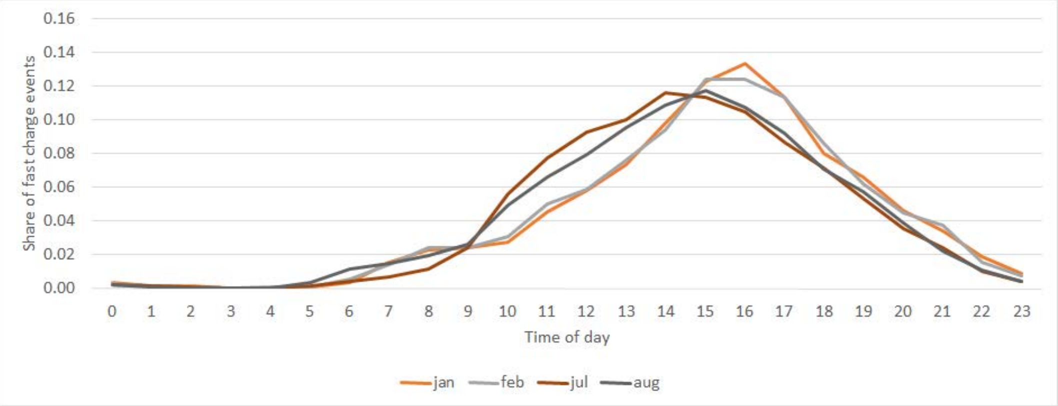

Figure 41. Share of hours with more than one fast charge by time of day, January, February, July, August. Dataset 1.

The development of charge demand per charger is shown for 2 counties in Figure 42.

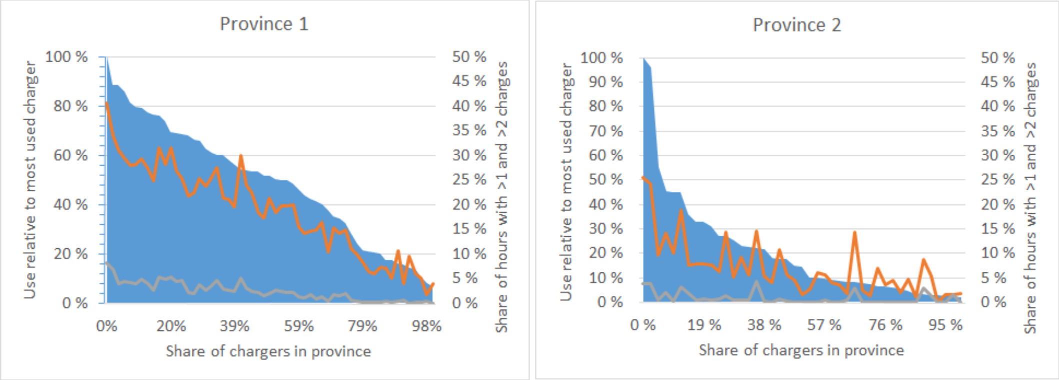

Figure 42. Chargers in decreasing order of use hours per year (blue area, 100% is set to the number of hours the most used charger is used), the share of use hours with >1charge started (red lines) and >2 charges started (grey lines), for two counties in 2017. Dataset 1.

Province 1 has a high overall demand and likely many chargers with potential for queues. Province 2 has a much more variable demand, but some specific chargers have a location that results in a fairly high share of hours with more than one fast charge being initiated, which is typical of counties with a small fleet of BEVs and a large vacation through traffic from other counties on main roads.

6 Results – User survey

The user survey contained a number of questions on long distance travel both for BEV and ICEV owners, and on BEV owners use and perception of the fast charger infrastructure. The goal of the survey was to establish a better understanding on how vehicles are used on long distance trips, especially on peak travel days, and how the network of fast chargers assists users travels. The user survey design is presented and analyzed in detail in Nordbakke and Figenbaum (2019). In this chapter, additional analysis on fast charging and driving behavior on long distance trips, is presented. Unless otherwise stated, all data have been extracted from the user survey.

6.1 Where and how often do people say they fast charge

The first question of interest in the survey is where BEV owners say they fast charge their vehicles. The result is shown in Figure 43, grouped by how the users have responded to three individual questions about fast charging use in (1) their own municipality, (2) the neighboring municipalities and (3) on long distance trips. Of the respondents, 15% did not use fast chargers in any of these locations, and the average number of fast charges is calculated to be 19 per year for non-Tesla vehicles. The number is heavily influenced by a low share of super users, and could be on the high side. It is possible that the super users are BEV owners without access to home charging. They could also be craftsmen or other types of professional users. In a similar survey in 2016 the question was phrased differently, and the result was a lower number of fast charges, i.e. 13-16 per non-Tesla BEV user/year (Figenbaum and Kolbenstvedt 2016), bearing in mind that the infrastructure was less built out then. It was most common to use fast chargers for a mix of local, regional and long distance trips among the respondents to the 2018 survey. The least common behavior was to use fast chargers only locally. About 17% said they never use fast chargers. The 2% of users that said they charge daily or 3-5 times/week, stand for 24% of the total number of estimated fast charges per year.

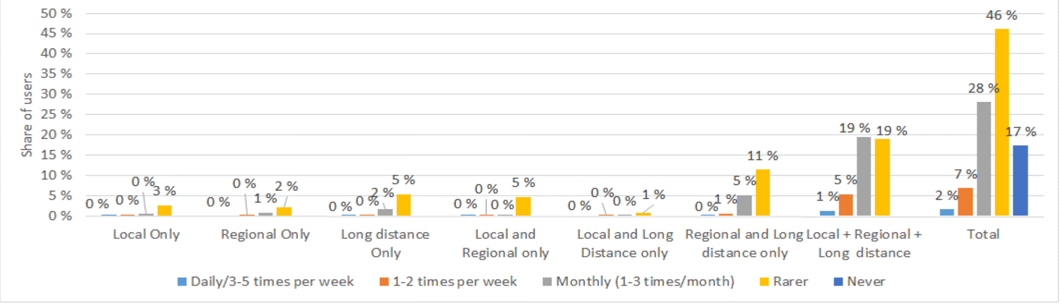

Figure 43. Where and how often non-Tesla BEV owners say they use fast chargers. n=2967.

Charge queues are most often experienced outside of the users own municipality, and in particular for long distance trips, as seen in Figure 44. However, most users experiencing queues only experience them sometimes, whereas 10-16% often experience them. Only 2% state that they always experience charge queues. The users that do not know are unlikely to be experiencing charge queues.

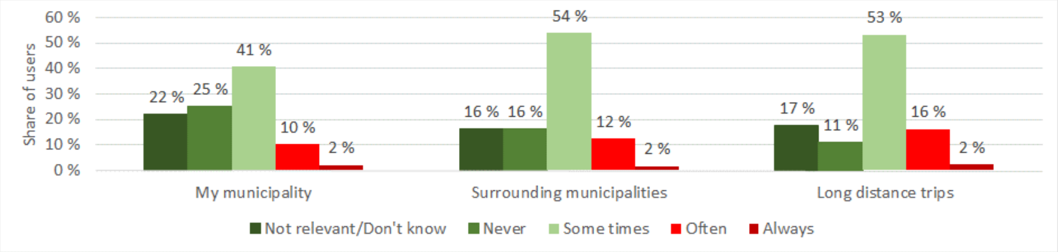

Figure 44. Where and how often BEV users (n=1471) experience fast charger queues.

6.2 Long distance travel

ICEV users do long distance trips more often than BEV owners in all trip length intervals apart from trips in the interval 100-199 km, as seen in Figure 45. A larger share of ICEV owners do long distance trips, especially the longest trips above 300 km. The share of users that do not do long distance trips is higher among BEV than ICEV owners.

