Energy & Transport

Assessing range and performance of electric vehicles in Nordic driving conditions –Project Final Report

Activities and outcomes of the "RekkEVidde" project

Title: Assessing range and performance of electric vehicles in Nordic driving conditions – End of Project Report

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Abstract:

Shortage of range is by far the greatest flaw in current electric vehicle technology. Furthermore, energy use is also highly dependent on duty cycles, driving conditions and traffic situation. Additionally, cabin heating in an EV will not be supported by energy losses as in an ICE-car. Therefore, actual range can differ substantially in real-life situations, and can be much shorter than the official figures given by the manufacturers. The Project RekkEVidde is drafting a testing scheme that addresses EV driving in Nordic conditions, and produces realistic range estimates for the consumers to help them understand this raising technology and make successful purchase decisions.

Keywords: Electric vehiles, EV Range anxiety, Cold temperature range, EV field test, EV laboratory test, EV range test protocol, EV energy label, Nordic climate, EV status in the Nordic countries, EV owners and their attitudes, EV driving patterns

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Project Participants

The project was executed in collaboration by partners that had either main role or supporting role. Main actors carried out larger tasks and were responsible for work packages and deliverables. Supporting partners collected and delivered national-level data and brought in the local insights to help main actors.

Main Partners

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Lindholmen Science Park / TSS (S), Lindholmen Science Park has been commissioned by VINNOVA to manage and develop Test Site Sweden (TSS), a national resource/center for new business within the test area. Electrification of vehicles is one focus area for TSS. Development of test methods for in-field winter testing of EV's and PHEV's started 2008. TSS is also engaged in projects concerning charging infrastructure, ITS solutions, active safety etc.

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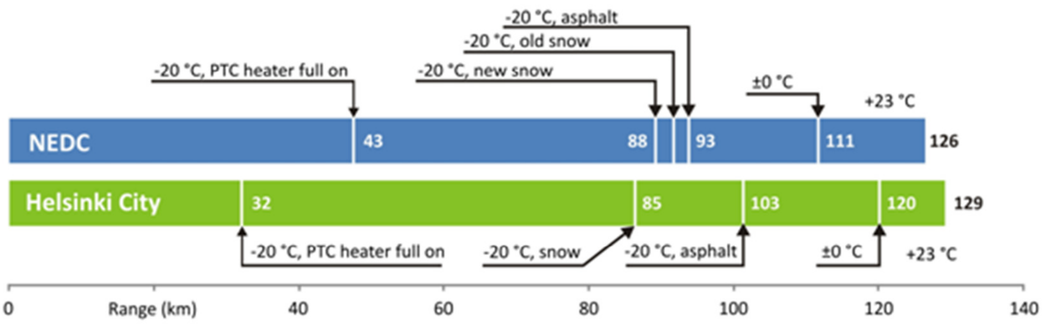
None

Executive Summary

Electric vehicles (EVs) are entering into the market. In the Nordic countries, Norway is leading the way with fast growing EV fleet. Nordic countries with their severe climate are a challenging market for EVs. The RekkEVidde project was established to produce new and coherent information of energy use of EVs in various different applications and related driving conditions (traffic situation, ambient conditions, and topography/gradients) in the Nordic countries.

Transportøkonomisk Institutt (Norway) studies show that average citizen in Norway is travelling less than 50 km a day. EV users are using their EVs almost daily and very often for trips to the city centre. EV users also make trips which are longer than 60 km.

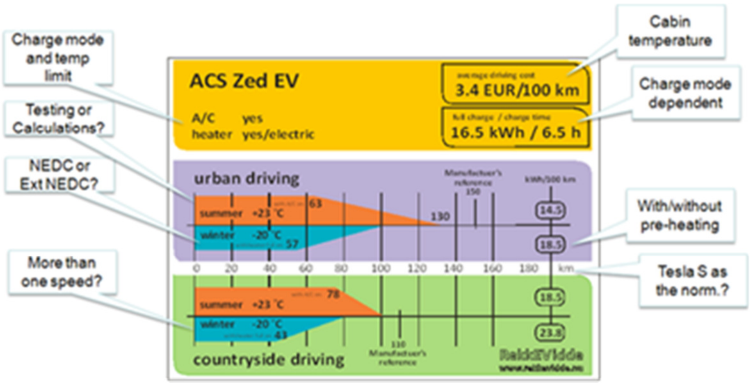
VTT (Finland) has performed a series of EV range tests up to 8 different driving cycles. Tested EVs are the most common on the market. Results show that when temperature falls from +23 °C to -20 °C the range goes down with -27 % even if the cabin heating is not used. When battery powered cabin heating is on, the range reduction can be as high as -76 % down from original warm temperature range.



TTS (Sweden) have performed cold temperature field tests in a circular track with same type EVs than VTT and with additional EVs as Tesla Roaster. Results show that laboratory tests give similar results.

	NEDC @ '-20 °C using heating at full		
	field	in-lab	
Car	TSS	VTT	TSS/VTT
	kWh/km	kWh/km	ratio
Citroën C-Zero	0.37	0.33	111 %
Nissan Leaf	0.46	0.44	105 %
Renault Kangoo	0.51	0.23	n/a
		no heater	

The RekkEVidde project has also developed a draft of the RekkEVidde energy label for the future development to visualise a realistic performance of EV to the buyer.



In the project, also a "Basic field testing" procedure was developed. It was developed for motor magazines and other interested parties in order to them to apply it and get comparable results. The RekkEVidde published also more advanced field test for research laboratories and test sides.

Summary of the project conclusions:

Nordic climate challenges the use of EVs in many ways

- Cold weather and adverse road conditions increase driving resistances >> range becomes shorter.
- Cold weather necessitates slower charging and battery warming.
- Heating and ventilation consume high amounts of prime battery energy >> range is adversely affected.
- Heating and ventilation must be properly supported, otherwise EVs will not enjoy great success in sales.

Further work is needed to continue the cold temperature range measurements with new generation heat pump and fuel heater EVs, as well as a range testing method for the Plug-In-Hybrid-Vehicles. In the BEV perspective the traffic jam related range losses in urban areas, while keeping the car comfortably warm, needs special attention and further test-development.

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1 Introduction

1.1 Purpose of project and main objectives

The main objective of the project was to produce testing protocols that gave realistic performance figures for electric vehicles attributed to Nordic driving and weather conditions, as well as apply that protocol to a group of candidate vehicles.

Realistic estimate of the range is the most critical factor for EVs success, but because of this disparity in range, the industry is tempted to quote (over)optimistic figures. However, if the numbers do not reflect the true performance and the customers are in practice seeing drastically lower driving ranges than those advertised, there is a danger that the market-acceptance of EVs suffers strongly. Therefore, assessing vehicle performance using most realistic driving patterns and weather conditions (low ambient temperatures) is essential. Otherwise, this may even cause a severe backfire effect to the deployment of EVs.

There should also be some sort of vision and understanding of what kind of additional testing is needed for EVs apart from the regulatory test (ECE-R101). Otherwise the testing might result in having too many ways of testing and poor correlations. So if today we have only one "official" reference figure, there is a possibility to end up with 10 different non-official figures and no understanding of their correlation to each other and to real driving conditions. Even if the objective of the project is not to stimulate more official/mandatory testing, it would be beneficial for all parties if the supplemental testing is "harmonised" in some way.

1.2 Project background

Electric vehicles are still fairly immature technology compared to IC-driven cars when it comes to the driving range. The phenomenon of "range anxiety" is common among those who already use EVs or consider buying one. Today we know that Tesla Model S is good for almost 500 km of driving, but more or less no one knows what the true range is in a Nordic context. And still most of the OEMs are providing EVs to the market with a range around 160-180 km only achievable in optimal conditions. Those are really needed to be tested in a customer oriented way.

Energy use is also highly dependent on duty cycles, driving conditions and traffic situation, and the cabin heating in EV will not be supported by energy losses as in an ICE-car. Therefore, actual range can differ substantially in real-life situations, and can be much shorter than the official ECE-R101 figures given by the manufacturers.

EV manufacturers have started to quote range values resulting from their own testing, but those are not comparable to each other. For example for Peugeot Ion/Citroën C-ZERO the range given by the manufacturer is 130 km, but for Mitsubishi iMiEV the range is 144 km, even if they are almost 100 % identical vehicles with equal battery capacity. Furthermore, for the Japanese market, Mitsubishi quotes the range to be 160 km (100 miles), because the reference is then the Japanese 10-15 cycle having lower speeds than its European counterpart. Furthermore, Nissan has released in United States range figures for their EV Leaf, referring to 6 different types of driving vs. climate conditions, ending up to 6 different ranges between 47 miles and 138 miles. Thus having a common Nordic protocol could help the industry to test their products in a harmonised way, instead of each having their own tests.

Energy need also differs between vehicles. Think City weights as much as the iMiEV, but has 40 % more battery capacity (22-23 kWh vs. 16 kWh in iMiEV). Yet the range promise is about the same, 160 km.

Contrary to the ICE that allows sustained full power even to the last drop of fuel, full acceleration may not be possible in an EV at low state-of-charge, and driving at highway speeds becomes impossible, if the "falling voltage problem" is not properly taken care of with good battery management.

1.3 Expected results of the project

The plan for the project was to produce new and coherent information of energy use of EVs in various different applications and related driving conditions (traffic situation, ambient conditions, topography/gradients) in the Nordic countries. The developed in-lab test protocol as well as methodology for in-field data collection/retrieval was set up to enable further progress to maintain and update public information or a public data-base of which the project shall produce the seed.

Public availability of comparable data should enable both current and prospective new future EV users to make better selection of vehicles to suit their particular application and duty cycles, and to avoid serious mismatching and resulting disappointments, if "fit-for-need" principle can be followed. Surely, this should support successful deploy-ment of the technology in all countries, not only in the Nordic countries.

More accurate estimation for the actual energy use of EVs in real driving conditions gives also valuable data for the process of planning and calculating the capacity and of the charging infrastructure as well as allocation of the charging points. Station-to-station distances need to be in relation to the actual range of the vehicles in all condi-tions. In extreme situations local conditions may lower the range of EVs and the densi-ty of the charging network needs to be increased for all-year trouble-free operations.