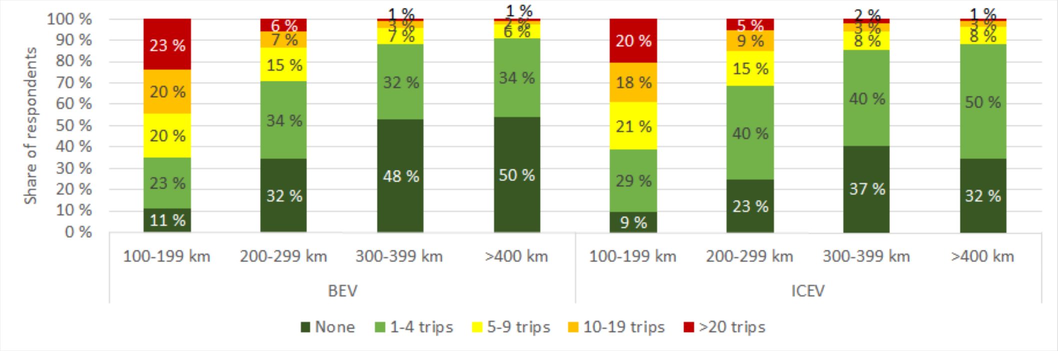

Figure 45. Number of long distance trips (regardless of means of transportation) per year by the share of BEV owners (n=3487) and ICEV owners (n=2048). User survey May/June 2018.

Long distance travel on peak travel days.

The biggest differences in the long distance vehicle based travel on peak travel days is seen in the summer vacation period when a much larger share of ICEV owners than BEV owners do trips exceeding 300 km, as seen in Figure 46. For all trip types the "not relevant" category is larger for BEV owners. One can assume that these responders are not doing long distance vehicle based trips in these time periods. The Easter, Winter and Fall vacation travel patterns are rather equal for BEV and ICEV owners, but a higher share of ICEV owners than BEV owners tend to do the longest distances in the Fall and Easter vacations.

Figure 46. Distance of the longest vehicle trip in the main Norwegian vacation periods by the share of responding BEV owners (n=3487) and ICEV owners (n=2048). User survey May/June 2018.

BEV owners were asked how long real world range they would need to embark on vacation trips with a BEV. The range required is longer than the range of most of the BEVs in the fleet as seen in Figure 47. The Tesla vehicles' range is in comparison about 350 km in the winter and 450 km in the summer (100 kWh battery), which is deemed acceptable by more than 63% of the users for summer driving and 50% for winter driving.

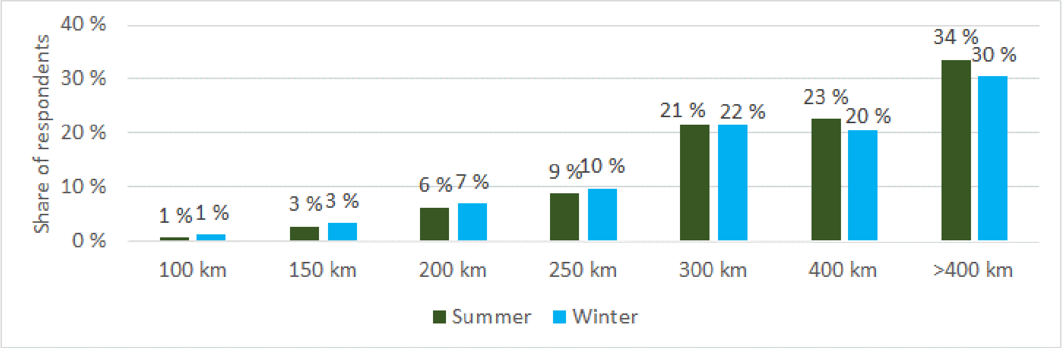

Figure 47. BEV owners (n=3487) assessment of the required real world range a BEV needs to have summer and winter to be able to use this vehicle type on "longer" vacation trips.

Figure 48 shows the number of charge stops and how long charge queues that users say they accept on long distance trips on days when many people travel at the same time. 1-2 stops and 5-20 minutes of wait time seems acceptable to over half of the users. The acceptable number of charge stops and wait time is likely influenced by what is reasonable to expect given the vehicle these owners have. The most surprising finding is the willingness to accept moderate charge queues up to 20 minutes on peak travel days.

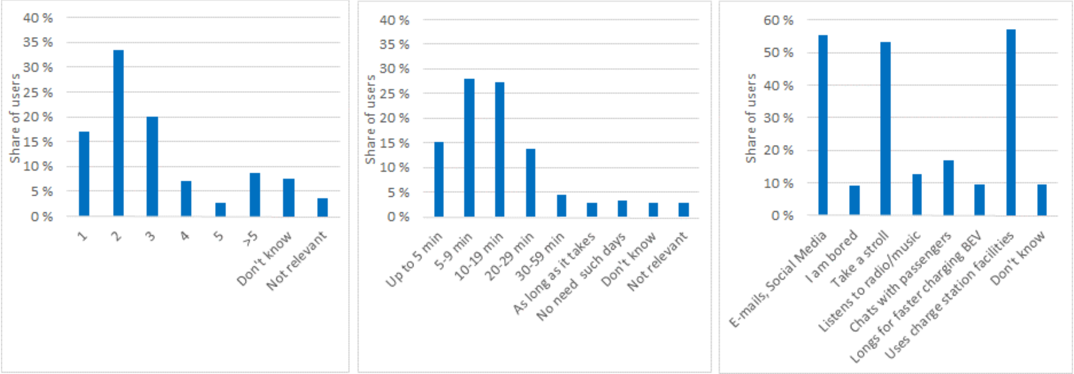

Figure 48. Number of charge stops that BEV owners (n=3095)_are willing to have on long distance trips (those that do trips >100 km within a year), willingness to accept charge queue length on days when many people are travelling at the same time, and activities that BEV owners undertake while fast charging.

People tend to use social media and e-mails, take a stroll or use the facilities at the charging station while fast charging, as seen in Figure 48. It might be a good idea for charge operators to offer free WIFI at the charge station so that people have something to do while charging, especially if the cellular network is poor. Locations with facilities of different types will be more attractive than locations with only fast chargers.

The willingness to change travel start time to avoid queues is rather limited. A third of the users will not change travel time or day, a third is willing to start earlier or later on the same day, and 7-8% would be willing to change travel day, as seen in Figure 49. The rest see no need to charge or the question is not relevant/they don't know.

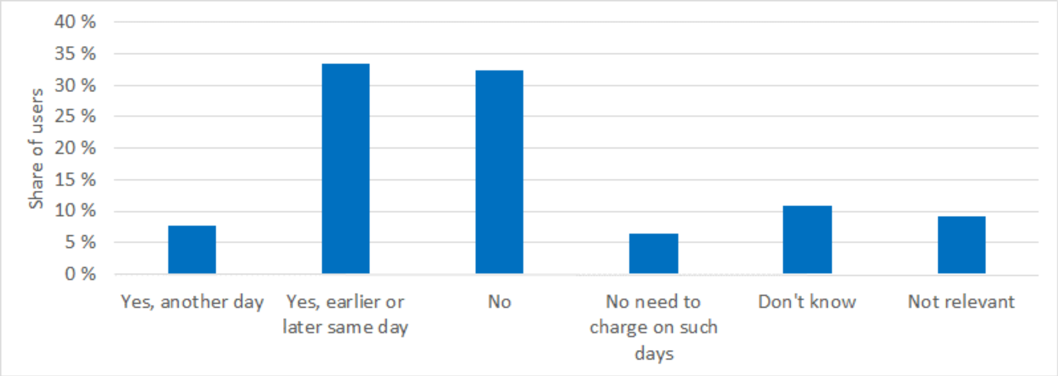

Figure 49. BEV owners (those that do long distance trips, n=3095) willingness to adapt the travel start time to avoid charge time queues (n=3095).

Users in general rate the availability, location, payment solutions, reliability and quality of fast chargers to be fairly good as seen in Figure 50, although 1 in 10 of non-Tesla users are not satisfied.