If the Nordic test protocol comes available, and if it shall be used as reference for e.g. procurement, EV manufacturers are sure to start to use it as part of their supplemental testing in addition to the official figures (ECER No. 101). One expected result from the project is an "entire-journey-picture" of energy use while driving, heating, preheating and parking (the EV in a multimodal transport perspective). This picture will be of great importance in a triple helix dialog regarding EVs in a Nordic perspective. A com-mon test protocol will be a good way of presenting the advantages of Nordic countries as a region for EVs.

2 Methods and implementation

2.1 General workplan

The work plan of the project consisted of the following sub-tasks:

a) assessment of applications and user groups associated with the early stages of EV deployment (separately for participating country)

b) analysis and characterization of duty-cycles and driving conditions attributed to those users and applications (separately for participating country)

c) designing test protocol (driving cycles, ambient conditions etc.) reflecting to these conditions to be used in testing of EVs

d) employing this test protocol to a number of EVs

e) collect data from real driving using a control group

f) establish a public database for collection and open retrieval of these perfor-mance figures

The project was executed in collaboration by partners that had either a main or a sup-porting role. Main actors carried-out larger tasks and were responsible for workpack-ages and deliverables. Supporting partners are responsible for sourcing and delivering national-level data and bringing local insight to help the main actors.

WP1 – User groups, applications and duty cycles

In the first phase user groups and applications that are candidates for EV deployment are determined. Data is collected of typical duty-cycles and ambient conditions related to these applications and driving environments. Data collection covers also real-world experience that is available from EVs already in operation. Swedish "Bilrörelseprojekt" will serve as a first source of in-use information, but as Nordic countries have different climate and topography, it is imperative to sample data from all countries. Along with measured data statistics will be used.

WP2 – Development of test protocol and evaluation tools

Test cycles and set of test conditions reflecting real-world use are developed using data from WP1. These will form a test protocol addressing EV performance in typical Nordic conditions. It shall produce realistic estimates of energy use and enable calculations of range in different conditions. Parallel to this, in-vehicle data collection methodology and devices will be formulated following the experience from "Bilrörelseprojekt", and data transfer & handling will be developed. The aim is to verify that the figures from the in-laboratory tests match with true in-use values.

WP3 – Application of the test protocol on some candidate vehicles

In this project phase three EV types will be chosen that represent expected market offerings in Nordic countries. One of each type is subjected to the detailed in-laboratory testing using the new protocol.

WP4 – Field test of EV's in Nordic conditions

A suitable-sized control group of EVs is equipped for the parallel in-field testing. This should involve all participating countries. An invitation is also sent to selected group of EV users to broaden the in-use data retrieval outside main control fleet. Electronic driver feedback system will be used to collect information from this pool, and an internet server for data input will be set-up.

3 State of art in the Nordic countries and EV user groups and duty cycles

Within this chapter we are summing some important input to the project in terms of:

- Nordic Climate
- EVs in the Nordic Countries in short
- Norway in detail

Due to the fact that Norway is the leader when it comes to the EVs (globally and not only in the Nordic perspective), an important issue during the entire project was to acquire information about the Norwegian EV phenomenon. Due to this fact we made a complete chapter about Norway for the reader to study and reflect upon.

3.1 Climate in the Nordic countries

Climate is information about the weather over time. More accurately, climate describes the average weather of a place or area, as it appears when individual observations are processed statistically according to international guidelines. The climate in the Nordic countries can be ascribed as being cold. We see from figure 1 that especially north of Sweden and north of Finland has a very cold climate with the mean winter temperatures being around -20 °C.

Despite the moderating effect of the Atlantic Ocean and the Golf Stream, the Asian continental climate at times extends to the Nordic region, manifesting itself with severe cold in winter and occasionally very high temperatures in summer.

The climate of the Nordic countries is strongly influenced by the polar front, which is the front where tropical and polar air masses meet. The temperature can thus change quite rapidly, particularly in winter. The systems known to affect the weather are the low-pressure system usually found near Iceland and the high pressure systems in Siberia and the Azores. The position and strength of these weather-systems vary, and anyone of them can dominate the weather for a considerable time (Tveito et al. 2000).

Denmark and south Sweden has a slightly warmer climate than Finland, north of Sweden and Norway, while south of Finland and Norway and middle of Sweden has similar temperatures in winter, ranging from -14 to + 2 °C.

Even with the relatively warmer climate of Norway, compare to north Sweden and north Finland, the EV producers state up to 50 % reduction in the EV winter. One should therefore expect even more reduction in north of Sweden and the north Finland as low temperature severely may effects the battery output and the use of energy in the vehicle.

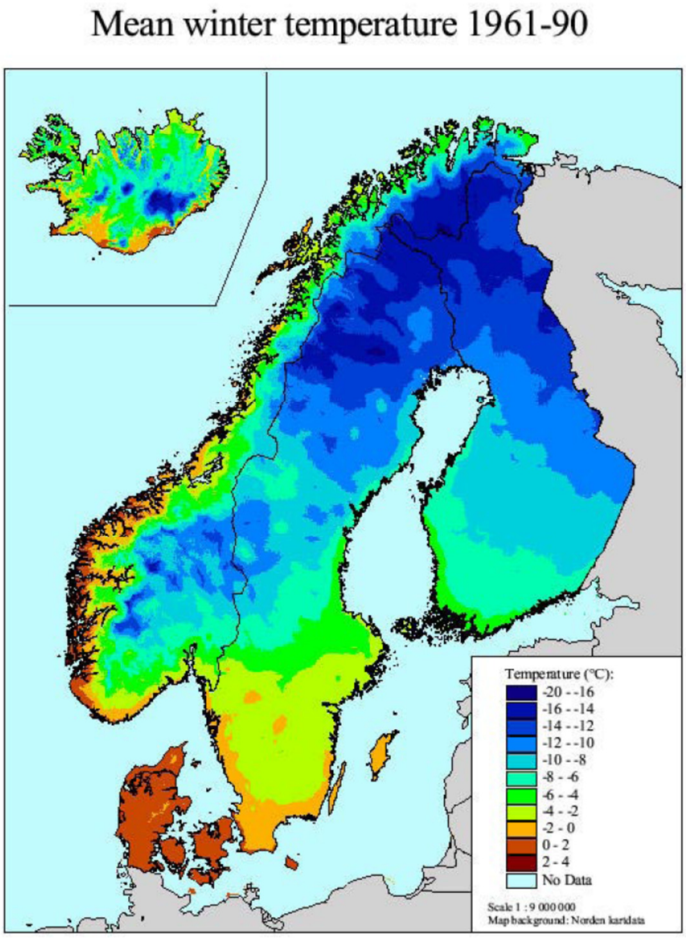

Figure 1 Winter (December – February) temperature average for the Nordic countries in °C 1961-1990 (Tveito et al. 2000)

3.2 EVs in the Nordic countries

The activities and the developments of EV markets are different and vary among the Nordic countries. This chapter aims to give a rough overview of the situation of the EVs in the Nordic countries. Further on Norway with its large number of EVs is given deeper attention.

The activity and the development of EV markets vary among the Nordic countries. In total Sweden has about 1285 modern BEVs (4/2013), mostly Mitsibushi IMiev and Nissan Leaf and about 150 older EVs like for instance Renault Clio Electric. Most of the modern EVs in Sweden are owned by companies.

In Denmark there are approximately 1386 BEVs (4/2013). Denmark is a geographically small country with a dense population. It is also considerably warmer compared with the other Nordic countries. Denmark has because of geography and a mild climate compared with the other Nordic countries a favourable situation for developing an EV market and infrastructure for EVs.

The Finnish authorities have an ambition to lower their CO_2 emissions with 80 % by the year 2050. Initiatives to increase the interest for EVs are for climate reasons and partly carbon free electric power production expected to come in Finland. There are about 271 modern BEVs in Finland (4/2013).

Norway is the leading Nordic country in developing markets for BEVs. There has been a steady growth of EVs in Norway from 2008 to 2013. The 18 000+ BEVs spread around the country but they are mainly located in the main cities. Most of them are located in the Oslo region. The Norwegian government is in favour of and strongly support electrification of the car park. The unofficial goal is to have 200 000 EVs on the road by the year 2020.

Since short distances on the highways into the city centres are common for EV commuters, potential EV owners desire sufficient speed capability from their EVs.

A realistic estimate of range is a critical factor for the trust and success of fully electric Battery Electric Vehicles (EVs). If the vehicle specifications that the industry advertises not reflect the true performance, the EV will lose trust and shares in the marked.

The overall objective was to collect information about typical driving patterns and ambient conditions related to the use of EVs in the Nordic countries. Temperature, weather and driving patterns are essential background information for development of relevant tests and test driving cycles for EVs.

Information about EVs in the Nordic countries for this study have been collected from literature studies, the national travelling surveys, contact with stakeholders and Norwegian EV associations. Among the Nordic countries, only Norway has a substantial numbers of EVs on the roads. After a brief overview of the situation in all the Nordic countries, Norway is our focus in this study.

3.2.1 Sweden

Sweden is one of the leading countries in bio-fuel, but is not in the frontline in using EVs. The EV sales figures in total, for BEV (Battery Electrical Vehicles) and PHEV (Plugin Hybrid Electrical Vehicles) together are still growing exponential (double up trend) and are supposed to reach above 3000 EVs in total by the end of 2013. There is a huge interest in PHEVs like the Prius Plug in and Volvo V60 Hybrid. On the BEV-side Nissan LEAF´s and Renault Kangoo is the leaders and more BEVs are about to be introduced to the market.

Test Site Sweden, TSS is a national resource for demonstrations and validation of research results in the automotive sector. TSS mission is to cooperate with testing and winter testing facilities to identify and create new test methods, techniques and facilities that focus on active safety, intelligent transport systems and Electric and hybrid vehicles. TSS is creating a database over experiences with EVs in Sweden. In general Sweden is well equipped with both research communities and organizations for testing all kinds of vehicles including EVs.

In 2011 the vision was stated that Sweden will have 600 000 EVs by the year 2020. This vision vas shared by Elföretagen, Svensk Energi, Power Circle, TSS and others. The vision is no longer “new news” and in some areas regarded as nonsense. But with the global trend with twice as many EVs sold every year the vision of 600 000 EVs is still able be reach shortly after 2020.

Volvo Cars first plug in hybrid car based on the Volvo V60 is selling more than the initial prognosis and the production is increasing. This success is based on the V2 co-operation with Vattenfall, a co-operation with more than 6 years of history already and with co-operational plans until the year 2020.

There are no special incentives for EVs in Sweden. However EVs are included in the incentive package given to cars qualifying for the criteria as Swedish environmentally friendly cars. And this (approx. 5000 EUR/car) incentive package run out of money during 2013 and are now gaining money from the 2014 budget. One big difference to the Norwegian strategy is that BEVs and PHEVs are gaining the same level of incentives. This is by some experts considered as a more neutral approach and not only on the technical side. By giving incentives to PHEV the electromobility is also expected to spread more easily to non-urban regions.

Sweden has also incentives for EVs in terms of a lower tax (- 40%) on privately driven cars owned by the company you work for. With this system for so called “tjänstebilar” both the company and the employee can receive incentives, and work commuting is pointed out as an interesting application area.

Sweden has launched a national program called “Demo-programmet”. The focus for this program is to identify and reduce obstacles for the EVs to reach the market. Within this 30 MEUR-program a lot of projects are looking on the charging infrastructure issues. But other initiatives, for example studies on driver behaviour and range anxiety, are also of great interest.

Regarding infrastructure issues initiatives like the energy company Fortum's work with large scale launching of charging infrastructure and EVs in Stockholm (Sweden) and Espoo (Finland) is developing in parallel to the more rural oriented Green Higway co-operation from Sundsvall to Trondheim, via Östersund. An initiative with a true fore-front approach - installing the first CHAdeMO charger in Sweden already in the begin-ning of 2011. Österund was also one of the first regions in northern Europe to install type2-mode3 chargers. Green Highway and Östersund are also working with EV guides to promote EVs for the market.

A research program related both to ”Demo-programmet” and to our project ”RekkEVidde” is the ongoing program called " Mätning och analys av bilrörelser i den svenska bilparken av relevans för framtida elektrifiering” or in short BRD**, "**Bilrörelse-databasen” (the car movement database). This research program aims to gather large amount of data concerning private vehicle users' driving patterns by equipping their vehicles with measuring devices. Today the database consists of over 130.000 individ-ual trips.

As a result from the RekkEVidde project a Swedish report based on the measurements from RekkEVidde and the statistics from the BRD-project is about to be launched. In this report TSS states that BEVs with the range that is provided today will give a good match to the Swedish daily commuting. Close to 90% of the total amount of mileage with cars is on trips shorter than 100 km. The average speed is 53 km/h and the big majority of average daily commuting is in the area from 15 km to 55. But to stimulate the electromobility in the best way we still need to investigate and test. In a society with approx. 1.3 cars per family and with about 50 % more cars/citizen in rural areas than in Stockholm the "two cars family” is now the next object for the BRD studies and a good input to a coming next step in the RekkEVidde-process. And with this picture the BEVs might be more interesting than we expected for non-urban areas and per-haps PHEVs of higher interest for urban areas than we expected for the next phase of RekkEVidde.

As an initiative from the Swedish government the report from the so called "FFF-study” (Fossil-Fri Fordonsflotta) is launched in the last week before Christmas 2013. This study has already pointed out the need for more actions like RekkEVidde. The FFF-study states that the information to customers about "green cars” is no longer trust worthy. A "fridge-sticker-approach” to EV-customer information is highly recommend-ed and the study also pointed out that Sweden should take the forefront in initiatives to develop methods and good examples in this area. Based on this "Konsumentverket” and "Energimyndigheten” are about to initiate a process, focusing on how to give cus-tomers proper information. This initiative will be a perfect complement to the work done in RekkEVidde. And RekkEVidde is from start a perfect input to that process. The overall picture is that the lack of adequate information about EVs and their usability is the main obstacle hindering the introduction of EVs to the Swedish market.

Figure 2 Winter testing ground in Norrland

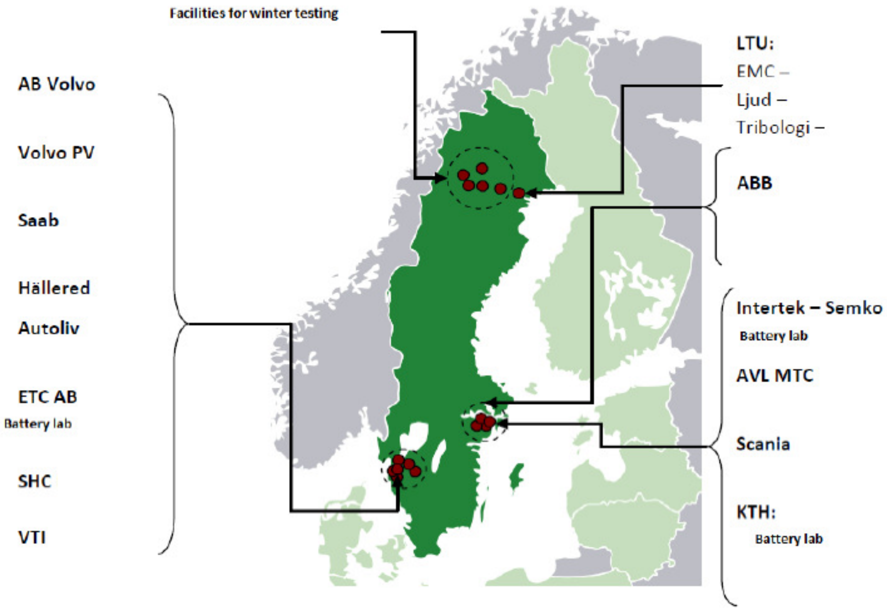

Figure 3 Research and testing locations for vehicles in Sweden (Elforsk et al. 2010)

3.2.2 Denmark

There was approximately 300-400 EVs in 2011 (Grønnbil 2011b) and the fleet have grown up to 1388 EVs in 2013 (IEA 4/2013) in Denmark. Denmark is a relatively small country with a dense population. The climate in Denmark is considerably warmer in comparison with the other Nordic countries.

The geography and climate give a favourable situation for EVs and developing infrastructure for charging facilities. The energy company DONG is investing 770 million DDK on building of charging points across country (by the year 2012).

A relatively large proportion of the energy in Denmark (20 %) is produced by windmills. The windmills give Denmark a rather unpredictable energy production rate. Denmark aims to be the global leader in developing a national electric vehicle charging network that uses the cars' batteries as a storage reservoir to balance the intermittency of wind. The project was called "The Edison project" (Edison 2011).

In order to facilitate the integration of electric vehicles (EVs) into the Danish power system, the vehicle driving patterns in Denmark were analysed to extract the information of driving distances and driving time periods (Wu et al. 2010). However mostly data from the general Danish National Transport Surveys was used to analyse the driving patterns as no data for actual EV driving was available.

The driving distance analysis shows that the average driving distance in Denmark is 29.48 km. On Fridays, the average driving distance is 33.96 km. Of the cars 75 % are driven 40 km or less per day. The 40 km driving distance can be used to determine the EV battery size to meet the driving requirements in Denmark (Ibid).

In Denmark, DONG Energy collaborated with the company "Better Place" in a research large scale demonstration project with EVs from Nissan. The planned start was in 2011. The consortium collected funding of 103 million DKK to build the necessary charging infrastructure. However, the company Better Place filed bankruptcy in May 2013, and German energy company E.ON purchased Better Places network of 770 charging stations spread over Denmark in September 2013.

The EDISON project in Denmark had a budget of just over 43 million DKK and was operated by different stakeholders with a view to develop future charging infrastructure. The project consisted of a number of specific work packages.

The first work package was a state-of-the-art study. The other packages include contacts with the automotive industry, survey of driving patterns, battery modelling and economic analysis.

The second and third work packages more specifically dealt with the power system and the integration of electric vehicles and grids. The fourth and fifth work packages were more specifically about the charging infrastructure and communication between networks and vehicles.

The sixth work package was focused on practical tests and Proof of Concept (POC). A technical demonstration included field tests to run electric vehicles on the island of Bornholm and a study what happens in an environment with strong winds.

Denmark has a tax for registration of new cars that add 180 % of the import value of the car to the price for the customer (reductions are made for different Electric Vehicles weighing below 2000 kg are totally exempted from the 180 % registration tax). In contrast to Norway and exemption of Value Added Tax, Danish EVs are not exempted from the 25 % Danish VAT.

3.2.3 Finland

The Finnish authorities have an ambition to lower Finnish CO_2 emissions with 80% by the year 2050. Amount of EVs is therefore expected to increase in Finland. There are about 271 modern EVs in Finland (IEA 4/2013). Serial production of the car brands THINK, the American Fisker Karma and the golf-car "Garia" was located in Finland but recently these activities have been closed.

An EV prototype called "Electric RaceAbout" (ERA) is developed in Finland. Electric RaceAbout has four electric motors, one for each wheel, which gives the car an acceleration of 0 – 100 km/h in 6 seconds and top speed of 200 km/hours. Its range is 200 km per charge (Electric Race About 2011). Figure 4 shows the car on an icy lake in Lapland, where it achieved top speed record of 252.09 km/h for electric vehicles driving on-ice.

Figure 2 Electric RaceAbout (ERA prototype EV)

Valmet Automotive and Fortum have developed in co-operation an EV called EVA which was shown in Genève in 2010 (Elforsk et al. 2010).

In Finland TEKES has established an 80 M€ national program, which will be running all together 5 years in 2011-2015. The aim of the EVE programme is to create a community for electric vehicles and to support the system developers with close contacts to international research and business networks. The programme also focuses on developing test environments and standards for the industry.

3.2.4 Iceland

The Icelandic winter time is relatively mild for its latitude. The southerly lowlands of the island average around 0 C in winter, while the highlands tend to average around −10 °C. The lowest temperatures in the northern part of the island range from around −25 to −30 °C. Warm summer days can reach 20–25 °C.

Number of the BEVs has grown in the end of 2011 – 6 BEV vehicles were registered. After VAT incentives BEV number grown to 14 (2012 situation). In august 2013 3.7% of the vehicle registration when 12 i-MiEVs was delivered to Icelandic companies.

3.2.5 Norway

Within the Nordic countries, Norway is the leading country in terms of governmental incentives and numbers of sold EVs. Even with Norway's cold weather conditions and scattered population there has been a steady increase in the number of EVs in the country. The Norwegian government is prioritizing the electrification of the car fleet. The unofficial goal is 200 000 EVs on the road by the year 2020 (NyTeknikk 2009).