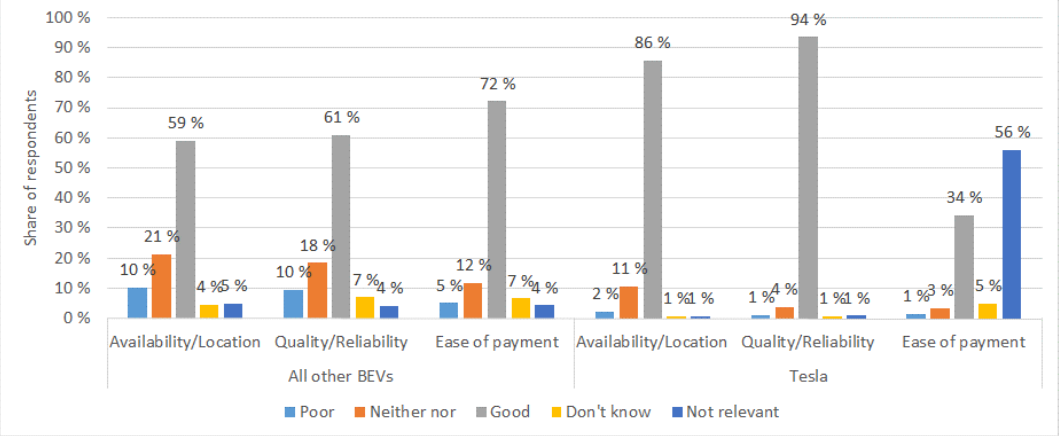

Figure 50. BEV owners rating of fast chargers availability, location, quality, reliability and ease of payment. (n=2494, of which 473 Tesla).

It seems that the ease of payment is rather well taken care of. All operators now offer a pay per minute solution through the use of an App, an RFID card or with an SMS message via the cellular phone networks. A large share of Tesla owners has answered not relevant on the ease of payment which is understandable, as most of them do not need to pay in the Tesla Supercharger network. Tesla owners rate fast chargers much more positively than the other BEV owners on all parameters. It is however a bit surprising that Tesla owners are more satisfied with availability/location than other BEV owners. Currently there are more than 500 locations for Chademo/CCS chargers versus less than 50 Tesla Supercharger locations. But, Tesla owners can drive longer distances before needing to charge, so fewer locations will be needed. Tesla owners can also get access to the 500 other locations by using an adapter for Chademo chargers.

Tesla do have an easier job in making the fast charge experience seamless, as they have control of the hardware and the software both in the vehicle and in the charger. They for instance already have a plug and charge system that automatically recognizes the vehicle. Such solutions will in the coming years be rolled out also in other fast charge operator networks.

6.3 Destination – Cabin

There are 431,000 (SSB 2018) cabins (and summer houses) and 32,000 houses that are used for vacation and recreational purposes in Norway. These cabins and summer houses are typically located in the mountains or seaside. A smaller share of these are located in woods and other rural areas. 58% of BEV owners and 51% of ICEV owners in the survey stated that they have access to cabins. Of these, 65% of

BEV owner can charge their vehicle at the cabin, while 35% of ICEV owners say that electricity for charging is or can be made available where the vehicle is parked.

BEV and ICEV owners travels equally often to their cabin, but ICEV owners more often has shorter, but also the longest distances to their cabins compared to BEV owners, as seen in Figure 51. One reason can be that BEVs are less common in rural areas where people tend to have shorter distances to their cabins.

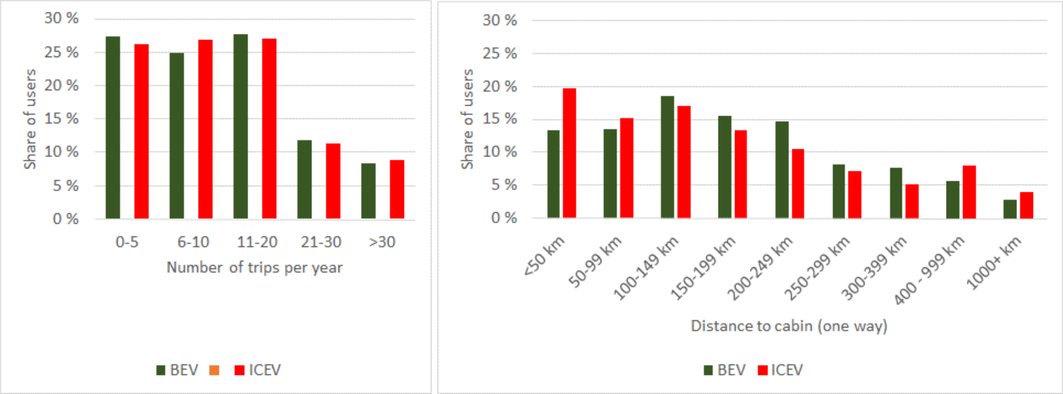

Figure 51. Frequency of use and distance to cabins. n_{BEV}*=2027,* n_{ICEV}*=1050.*

A share of BEV owners get to their cabins using their BEV, but it is more common to use another household vehicle (72% are multi-vehicle owners), as seen in Figure 52. If they use the BEV to get there, the dominant places to charge are at the destination and at fast chargers along the way.

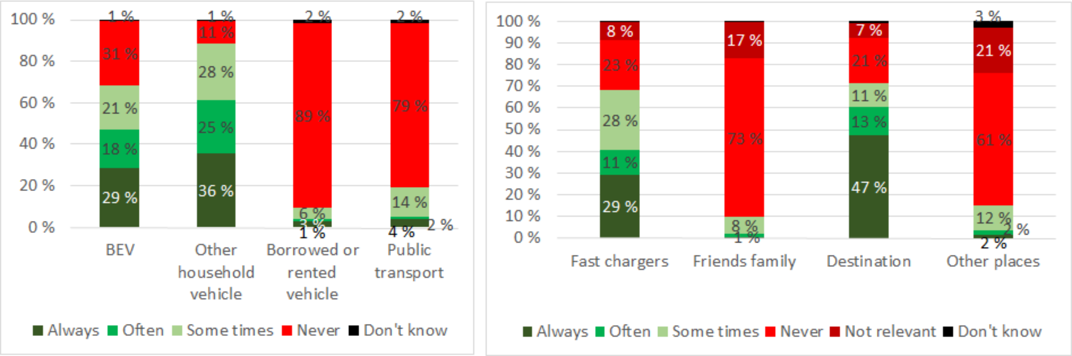

Figure 52. BEV owners means of transport and charge locations on the way to cabins (n=2027, except for other household vehicle n=1597).

6.4 User reactions to range and charge issues

BEV users were asked about range anxiety, charge queue stress and the risk of lacking access to chargers on long distance trips, as seen in Figure 53. The most interesting result is the small difference between single- and multivehicle households. It seems the BEV user experience related to these aspects are rather similar between these groups, although those with more than one household vehicle are less stressed by charge queues, but also somewhat less inclined to use the BEV for long distance trips due to charger access issues. The fleet composition could explain some of the differences although it is fairly equal among single and multivehicle BEV owners. The share of small and compact vehicle is 76% (single vehicle household) and 79% (multivehicle household). The Tesla share is 19% and 13% and the mini and small vehicle shares 20% and 25% respectively.