Norway is the only Nordic country with a fast growing and relatively large established EV-fleet with about 18 157 vehicles (11/2013). In the rest of the Nordic countries there is a lot of interest and research going on, and one could expect the share of EVs in the relative near future to increase. PHEV's are not supported in the same way I Norway as BEV. Note also that the following chapter is based on the Norwegian definition of EVs where PHEV is excluded from that picture.

3.3 Norway in detail

3.3.1 Climate in Norway

Since Norway, as a leading Nordic EV-user country with an established EV-fleet is in our focus, the weather in Norway is dealt with in some more details than the weather in the other Nordic countries.

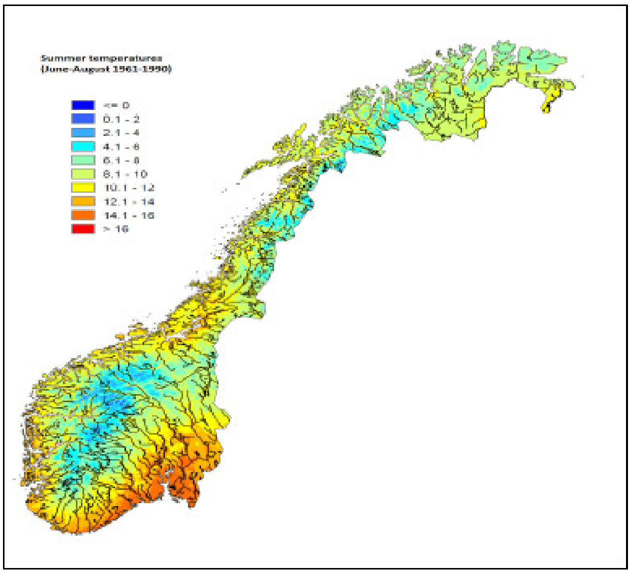

Figure 3 Summer (June - August) temperature average for Norway in °C 1961-1990 (Correspondence 2011a)

Norway is a country with a fluctuating weather. In the summer the temperatures can rise up to 30 °C, while in winter, the temperatures in some areas can be as low as -50 °C. However, in average the temperature in Norway varies between - 8 and + 8 °C. Oslo (where the most of the EVs in Norway are located in) is a relatively cold city with temperatures in average from -10 to -12 °C during December and February as can be seen from figure 6. However, it is not so unusual for the temperature to creep down to -20 °C.

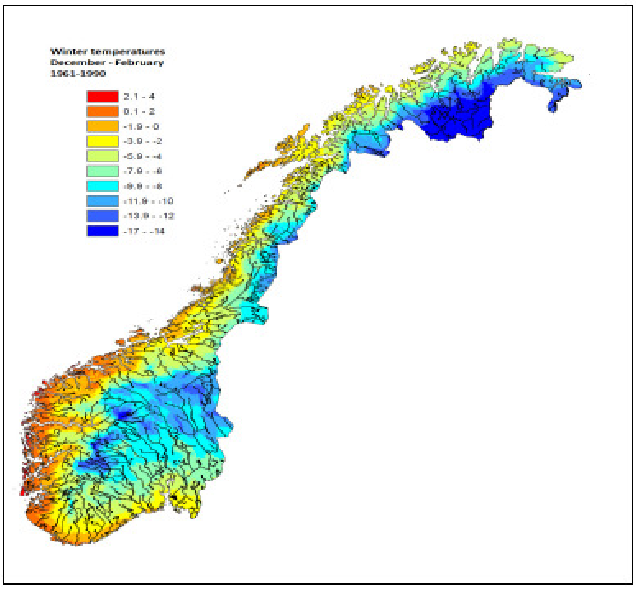

Figure 4 Winter (December -February) temperature average for Norway in °C 1961- 1990(Correspondence 2011a)

EVs in the Northern countries have to tackle extreme temperatures. In the summer the temperatures can raise up to +30 °C, while in the winter it can fall to -50 °C. Therefore, Sweden, Finland and Norway are well suited for testing EVs in winter climate conditions.

Not all producers of EVs inform the market about the reduction of driving range due to cold climate. Those who do so, tell that the range can be lowered by 40 – 50 % of the maximum summer range. In Sweden, Finland and Norway EV producers generally state in their information packages up to 50 % reduction in the vehicles driving range during winter. One should therefore expect even more reduction in north of Sweden, north Finland and parts of Norway with extremely cold temperatures.

3.3.2 EVs in Norway

The increase in numbers of EVs in Norway is partly caused by the many economical incentives and other advantages that the Norwegian authorities give to the EVs. The economic incentives help EVs to compete successfully with conventional combustion engine vehicles. The access to public transport lanes and free parking is in addition essential to the Norwegian EV owners.

The typical EV owner in Norway is a person with three or more children, has higher education and high employment participation. The EV is often the second vehicle in the family, since most likely there is more than one vehicle in the family that has acquired an EV. Especially, the owners appreciate access to the public transport lanes and free use of toll roads and state-owned ferries.

Surveys among EV drivers' attitude suggest that their choice of EV is not only caused by the EV's advantages as a practical and economical car alone. They strongly appreciate EV positive contribution to the environment, in addition to the use of the public transport lanes on the roads, which they appreciate even more.

The length and the number of travels per day are important when considering buying an EV. The reasons for this are that an EV generally needs to be recharged 8 - 12 hours, every day. Somewhat surprisingly 95 % of the private EV owners say that they use their EV as much in winter as in summer, and 80 % of the companies state the same.

Most of the EV owners have free parking at their workplace, and possibility to charge their EV free of charge. Of the owners of EVs 29 % are companies, 49 % are men and

22 % are women (2011). It can be inferred from the national surveys that access to efficient public transport reduces the need for a personal car and also an EV.

EVs are generally small vehicles, but the number of passengers in the EVs is in average the same as in conventional cars. Social activities are the type of trips with the highest number of passenger, 1.95 persons per vehicle in Norway. Of all journeys by car 63 % are done by the driver alone.

The EVs in Oslo are frequently used as commuting vehicles. They can bypass the rush traffic by using the public transport lanes, and they pass the toll rings free of charge. The producers report the maximum speed of their EV, which is important for driving on highways. It is expected that a high percentage of the EVs in Oslo are driven on a blend of highways and city roads.

Assessing range and performance of Electrical Vehicles in Nordic conditions EV drivers more frequently pass the toll rings in Norway than other drivers. Two main driving patterns are typical for EVs in Norway:

- City driving
- Commuting to city centres.

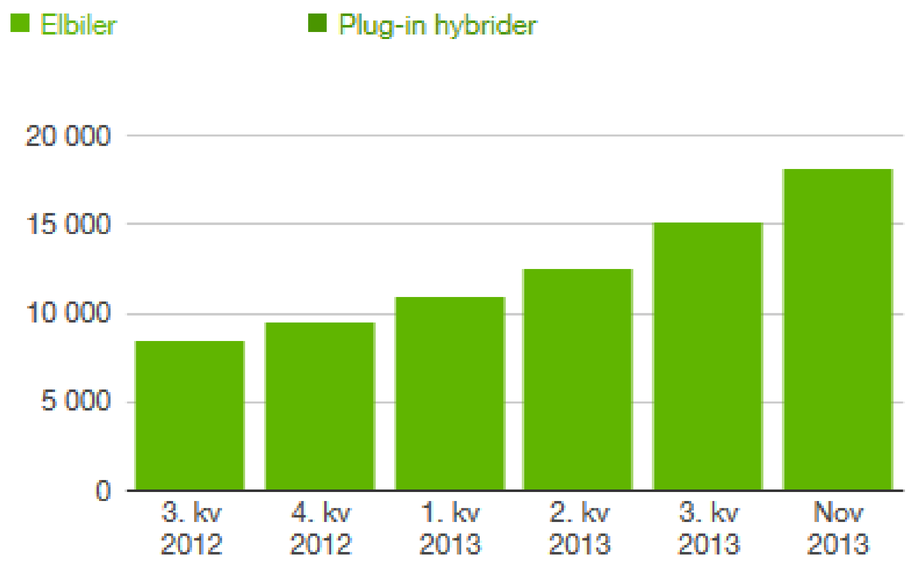

Figure 5 Growth in number of EVs in Norway 2012-2013 (Grønnbil 2013)

3.3.3 Car ownership

In Norway the idea about introducing and supporting EVs is that there, in order to be climate and environmentally superior, shall be competitive alternatives to vehicles with combustion engines. It is essential to know and understand the benefits of different segments of conventional cars and how they are used. When segments of conventional cars are found to be replaceable or almost replaceable with EVs it is possible to find the necessary incentives to make this replacements accepted by the market.

In Norway generally, the numbers of people without car ownership is fairly high in the main cities compared with the rest of the country. In Oslo 32 % of the population live in a household with no car, while the percentage for the whole country is only 13%. 97 % of the households with children own at least one car, and 54 % own at least two cars. Owing a car is higher among people who work than among non-working and retired (Vågane 2006).

From table 1 we can see that when the density of population gets lower, the number of cars in the household increases. Also the low availability of public transportation affects the amount of cars by increasing it. The number of cars increases with the increase of income and children in the household. These general conditions are expected not only to be true for ordinary cars but also for EV owners.

Table 1 Number of vehicles in a household after residency, access to public transport, income and family (Vågane 2006)

	No car %	One car %	At least one car %
Residence			
Oslo	32	49	18
Oslo environs	10	45	45
Bergen/Trondheim/Stavanger	21	54	25
B/T/S environs	5	47	48
Minor towns	9	49	41
Rest of Norway	9	44	47
Possibility of Public transport			
Very good public transport supply	28	50	22
Good public transport	11	53	36
Average good public transport supply	10	48	43
Bad public transport supply	7	43	49
Very bad public transport supply	5	42	52
Income			
0-200 000	61	35	4
200000-399999	28	63	10
400000-599999	10	65	25
600000-799999	2	50	48
80000-999999	2	43	55
1000000 -	2	34	64
Familiy			
One person	42	53	5
Household with children	3	42	54
Household with no children	12	52	36
All	**13**	**48**	**39**

Looking specifically at the EVs, a large number of them is owned by companies. There is no big difference between genders regarding ownership of EVs and ownership of ordinary cars in Norway 49 % men and 22 % women. The typical EV owner is a person with children, higher education and higher employment rate than the average car owner. EVs are often the second vehicles in the family, since all the indicators show that an EV household most likely has more than one vehicle in the family.

3.3.4 How cars are used

The car is without doubt the most important mean of passenger transport in Norway. Most people use it for travelling to their workplace. In general, the population in the larger towns of Norway drive less than the population in smaller towns and the minor towns (Vågane 2006). However, we have not found available data describing the EVs driving patterns in Norway.

3.3.5 Analysis of driving

Based on a series of interviews in the Norwegian national travelling survey the overall average length of a trip was calculated to be 3.3 km with 23 minute duration (Vågane et al. 2011).That average trip has an average speed of 29.5 km/hour. An average person older than 13 year, travels 38.5 km per day which makes the total duration of traveling per day 76 minutes. The average number of trips per day was 3.3. The number of trips has been relative stable from 1992 to 2009 (figure 8), but the average length of the traveling has slightly increased from 1992 to 2009.

Figure 6 Average number of trips per day (Vågane et al. 2011)

Table 2 Daily trips measured in km and minutes

	1992	2001	2005	2009
km/day	32,1 km	36,8 km	37,4 km	42,1 km
km/trip	3,12 km	3,09 km	3,33 km	3,3 km
Min/trip	19 min	20 min	21 min	23 min
Min/day	59 min	62 min	70 min	76 min

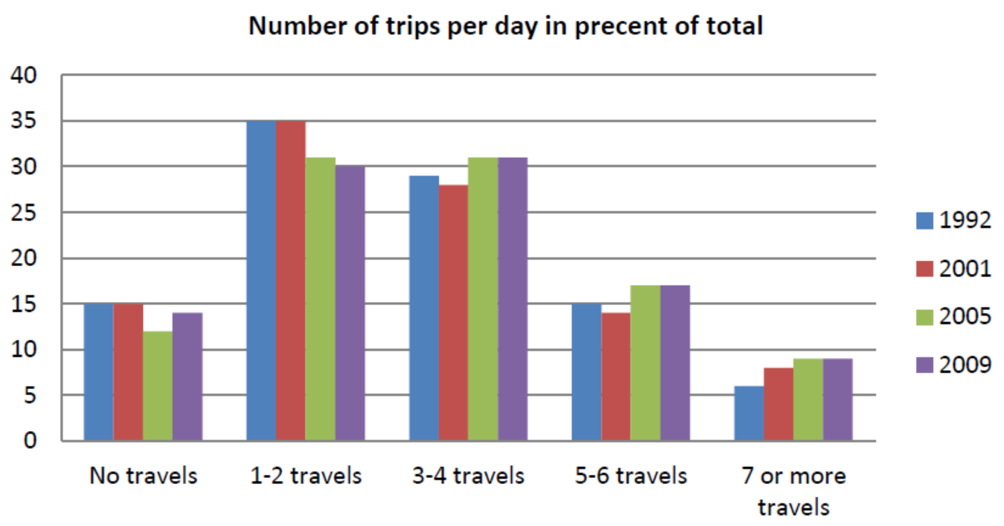

Figure 7 Number of trips (travels) per day from 1992 to 2009 (Vågane et al. 2011)

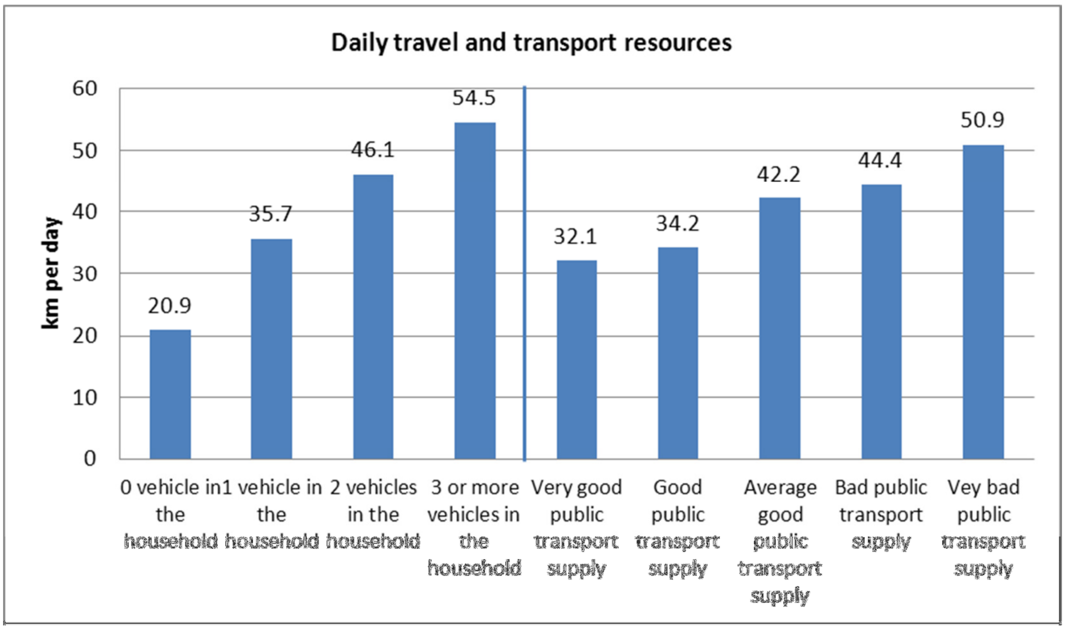

Figure 8 Daily travelling related to accessibility of vehicles and public transport accessibility (Vågane et al. 2011)

From figure 10 we see that high daily travelling distance is correlated to "Very bad public transport". Owners of EVs often have two or more vehicles per household and the potential of using their EV for daily driving should be high for most households.

According to figure 11, the daily travelling distances of the Norwegian population show that the people living in the surroundings of Oslo in average travel 48 km per day. The people living in the surroundings of the three other larger cities in Norway (Bergen, Trondheim and Stavanger) do not travel as much as people living in Oslo. People living in minor cities generally travel a little more (39 km/day) than people in big cities (30 to 35 km/day).

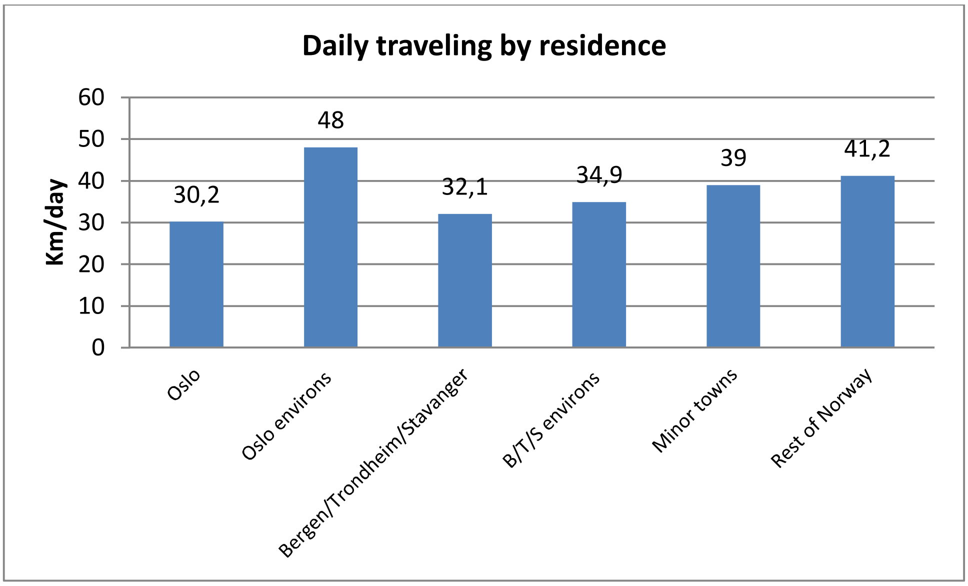

Figure 9 Daily traveling in km per person (Vågane et al. 2011)

We see from figure 12, that the level of income also is correlated to the daily traveling distance. In average, higher income corresponds to longer distances of travelling per day.

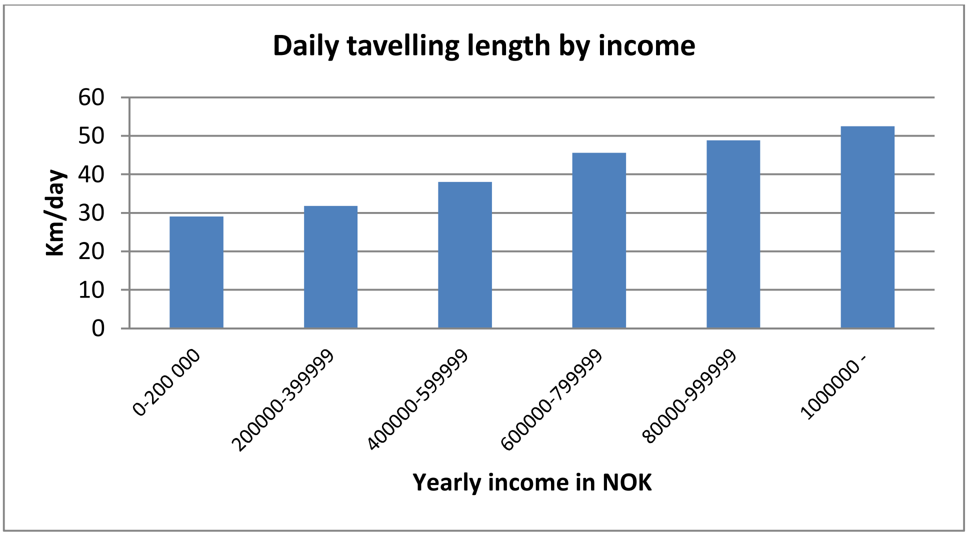

Figure 10 Daily travelling by yearly income in NOK (Vågane et al. 2011)

3.3.6 Purpose of the trips made by car

According to the data shown in Figure 13, most of trips in amount made by car are associated with shopping and taking care of daily errands (30 % in 2005). However, these trips are mainly short. When talking about the distance most of the traveling (33 %) was related to work related errands.