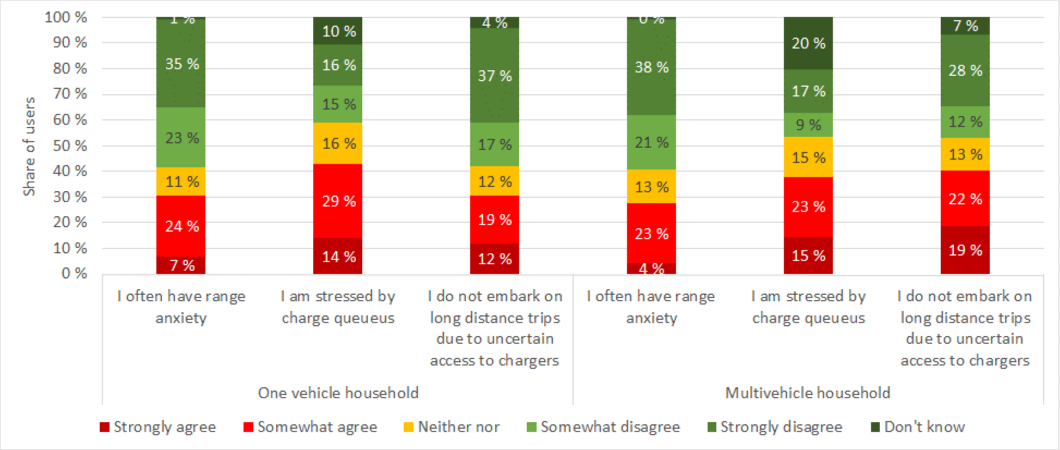

Figure 53. Range anxiety, charge queue stress and long distance charging access uncertainty among one- (n=965) and multi-vehicle households (n=2522).

7 Discussion

Fast charging is a complex socio-technical system where seven important parameters play a big role in the final result, as presented in chapter 3. These parameters are:

1. User needs for charging and user driving and charging 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 the time all vehicles charge
7. Charge queues built up from the total charge volume and the time dimension

Factors that based on the analysis in this report have an impact on these seven parameters, and the interactions between these parameters, are shown in Figure 54. An example of how these seven parameters interact is that the energy charged by a user depends on the average charge power if the time available for charging is limited. Another example is that the charge time for charging a certain number of kWh is determined by the achieved charge power.

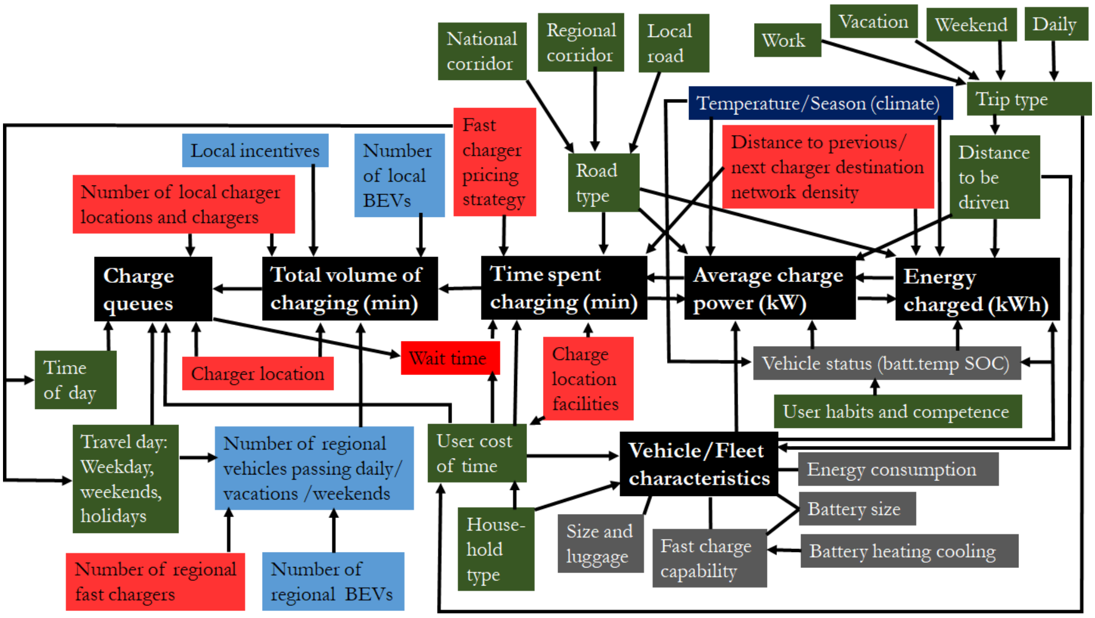

Figure 54. The fast charge landscape proposed as a result of the analysis in this report. Dark green are the user needs and habits that influence charging/vehicle choice. Black are the factors that determine the user interaction with, and perception of, fast charging infrastructure. Blue are factors 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 overall average charge power achieved in 2017 in Norway was 30.2 kW, the average energy was 9.6 kWh and the average charge time was 20.5 minutes. These numbers deviate substantially from the 50 kW nominal power of fast chargers, and the 15.5 kWh average battery capacity that should be possible to fast charge under optimal conditions and no time constraints.

7.1 User needs

The user needs is the core driver of the demand for fast chargers. The data from one of the fast charger operators shows that half of all users only charge within one province, and adding another province the share reaches 70%. Over 30% charge only within one municipality. The median user charges in two municipalities. 30% only fast charge in one location. The median is 3 locations although 2 locations covers 49% of user needs. 20% of the all year users in 2017, charged once and the median value was 5 charge events. These numbers, and data from the user survey about fast charging use, indicate that there are four fast charge archetypes:

1. Occasional user: likely use fast charger when they have a rare range problem
2. Local user: fast charge regularly to solve their everyday needs
3. Long distance trip user: fast charges to get to far-away destinations
4. Frequent user: people without home charging or professional users

Occasional users charges 1-2 times per year and make up about 30% of the users. About 10% are Frequent users. They charged on average more than 32 times per year in many different locations in different counties. The split between the remaining two categories is not possible to calculate, as there is no information in the dataset about where they live. The user survey indicate however that it is uncommon to only fast charge in the users' own municipality, so many BEV users can be a combination of these two user types.

The market is split in different regions, as seen in Figure 55. The South-East of Norway is one common fast charge market where most users charge within several counties. The markets in Trøndelag, Hordaland, Nordland and Rogaland are mainly separate and local.

The user analysis indicate that a wide network of chargers is needed in all counties to cater for the needs of different users. That leads to a need for a coverage oriented deployment of fast chargers. In 2018, ENOVA introduced a coverage oriented support program for the deployment in municipalities that do not yet have fast chargers. While the earlier main road fast charger network support

Figure 55. Charge regions in Norway. Green: South East, Red: Rogaland, Blue: Hordaland, Orange: Trøndelag, Grey: Nordland, White: Low use areas

program of ENOVA was designed to support travels across Norway, it also led to fast chargers being installed in or close to smaller cities along these travel corridors. These city corridor chargers therefore also support the local diffusion of BEVs. In areas with large BEV fleets in and around the largest cities of Norway, the deployment is demand driven without public support.

7.2 The BEV fleet technical characteristics

The characteristics of the BEV fleet heavily influences the use of fast chargers, mainly through the ability or inability to accept fast charge under different conditions, and the utility that different BEV models offer for long distance driving. The use of passive battery thermal management systems is a challenge in cold climates as the batteries have poor fast charge acceptance when they are cold. Another issue is the gradual heating of the battery when driving longer distances at higher speeds. In the end the battery can be so hot that the fast charge capability decreases.

The smallest BEVs are little used for long distance driving as most owners of these vehicles also owns an ICEV that can be used instead.

7.3 Energy charged

The energy that can and is recharged depends on a number of conditions. Considerably less energy is being fast charged than what is theoretically possible. The most important factor is the distance to be driven, which again will depend on the trip type. The distance to the next fast charger or destination (or from the previous charger/start point), i.e. the density of the charger network along the route, also influence the user needs for energy on long distance trips.

The energy consumption of the vehicle is an important factor together with the status of the battery at the start of charge and end of charge, which is influenced by the distance to be driven, and user habits and competence.

Other factors include when and where the trip is done, i.e. if it is the winter or summer season, and the type of road the user is driving on, and the topography along the route. In the winter, many vehicles limit the cabin heat output when the SOC is low. Users are therefore likely to start the fast charge at a higher SOC in the winter than in the summer. Long distance drivers are also more likely to charge beyond 80% SOC in the winter than in the summer, to be certain to reach the next fast charger. The difference in the average kWh recharged between winter and summer is however fairly small in the datasets. The average charge power may influence how much energy is charged if the user has limited time.

7.4 Average charge power

The average charge power mainly depends on the vehicle type and the vehicle's fast charge capability, which again depends on the battery heating and cooling system, and the size of the battery. The seasonal effects are very large, with a difference of about 4.8 kW in the average achieved power between summer and winter. The high dependency on ambient temperature is likely due to the fact that 64% of the non-Tesla vehicles in the Norwegian BEV fleet have passive battery thermal management systems. These vehicles are therefore more influenced by ambient temperature. The status of the battery at the start of the charge (SOC and temperature), and the point where the users ends the charge (SOC), are also important parameters. These parameters are influenced by the user habits and competence, but also the needs for the actual trip to be undertaken, i.e. the distance to be covered. Users may for instance need to continue to charge beyond 80% SOC to be able to reach the next charger or the destination. This behavior would lead to a large reduction in the average charge power. Some might also be charging past 80% SOC as a precaution in case the fast charger in the next location is not operational. The short range of most BEVs in the fleet means that this issue is likely to be a major contributor to the low average charge power for the fleet. This issue is more important in the winter season. The vehicles then have a much higher energy consumption, and users may not be able to use the lowest end of the SOC efficiently, because the cabin heat output is reduced at low SOCs in many BEVs. A denser network of fast chargers along major roads will reduce the need to charge beyond 80% SOC.

The fast chargers from different producers can potentially have different abilities to deliver the full fast charge power under different ambient temperatures. Trentadu et al. (2018) found for instance that one fast charger type had a lower fast charge power output under some conditions than other chargers had. The same vehicle was used in these tests and the test conditions were the same for all chargers. The maximum fast charge power was however above 45 kW for 94% of the fast charger units in use in dataset 1 analyzed in this report, so this issue is not a primary reason for the low average fast charge power in Norway.

The road type is another parameter that can influence the average power. High speed roads may lead to higher temperatures in the batteries, which could be good for the charge power in the winter, but bad on warm summer days. The datasets are inconclusive on this issue. If this was an issue one should see less variation summer to winter on chargers along main roads, but the datasets do not prove conclusively that this is the case.

Finally, the time available to charge also influence the achieved fast charge power over the charge session. Longer charge times increases the achieved power calculated from the dataset, likely because batteries heat up during winter charging and thus accept a higher power. The effect is seen as a continuous increasing power up to above 20 kWh of charging, thus indicating that heating up is the major effect. An added effect is that vehicles with longer charge times on average are likely to have larger batteries that will accept faster charging than vehicles with smaller batteries.

Consumers should be given advice on how batteries work in practice and how the fast charge power they get from fast chargers can be increased. It is for instance in cold climates better to charge the vehicle immediately after a trip. The battery temperature will be higher and the vehicle will accept a higher fast charge rate.

Professional users such as taxi drivers and craftsmen should also be made aware of the importance of temperature for the speed of fast charging. Slower charging means less income to these groups. Taxi vehicles are however used frequently during the day, and the batteries will therefore likely be warmer than the batteries in a vehicle used by a consumer. Taxi owners should nevertheless choose vehicles with advanced battery thermal management systems to keep winter charge times at its minimum.

The average cost per km of the energy charged from fast chargers is more expensive than running a vehicle on diesel fuel if the average power gets as low as 30 kW[3], as seen in Figure 56. If the power had been 40 kW the diesel cost-equivalent consumption would have been 3.4 and 4.7 liter/100 km for the summer/winter respectively, well below what diesel vehicles can deliver today. To reach cost parity in the winter, the fast charge power needs to be above 35 kW. This level was achieved in less than 30% of the charge sessions in January-March in 2017, as seen in Figure 15. The current situation is therefore that the kilometer cost of fast charging is barely equivalent with running on diesel fuel. There is however a potential for lower costs as seen by the 20% that achieved a fast charge power above 40 kW in 2017.

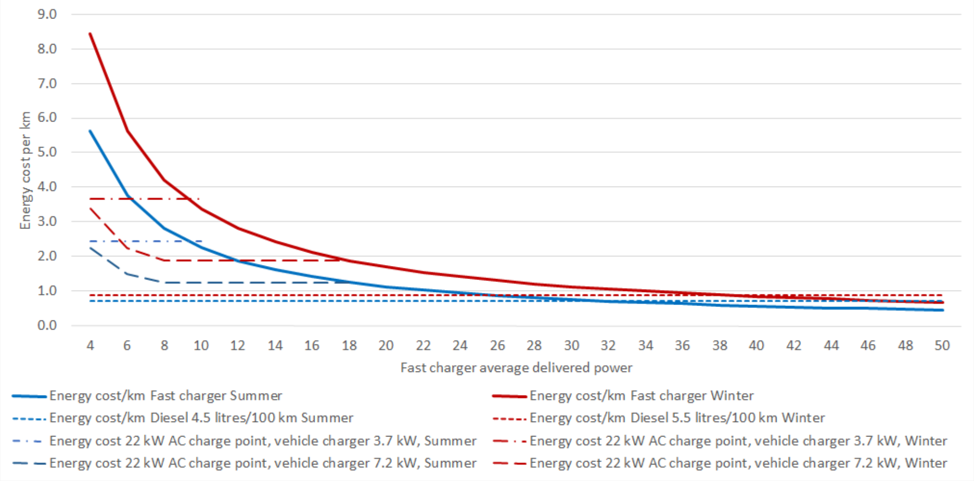

Figure 56 Equivalent cost per km for BEVs getting energy from fast chargers and 22 kW AC chargers, compared to diesel vehicles.

Most charge locations also have Type 2 22 kW AC chargers that cost 1 NOK/minute to use. Those that have only a 3.7 kW onboard charger will find it cheaper to use the DC fast charger until the power falls below 9 kW, which for most vehicles will be at SOCs higher than 90-95%, as seen in Figure 3. The cost will be higher below 9 kW than when using an AC charger socket. If they have a 7.2 kW charger onboard their cost will be lower if the average achieved power on the fast charger is less than 18 kW. While charging might be cheaper from the 22 kW sockets

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[3] Assuming a diesel consumption of 5 liter/100 km in the summer and 6 liter/100 km in the winter. The diesel cost is 16 NOK/liter. It cost registered users 2.5 NOK/minute to fast charge.

in some cases, it will for almost all vehicles be much slower than using the 50 kW fast charge, due to small on board chargers. Users that need more energy than up to 80% SOC are therefore likely to keep charging from the fast charger if they only have a 3.7 kW on board charger in the vehicle.

7.5 Time spent charging

The time spent charging depends on many factors. The most important ones are the achieved average charge power for the energy to be charged, and the user cost of time. Other factors will be the pricing strategy of the operator, the road type the user is on since this influences the battery condition at the start of the charge, the distances to the next (or the previous/start point) fast charger location or destination, the facilities available at the fast charger location, and the wait time (charge queues).

7.6 Total charging volume

The total volume of charging is the sum of all users' charge times. It is influenced mainly by the number of local and regional (counties) BEVs passing the chargers, the number of local and regional chargers, and the locations of the chargers. Due to confidentiality reasons the total charge volume cannot be calculated based on the data from the charge infrastructure operators.

Figenbaum and Kolbenstvedt (2016) found in 2016 that the average user fast charged 13-16 times/year from the non-tesla charging networks. If one uses the 2018 survey results reported in this report (sum of charging in own and neighboring counties, non-tesla vehicle), then about 19 fast charges are done per year on average, as presented in section 6.2. If one uses the results from these surveys as an uncertainty interval, then the charged energy from all Norwegian fast chargers can be in the order of: (13 to 19 times/year)*(Fleet_size)*9.6 kWh.