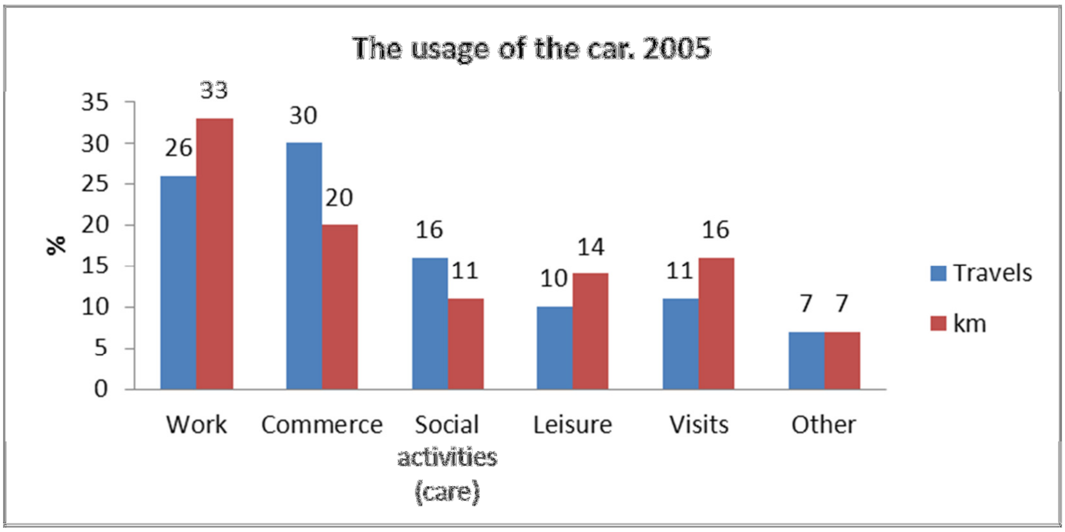

Figure 11 Travelling by car – percentage of trips and distance accessed with different purposes of travelling, Norway 2005 (Vågane et al. 2011)

3.3.7 Average passenger occupation

The number of passengers in a car is usually very low in Norway. Trips to work are mainly done with only one person in the car. Other journeys, such as journeys for daily errands, social activities etc. are mainly done together with some passengers on-board. However in general with all types of travelling the number of passengers is low (figure 14). Most of the trips are done by the driver alone (63%), 25 % are with one passenger and only 7 % are with three passengers.

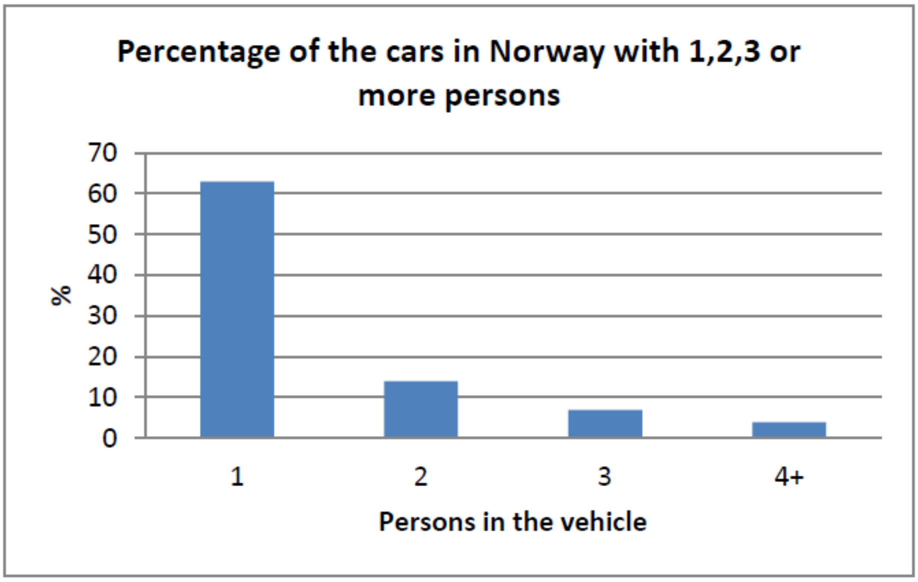

Figure 12 Percentage of the cars in Norway with 1, 2, 3 or more persons (Vågane 2006)

3.3.8 Number and distribution of EVs in Norway

EV owners generally live in all the main cities of Norway but the EVs are first and foremost concentrated in the Oslo region. By comparing the winter climate and average temperature map with the EVs locations in Norway can be seen that most of the EVs are located in regions with moderate cold weather. However also in many of the "milder climate" location, like for instance Oslo, the extreme temperatures in the winter can get as low as - 25 °C.

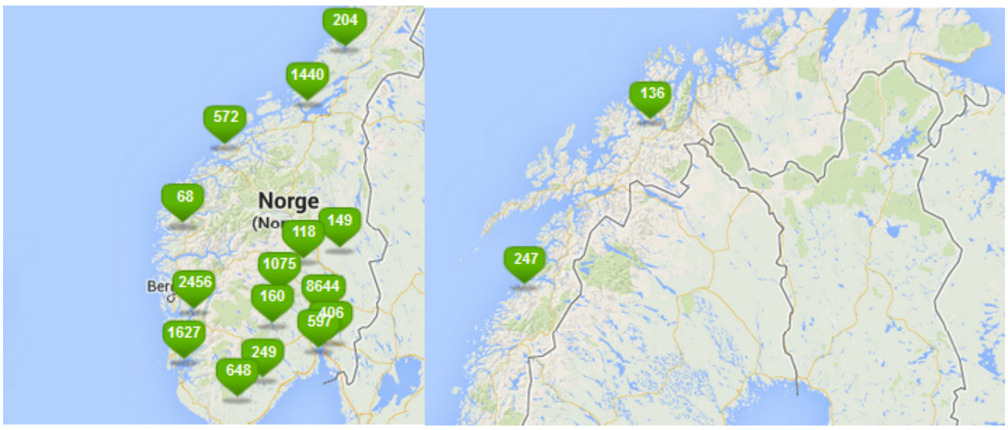

Figure 13 Location and number of EVs in the Norwegian counties (fylker) 2013 (Grønnbil 2013)

EVs have a high political image and the policy in Norway encourages dealers to offer EVs as an alternative to conventional vehicles.

3.3.9 Reduced range due to cold temperature

In cold temperatures the performance of the batteries is reduced and vehicle driving resistances are higher, hence reducing the EVs driving range. When the temperature drops the chemical reactions in the battery are getting slower and most of the batteries can't produce the same electric power and as when temperatures are around 20 °C.

A change of ten degrees (from +10 °C to -10 °C) can reduce as much as 50 % of a battery's output. In some situations the chemical reactions can be so slow and provide so low power output that the battery will appear to be dead that when it in fact if it is warmed up will return back to normal output (Johannsen 2011).

Due to the problems with low temperatures, the producers often install some kind of battery heater for the batteries to be efficient also during the coldest months of the year. The producers often give a driving range estimate for the winter climate along-side with the summer conditions. However, the producers do not state the range as a function of temperature. The numbers shown in table 3 are examples of the information given by the suppliers about driving range and climate impact.

Table 3 Winter and summer driving range information for some EVs available in the Norwegian marked (Norstart 2010)

Name	Type of batteries	Range	Top speed	Seats	Price (NOK)
Buddy	Lead Nickel hydride	30-80 km 60-120 km	80 km/t	3	124 900 169 900(2 seats)
Think City	Sodium Lithium	160 km	100 km/t	2 4	240 000 (2 seats) 244 000 (4 seats)
Mitsubishi i-MiEV	Litium	150 km	130 km/t	4	239 900
Nissan Leaf	Lithium /ion	155 km	145 km/h	5	264 000
Citroën C-ZERO	Litium	150 km	130 km/t	4	239 900
Peugeot iOn	Litium	150 km	130 km/t	4	239 900
Fiat 500 Electric-	Litium	130 km	110 km/t	4	420 000
Fiat Fiorino Electric-	Litium	100 km	100 km/t	2 (van)	400 000
Fiat Fiorino Electric-	Litium	100 km	100 km/t	5	400 000
Fiat Qubo Electric-	Litium	100 km	100 km/t	5	400 000
Tazzari Zero	Litium	60 – 130 km	100 km/t	3	169 900
Tesla Roadster	Litium	390 km	200 km/t	2	700 000

Figure 16 shows information of the Nissan Leaf driving range in different temperatures.