The estimated number of fast chargeable BEVs in Norway in 2017[4], except Tesla and Renault BEVs, was 95,000 passenger vehicles, and less than 3,000 vans (NPRA 2018, OFVAS 2018). Fast chargers thus provided about 12-17 GWh of energy to BEVs (passenger vehicles) in 2017. The average driving distance of these BEVs is about 16000 km/year (Figenbaum and Kolbenstvedt 2016). Assuming an average energy consumption per km over a year of 0.2 kWh/km (Figenbaum 2018), these vehicles consumed about 300 GWh in 2017. Fast chargers can therefore be estimated to have provided about 4-6% of the energy that these BEVs consumed in 2017. A few super users pull up the average significantly. The volume of fast charging done by Tesla vehicles and van users will come in addition.

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[4] Midpoint between vehicles registered 1.1.2017 and 1.1. 2018

7.7 Charge queues

Charge queues are the result of a large charging demand occurring simultaneously. Charge queues are thus influenced by the traffic flows over the day, week, and year, the number of chargers installed locally and nearby, the location of the chargers, as well as the users cost of time. There are two types of charge queues. Everyday charge queues are seen in cities where there is a large number of users, such as in the Oslo-Akershus area. These queues occur in the afternoon rush hours. The charging infrastructure build out is demand driven in these areas and the operators work hard to keep up with the increased demand from the rapidly increasing BEV fleets. The other main reason for charge queues is an imbalance in the number of local daily users and induced use from vehicles originating elsewhere. These queues typically occur in major travel corridors in weekends and on specific peak travel days, such as national holidays and school vacation periods.

The pricing strategy for fast chargers can potentially be used to even out the demand over the day and between peak travel days, for instance through dynamic pricing[5]. Dynamic information[6] about queue times could also be used to reduce the demand peaks. A challenge is that the charger itself only register actual use, one cannot see queues lining up in front of the charger. Some sort of vehicle to vehicle or vehicle to cloud communication would be required to collect online queue information.

Charge queues naturally follow closely the total traffic flows and occur mainly between 14-16 in the summer and 15-17 in the winter, based on a calculation of the number of hours that more than one user fast charges. The risk of queues seems to increase when the total number of hours per year the fast charger is actively used passes 2000-3000.

National strategies that target a balanced development of the BEV fleet across counties and regions will be needed to reduce charge queues along main roads. If the number of local users in these areas can be increased they will provide more income for fast charger operators on weekdays, so that more chargers can be built out economically and support long distance drivers originating elsewhere on peak travel days. In the counties of Oslo and Akershus the balance in demand is better across days, weeks and months, than in counties with small BEV shares. The balance is also better along the large main roads, the E6 and the E18 than on other roads, especially around cities.

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. These Tesla chargers take up spaces and locations along major roads that could have been used more efficiently if all vehicles had access. Some sort of market regulation might be required to limit the expansion of such proprietary charging networks. Tesla has announced that the Model 3 will come with a CCS charge inlet in Europe and will retrofit their Superchargers with dual connectors to fit the Model 3 and earlier models (CleanTechnica 2018). Model 3

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[5] For instance, higher price in the afternoon rush hour and on public holidays

[6] Based on actual use of fast chargers in real-time or historical data on peak demand periods

users will thus have access to all operator networks. For Model S and X a new adapter will become available that will allow Tesla's vehicles to use CCS chargers (CleanTechnica 2018). Tesla owners will thus gain easier access to the 500 fast charge sites of other operators. Authorities should therefore consider regulations that makes it possible also for non-Tesla vehicles to use the Tesla-Superchargers on fair terms.

7.8 Profitability of fast chargers

A challenge for charger operators is to build out fast chargers that in sum makes out a national network that is profitable and supports driving across Norway. The profitability of a fast charger rests on the annual total use hours per charger. The most used fast chargers are currently located in and around cities. These markets are now considered to be fully commercial. The further expansion in these areas is demand driven and the chargers are built out by commercial actors. Fast chargers are however also needed in less profitable areas to support driving between regions. The imbalance in BEV adoption between urban and rural areas is therefore a major national challenge. Few daily users exist in these rural areas so that the weekday use of fast chargers will be limited. The build out in these areas therefore requires a coverage oriented support program, and has therefore been supported by the government agency ENOVA. The BEV adoption in these areas is also rapidly increasing (Figenbaum 2018), so the situation should improve over time.

7.9 Modeling the fast charging market

The use of fast chargers and optimization of charger position models is an area with substantial research activities. Based on the analysis in this report it is concluded that models of the use of fast chargers needs to have sub-models for:

1. The BEV fleet composition over time, and geographically
2. Each BEV models technical fast charge capability, such as battery size, battery fast charge power at different ambient temperatures and SOCs, including deterioration factors to take into account vehicle aging.
3. The energy consumption for BEVs on different road types and for different climatic conditions (temperature, road surface, precipitation, snow cover etc.)
4. User behavior, i.e. their energy needs, time availability, SOC and battery temperature at the start of the charge, and the SOC at the end of the charge, user time cost, user preferences for charging locations, charging habits
5. A model of the road network
6. A model of vehicle users' travel behavior locally, regionally and on long distances
7. The characteristics of the fast charger network per operator and in total, i.e. the geographical position and number of chargers, the cost of charging etc.
8. Climatic conditions in different regions
9. Pricing schemes for fast charging

User behavior and the vehicles' technical capabilities over different times of the year are particularly important parameters that needs to be modelled carefully to get valid results.

7.10 Revisiting the Hypotheses in Chapter 3

A set of 11 hypotheses about fast charging was set up in chapter 3. They were:

1. Fast chargers are used rarely by most users, as most of the energy required will be charged at home at a much lower cost than from fast chargers.
2. People that only own a BEV use fast chargers more often than people in multivehicle households that also owns ICEVs.
3. People without charging capability at home use fast chargers more often
4. Fast chargers are mainly used for supporting local and regional traffic
5. Shorter range BEVs fast charges mainly at intra-urban locations, whereas longer range and larger BEVs fast charges at inter-urban locations.
6. Fast charging increase e-VMT as user's complete trips longer than the range.
7. Major travel corridor fast chargers far from cities are primarily used on peak travel days, and users charge more energy from them than from city chargers.
8. Users charge just enough to reach home/destination, not to fill up the battery, due to the huge cost difference between home and fast charging.
9. Use of fast chargers varies with the traffic flow over the year
10. Use of fast chargers is higher in the winter than in the summer due to an increased energy consumption in the winter season
11. The average fast charge power is lower in the winter than in the summer

Based on the analysis in the report, the following conclusions can be made. Fast chargers are rarely used as stated in hypothesis 1, but a segment of users use fast chargers often, as seen in section 5.10, thus potentially supporting hypothesis 2.

It seems that the much larger seasonal difference in fast charging in Oslo compared to Akershus, as seen in section 5.11, can be an indication that there are users living in Oslo that cannot charge at home, and therefore frequently fast charge, and more frequently in the winter, which could provide support for hypothesis 3.

Hypothesis 4 is difficult to analyze with the datasets. The users are anonymous and one only knows where they charge, not where they live. It is however proven that 30% of users only fast charge in one location, another 20% use two locations, 50% of users do all their fast charges within one province, and 32% even within one municipality. It can however not be known if these are local chargers for the user or if they are in the direction of a specific longer distance trip that these users undertake.

There is a small tendency that users charge more energy at intra-urban locations than interurban locations but the differences are so small that it cannot be determined if hypothesis 5 is reasonable or not.

As it has been estimated that 4-6% of the energy used by BEVs come from fast chargers, the average non-Tesla BEV gets about 650-1100 km additional kilometers of travel from the use of fast chargers. This result partly support hypothesis 6. A share of these kilometers will however likely be due to users who have forgotten to charge, which has nothing to do with driving longer than the range of the car. Section 5.10 shows however that although many users charge a few times from 1 or 2 locations (which could be users who have forgotten to charge), there is also a high share of users that charge more often and from several locations.

Hypothesis 7 is clearly supported in the material. The problem seems to be twofold. Problem one is a lack of local users around these locations. Problem two is that the induced traffic from other regions in weekends and peak travel days, is much larger than the local traffic on weekdays. Some main roads do however have a more stable fast charge demand over the year. They are along main roads where the chargers also serve local users such along the south-west corridor between Oslo and Kristiansand.

Hypothesis 8 is not possible to evaluate with data obtained in this report. Users fast charge less than the theoretical capacity of their vehicles, but it is not possible to know why they do this.

Hypothesis 9 is clearly supported by the analysis indicating that at least a share of the users has a driving pattern over the year that is similar to the overall traffic flows.

The use of fast chargers seems to follow a seasonal variation in support of hypothesis 10, as seen for instance in Oslo, but the variation is small, and overlaid is a much larger variation due to public holidays and vacation periods.

Hypothesis 11 is fully supported by the material, and the main reason is the poor fast charge acceptance of popular BEV models at low ambient temperatures.

7.11 Relevance for the future of fast charging

The data analyzed in this report was based on the use of fast chargers during a period of a rapid build out of the fast charger network in Norway. The fast chargeable vehicles in the fleet had during the period from January 2016 to the beginning of 2018 fairly small battery packs, and 87% (of non-Tesla BEVs) could only charge at 50 kW. Only a handful of the roughly 1000 fast chargers in use could deliver more than 50 kW.

The BEVs entering the market in 2018/2019 and beyond will have much larger battery packs leading to more user flexibility in when the vehicles will have to be recharged during long distance trips. Each charge event will likely occur at a higher power, both from 50 kW chargers and the 150-350 kW chargers that will be deployed in the coming years. The reason is that larger packs can accept a higher charge power. The larger battery mass will also make them more thermally stable, and they are more likely to be equipped with active cooling and heating systems that improve fast charge capability further. More users could then find BEVs attractive to use on long distance trips. The average distance between fast chargers can then be lengthened so it should be easier for the operators to find good fast charger locations with room for more chargers.

Few users today embark on long distance trips with their short range BEVs. Most of them are multi-vehicle households and have access to an ICEV for such trips. This situation will change with longer range BEVs that can match the user needs of single-vehicle households. The demand for corridor chargers that support long distance driving should increase and more corridor chargers should be needed.

The demand for city chargers is however not likely to be reduced. 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. Longer range, i.e. >300 according to the Worldwide harmonized Light vehicle Test Procedure (WLTP), means that BEVs used in local traffic will only need to be charged 1-2 times per week depending on use and the season. The likelihood of forgetting to charge might therefore paradoxically increase due to the seldom required charging. The long charge time with normal charging will then continue to be a barrier that can be removed with local fast chargers.

The risk of forgetting to charge could be solved with personal vehicle assistants ala google home, which would know on Sunday evenings where you would likely be driving to on Monday morning based on your calendar schedule. The vehicle could tell you (via the google assistant or similar system) the vehicle status and if needed start a charge.

It is possible that more people living in cities with only access to on-street parking will start to adopt BEVs when the range increases, especially if chargers are made available in city centers in cooperation with municipalities. BEV owners in dense cities may therefore in the future use more local fast charging than current users do.

8 Conclusion

The overall analysis shows that over a large spread of occasional, local, long distance and super-users, the average fast charge session in Norway in 2017 took little more than 20 minutes with 9.6 kWh being recharged with an average power of 30.2 kW.

The average energy charged was close to 40% less than the practical potential fast chargeable energy content of the average battery in the fleet if all users charged optimally. 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 SOC window is smaller, i.e. that the charge starts at a higher SOC than optimal. Fast chargers supplied about 4-6% of the energy consumed by BEVs in 2017.

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, some vehicle manufacturers strategy to use convection based battery cooling and heating systems, and that a share of users charges their vehicles inefficiently, for instance by extending the fast charge session beyond 80% SOC.

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. They will have to invest in more chargers in each location, and pay more than necessary for the grid connection. These costs are transferred to the users who will have to pay more to get the same kWh transferred into the vehicles' batteries. The users cost of time will also increase as the charging process will take more time. The strategy of the automakers to save money using passive battery thermal management system may thus be inefficient overall leading to poorer user experiences. 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 getss 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 of fast charging will thus be poorer for all actors, apart from grid operators that get paid for power availability anyway.

The biggest demand for fast charge and the highest utility rate of fast chargers are found in the counties of Oslo and Akershus. This result is not surprising as these counties have the largest BEV fleets in Norway. The largest charge queues are found in these areas, and on peak travel days in main-road travel corridors.

Charge queues occur in the afternoon rush hours, i.e. between 15-17 in the winter months and 14-16 in the summer months, and on peak travel days.

The expansion of fast chargers decreased the number of vehicles per charger up to 2017. The situation has been stable after that. The build out of fast chargers in Norway is demand driven in cities with large number of BEVs. In other areas a coverage oriented approach is followed with public support for fast chargers installed in travel corridors and low demand areas.

The present charge market is separated into 4-5 regions, South-East Norway (Oslo, Akershus, Østfold, Buskerud, Vestfold, Telemark, Aust-Agder, Vest-Agder, Hedmark and Oppland), South-West Norway (Rogaland), Western Norway (Hordaland), Mid Norway (Trøndelag) and Northern Norway (Nordland). In the remaining counties fast charger infrastructure is barely installed and little used.

8.1 Recommendations

Vehicle producers should build vehicles capable of fast charging at close to the full power chargers can deliver over a wide battery SOC-range by installing more advanced battery management systems in the vehicles. An ability to charge with high power beyond 80% SOC would increase the vehicle utility, and should be explored. User can then charge more efficiently and chargers can be spaced wider apart.

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. Chargers could for instance have an automatic stop at 80% SOC, but allow a manual override. Robust fast chargers that build user confidence are needed to avoid inefficient charging as a precaution in case the next charger is out of order.

Increasing the density of fast chargers along major routes should 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.

Operators should post the status of fast chargers (occupied or free) in an API so that vehicle producers can make the information available in the vehicle's navigation unit. Operators can also make the expected queue time at each location available to users.

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 use support chargers that are also needed for corridor travel. A measure could for instance be to stimulate local rural 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. They take up spaces and locations that could have been used more efficiently if all vehicles had access. If all vehicle manufacturers followed the Tesla model, the situation could soon become intolerable. Authorities could consider introducing regulations that make it possible for non-Tesla vehicles to use Tesla-Superchargers on fair terms.

EU vehicle type approval requirements should be updated with a test for charge speeds (i.e. power) as a function of ambient temperatures, as charge speed is an important parameter for the utility of a BEV compared to an ICEV.

The demand for city fast chargers is unlikely to be reduced. They are a back-up solution for users that have forgotten to charge overnight. They are also needed by professional users such as taxi drivers and craftsmen and those that cannot charge at home.

Longer range BEVs will enable BEV ownership in single vehicle households. A general driving pattern of vehicles could then be adopted by BEV owners and lead to a need for more corridor chargers.

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. More charging infrastructure can be put in place on peak travel days with the use of mobile charging units. Schemes that allow owners of short range BEVs to rent vehicles to do long distance driving in the most demanding travel periods could also be introduced. Finally, demand oriented pricing schemes on peak travel days could also reduce charging queues.

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Appendix 1 - Norwegian counties

Norway consisted of the 19 counties (Svalbard is not a province), shown in figure A.1 in 2017. From 2018, Sør and Nord-Trøndelag merged into Trøndelag. Some basic facts about the counties are shown in Table A.1. There were 428 municipalities in Norway in 2017.