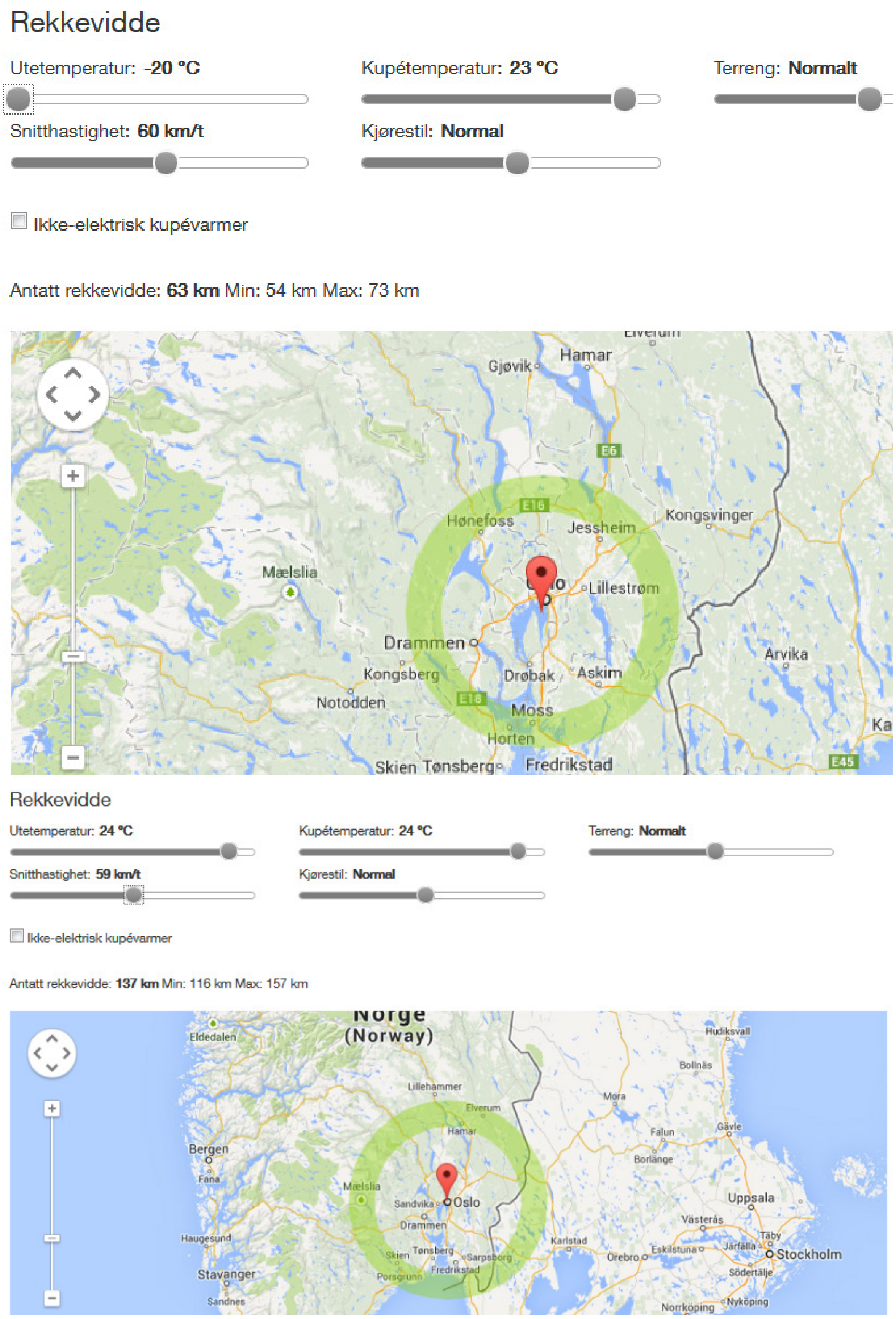

Figure 14 Nissan LEAF Gronn bil range calculator results at -20 C and +23 C (2013)

3.3.10 Seasonal variations in the use of EVs

Research by "Econ analyse" interestingly shows that the use of EVs doesn't have much season variations. In a survey with 703 respondents, 95 % of the private EV owners state that they use the vehicle as much in winter as in summer, and 80 % of the companies who state the same (Econ analyse 2006).

The travelled mean distance per day for EVs by residency in Norway and corresponding mean winter temperature in 2006 from the "Econ analyse" report is shown in table 4.

Table 4 Traveled mean distance (km per day) by residency (Econ analyse 2006)

Residence	km per day	Mean °C December – February
Oslo	44,8	-8 - -4
Oslo environments	50,6	-8 - -4
Bergen/Trondheim/Stavanger	34,4	0,1 – 4
B/T/S environments	42,1	0,1 - 4
Minor towns	42,6	n/a
Rest of Norway	45,3	n/a

"Grønnbil" conducted a non-scientific survey and analysis of among 700 vehicles in public services. Table 5 summarises the results. The result of the analysis showed that approximately 90 % of the vehicles were driven up to 50-100 km per day. There seemed to be small or no differences in driven distances between different EV models and brands.

Table 5 Daily mileages of vehicles in municipal services (Grønnbil correspondence)

Class	Daily milage in km				
	<50	50-100	100-150	>150	Totalt
Economy/Mini	2,7 %	0,1 %	0,0 %	0,0 %	**2,8 %**
Compact	26,1 %	20,8 %	3,5 %	1,1 %	**51,6 %**
Family size	2,1 %	4,5 %	1,0 %	0,1 %	**7,8 %**
Large size	2,1 %	2,7 %	1,0 %	0,6 %	**6,4 %**
Small van	3,1 %	0,7 %	0,1 %	0,0 %	**4,0 %**
Large van	8,3 %	12,7 %	2,0 %	0,6 %	**23,6 %**
Pickup	2,4 %	1,1 %	0,1 %	0,3 %	**4,0 %**
Total	**46,9 %**	**42,7 %**	**7,8 %**	**2,7 %**	**100,0 %**

According to table 6, EV generally are found in the major cities of Norway, especially around Oslo where the numbers much higher than in the rest of the country. In the Oslo area, the western parts show to be the more attractive for EV ownership. Bærum has 3.1 EVs and Asker has 8.2 EVs per 1000 citizens. In comparison Oslo has in average 1.2 and Norway has 0.6 cars per 1000 citizens (Asplan Viak AS 2009).

Table 6 EVs per 1000 citizen in Norway and Oslo area (Asplan Viak AS 2009

Area	Number of EVs per 1000 citizen
Norwegian average	0,6
Bærum	3,1
Asker	8,2
Western part of municipal Oslo	4,8
Oppegård, Ski, Ås, Nesodden, Lørenskog, Nittedal	0,7
Oslo area average	1,2

A survey from 2009 compare the owners of the EVs with average car drivers in Oslo, Trondheim and Bergen (Asplan Viak AS 2009). The survey show that the average EV owner is younger, has higher education, higher employment participation and have more children than the average car owner. 72 % of the EV owners belong to households with 3 or more children.

The EV drivers pass through toll rings more frequently than other drivers. The high frequency of the EV drivers passing toll rings is shown in figure 17. The Prosam report show that access to public transport lanes is important for EV owners, and a main reason for them to purchase an EV. High traffic density, public traffic lanes and toll road rings are typical for the western outskirts of Oslo.

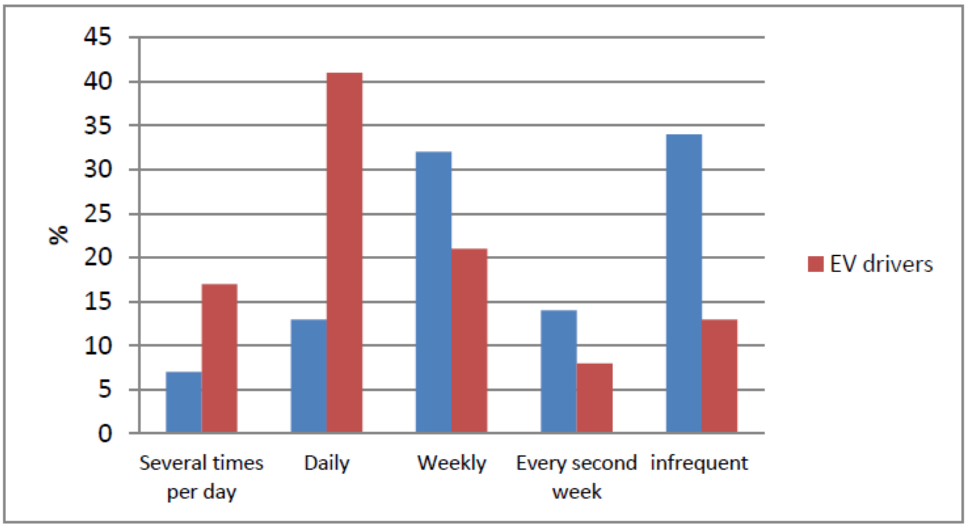

Figure 15 Frequency of passing through toll rings. EV drivers (red staples) compared with conventional car drivers (blue columns) (Asplan Viak AS 2009)

3.3.11 The frequency of use

EVs owned by private users are frequently in use. In a survey conducted in 2006 almost all of the 200 respondents (97 %) stated that they use their EV at least 4 times a week. 78 % used the EV six or seven times per week (Econ analyse 2006). There is however significant differences between private owned and company owned EVs in how the EVs are used.

Companies tend almost never to use the EV on trips over 60 km. Private owners more often make these kind of trips. About 50 % of the private owners use their EV for trips longer than 60 km, once a week or more, while the corresponding figure is 20 % for the company owned EVs.

3.3.12 The timing of the use

The EVs is frequently used both in rush hours and outside rush hours. Private users however tend to use their EV to and from work, thus travelling very frequently in rush hours. On the other hand companies use their EV during all day, and more infrequent the company-EVs are used outside work hours and in the weekends.

The private EV owners however also use their EVs less in weekends than during the rest of the week (Econ analyse 2006). 90 % of the private EV-owner respondents stated they had a fixed daily travel route (Econ analyse 2006). Almost all of these daily routes were to and back from work. If the trip to work is longer than 30 km, few people use an EV.

81 % of the private EV-owner respondents stated that they had free parking at their work-place, and 61 % stated that they also had possibility to charge their EV at their work-place free of charge. Only 38 % of the private EV-owner respondents stated that they had parking reserved for EVs.

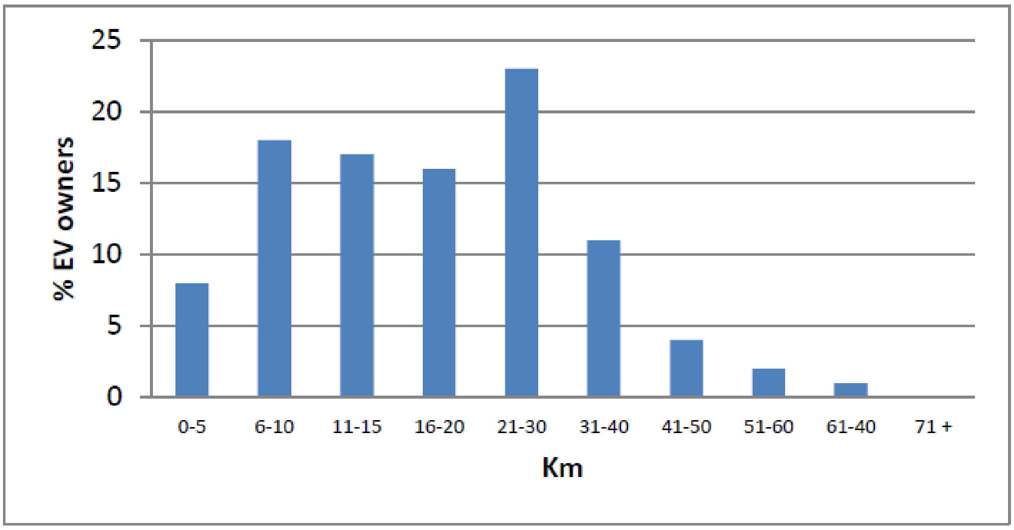

Figure 16 Distance from home to the daily destination for private owners of EVs

3.3.13 EV incentives in Norway

There are several incentives and advantages given to the EVs by the Norwegian authorities (Norstart 2011):

- Free parking at public parking places.
- Free use all toll roads.
- Access to use the public transport lanes.
- The annual fee (road tax) is 400 NOK, compared with 2 840 NOK for corresponding cars with combustion engine (in 2011).
- Free charging at public charging sites.
- Purchase of EVs is exempt from new vehicle registration tax and VAT.
- 50% discount on company car tax.
- Free ride for EVs on road ferries (driver must pay).