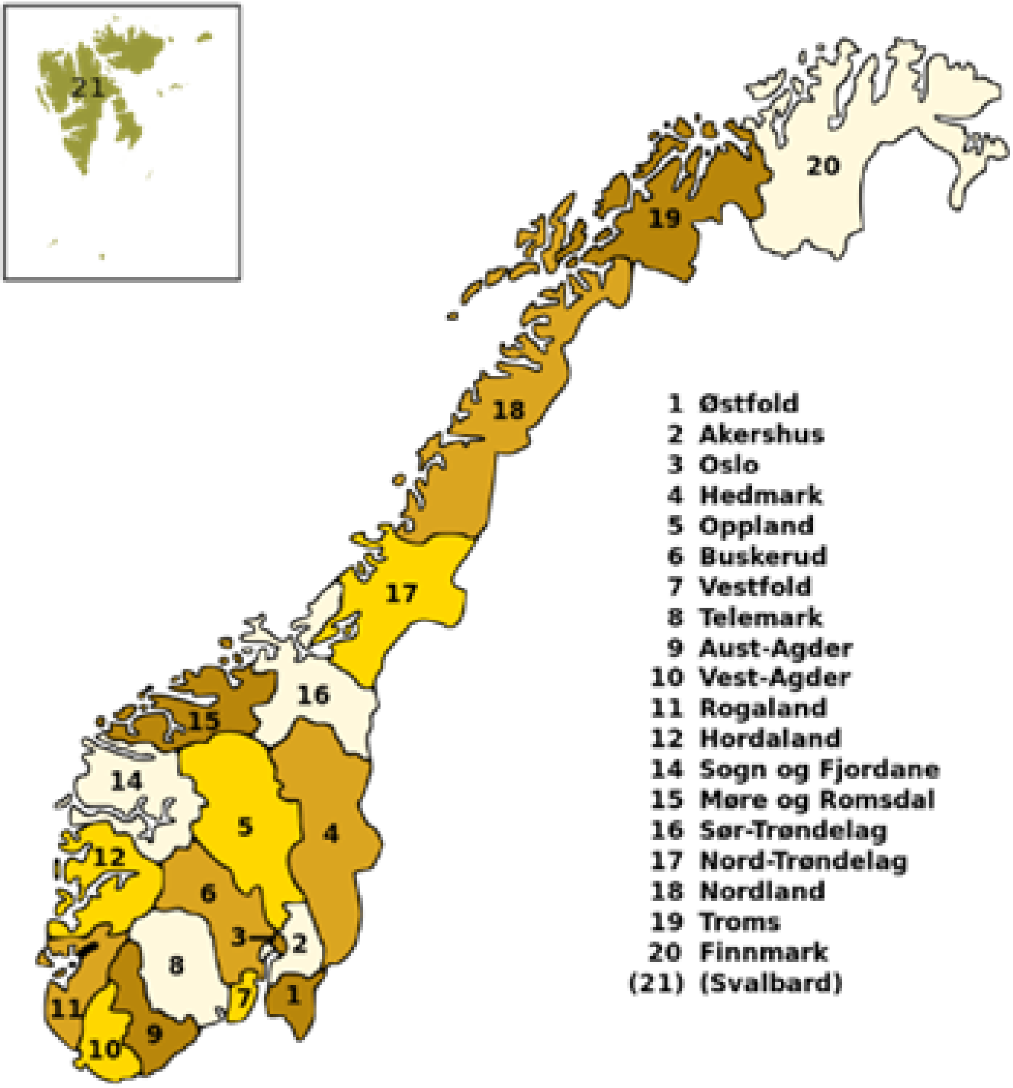

Figure A.1 Norwegian Counties. Nord-Trøndelag and Sør-Trøndelag have merged to become Trøndelag.

Table A.1. Basic facts about Norwegian counties, 2017. Source: Statistics Norway (www.ssb.no).

	Population	Vehicles	Households	Land area km^2	Municipalities	Vehicles per household	City areas >40000 inhabitants
01 Østfold	289867	149058	129094	3888	18	1.15	Fredrikstad/ Sarpsborg, Moss
02 Akershus	594533	331895	248153	4579	22	1.34	Oslo
03 Oslo	658390	288314	332568	426	1	0.87	Oslo
04 Hedmark	195356	116310	90513	26086	22	1.29	
05 Oppland	188953	110783	87184	23777	26	1.27	
06 Buskerud	277684	160746	122840	13778	21	1.31	Drammen
07 Vestfold	244967	128902	110212	2149	12	1.17	Tønsberg, Sandefjord
08 Telemark	172494	91302	79249	13832	18	1.15	Porsgrund/Skien
09 Aust-Agder	115785	60879	50924	8307	15	1.20	Arendal
10 Vest-Agder	182701	87200	80617	6679	15	1.08	Kristiansand
11 Rogaland	470175	228952	197654	8585	26	1.16	Stavanger/Sandnes, Haugesund
12 Hordaland	516497	235008	230616	14502	33	1.02	Bergen
14 Sogn og Fjordane	109530	56902	46289	17666	26	1.23	
15 Møre og Romsdal	265290	140859	115095	14569	36	1.22	Ålesund
16 Sør-Trøndelag	313370	150838	149931	17833	25	1.01	Trondheim
17 Nord-Trøndelag	136399	75857	58993	20781	23	1.29	
18 Nordland	241906	125162	109444	36087	44	1.14	Bodø
19 Troms	164330	83848	75688	24869	24	1.11	
20 Finnmark	75758	37898	33733	45755	19	1.12	
Total	5213985	2660713	2348797	304148	426	1.13	
50 Trøndelag	449769	226695	208924	38614	48	1.09	Trondheim

The climate varies substantially across the north south axis and between inland and coastal zones as seen on the map of average winter and summer temperatures in figure A.2.

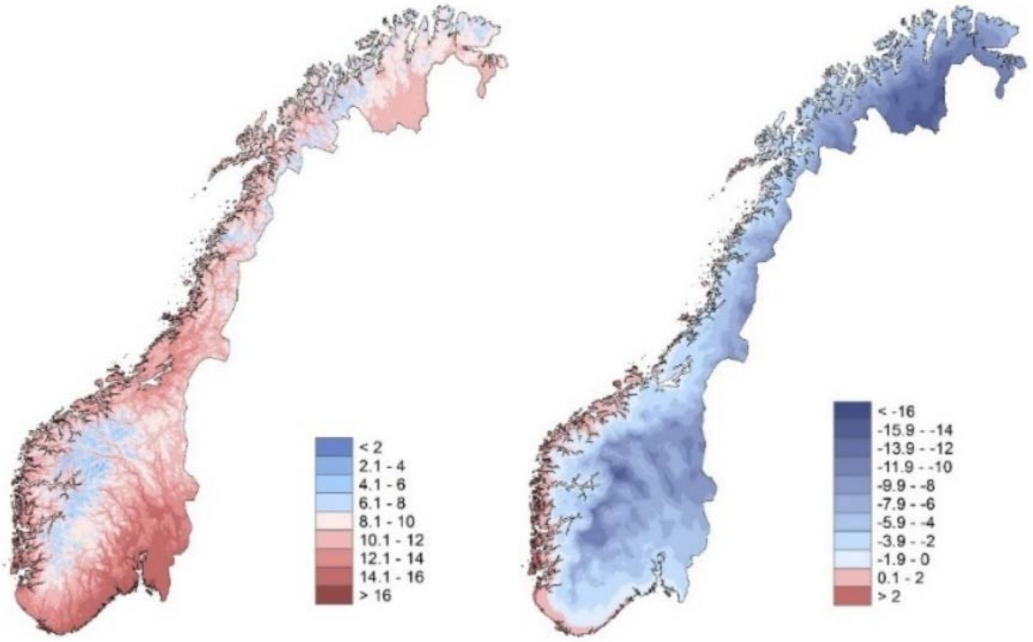

Figure A.2 Average temperature summer and winter in Norway.

Transportøkonomisk institutt (TØI)

Stiftelsen Norsk senter for samferdselsforskning

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