3.3.14 EV driver attitudes

Survey conducted on EV driver attitude towards these benefits suggest that their choice of EV is not dependent on the EV's benefits alone. They strongly appreciate EV positive contribution to the environment, except for the use of the collective lane on the roads which is even more appreciated.

When asked what the main benefits of EV's are, the owner of EV give somewhat different account than regular drivers. Fewer owners of EV than regular car drivers list the environment factor as the main benefit of EVs. "Inexpensive driving" and "access to collective lane" are other factors which the owners of EV point out as being the main benefits of EV, while regular drivers don't, figure 19.

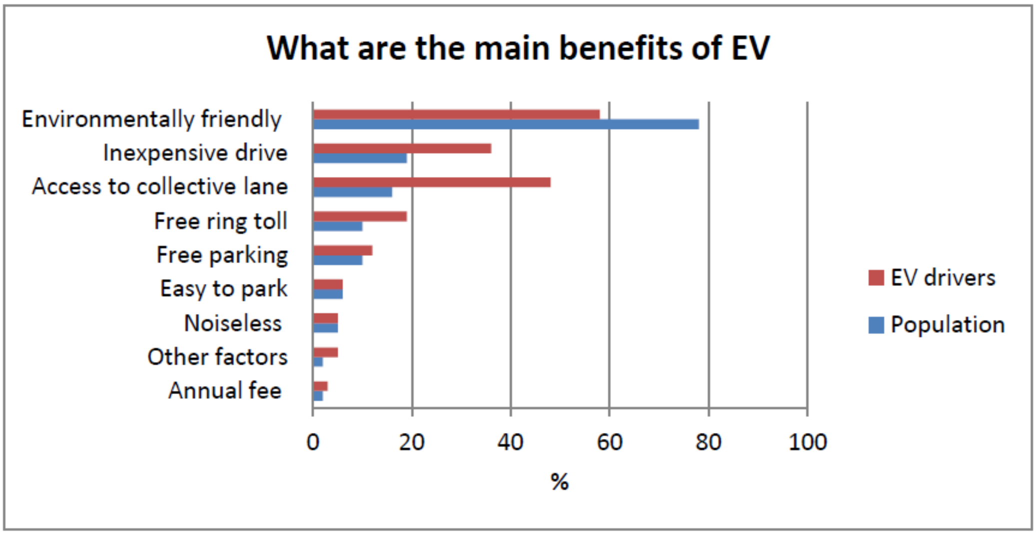

Figure 17 EV-drivers' opinion about the main benefits of EVs

From these results it seems like that the incitements from the government are important for the EV drivers. And some EV owners may even go back to normal vehicles if the accesses to collective lanes are denied them.

The importance EV drivers give to the access they have to the collective lane, free ring toll does explain why the number of EV owners are much higher in the Bærum and Asker area. There is heavy morning and afternoon rush from these areas to Oslo.

Good collective lanes and ring tolls have helped to increase the EVs popularity in these areas. We anticipate that typical EV owner don't have good access to the public transport supply.

Despite an average driving pattern with a high share of short trips that is perfectly suited for EVs, vehicle purchase is still rather determined by maximum range and performance requirements that cannot be completely fulfilled by EVs.

Because of the limited driving range, it is assumed that EVs may mainly be used as second cars for short distances, whereas a supplementary conventional vehicle would assure to cope with longer distances.

The use of electric vehicles is expected to be particularly suitable for households with private overnight charging capabilities b be offered poor public charging infrastructure

3.3.15 Fast charging

Short driving range and slow charging are limiting the market for of EVs. Charging the batteries is normally a slow process but the time for charging significantly reduced by so called "fast charging". Fast charging will make it possible to drive EVs much longer distances per day but there are also drawbacks as high costs and reduced lifetime of batteries.

Figure 20 shows the number and locations of fast charging units as 2013/11.

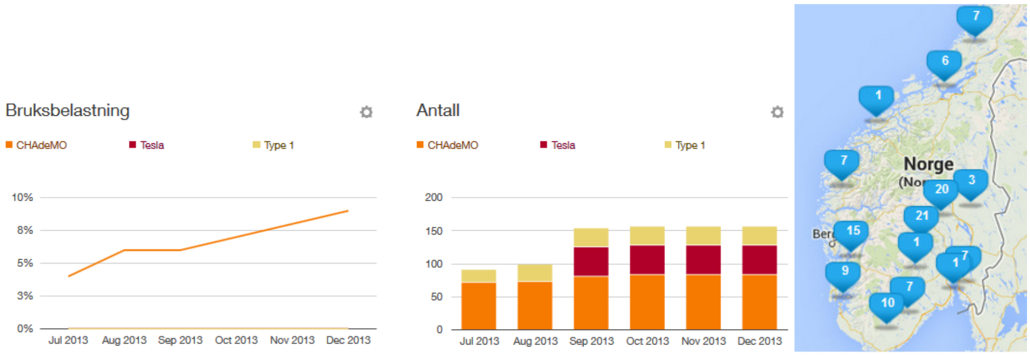

Figure 18 Fast charging (Gronn bil 2013)

3.3.16 Driving patterns and test cycle

In the nineteen-seventies and the eighties the state of California in the USA asked the automobile industry to develop engines with higher efficiency and lower emissions, and established emission standards. Emissions cannot be specified without specified test procedures to compare vehicle with each other. A test procedure first of all must specify a driving cycle that describes how the tested vehicle shall be driven during the test (Metricmind 2010).

A driving cycle is a standardized driving pattern. This pattern is described by velocity versus time. The distance to be driven is divided in time-steps (seconds). The acceleration during a time step is assumed to be constant. As a result the velocity during a time step is a linear function of time (Ibid). Figure 21 shows a summary of several trip records for an EV and sort them into different types of driving. Typical driving patterns for EVs can be found by recording and analyse how a large number of EVs are driven. A relevant test cycle for EVs should a representative sample of typical driving patterns for these vehicles.

Since batteries are sensitive to cold temperatures and the capacity of the batteries are heavily reduced in cold Nordic climate it is important that the cold temperature effect is showed in a driving range test.

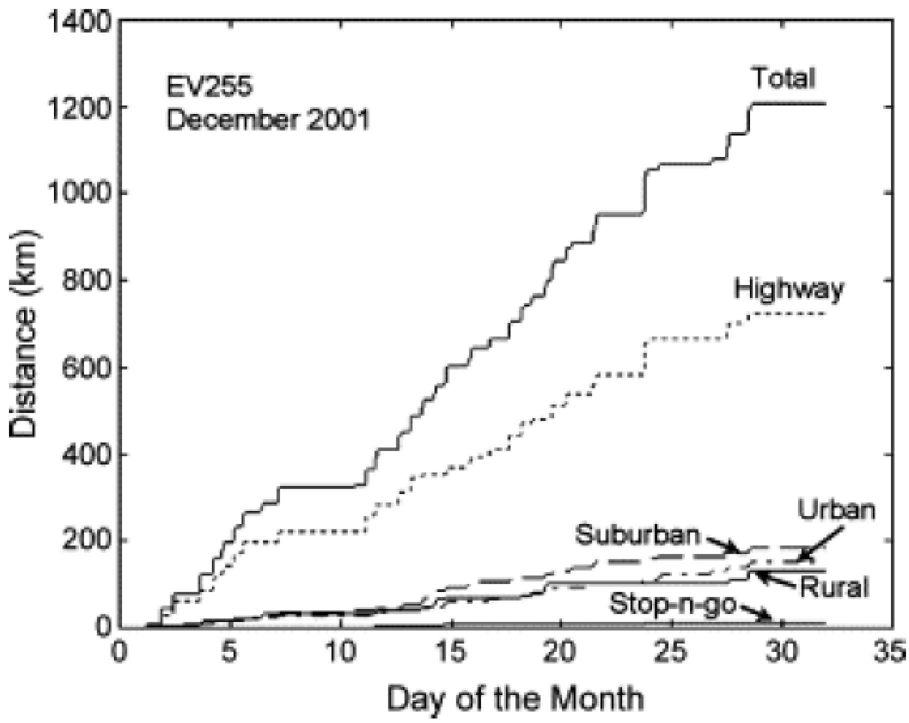

Figure 19 A monthly summary report on operation and usage of an EV (Liaw and Dubarry 2007)

3.3.17 EV driving patterns in Norway

The information we have about the use of EVs in the Nordic countries does not today allow us to specify very detailed patterns. We however from the current Norwegian experiences suggest a few types of driving patterns that are important to take into account when developing a test cycle for EVs to the Nordic countries.

- Urban driving
- Commuting to work in the city centre
- Short highway trips
- Performance in cold temperatures

Urban driving

Generally cars in Norway have an average driving distance in the main cities around 30-35 km per day, and an average speed of 35 km/h. EVs have a somewhat longer travelling distance in Oslo, about 45 km per day.

Commuting

The driving distance per day from the Oslo suburbs to the city centre is in average about 50 km per day for the EV users. The EV-users from the outskirts of the three cities, Bergen, Trondheim and Stavanger is about 42 km/day. About 80 % of the EV users say that their daily commuting one way is less than 30 km, and about 55 % say that they use less than 20 minutes in their daily commuting one way (Econ analyse 2006).

Short highway trips

When creating a driving cycle that is relevant for commuting, one should include both city driving and highway driving. Commuting from suburbs to city centres often include shorter or longer distances on highway and it is important that the EVs are capable of keeping up with the speed of the rest of the traffic.

Performance in cold temperatures

In the wintertime, the driving range of the EVs could fall with 50 % and make the possible driving range only 75 km. The real wintertime range is important information for people commuting and regarding an EV as an option. Even if only one percent of the population say that they commute more than 60 km one way, it is known that the battery capacity is reduced with time and number of discharging cycles.

4 In-laboratory testing (VTT)

The most important features of the driving conditions and style that characterize Nordic driving and differentiate it from the normative conditions used in type approval testing were determined to be ambient temperature, conditions of the road surface as well as the duty-cycle. All these parameters were selectively addressed in laboratory testing to assess their influence on the total energy use and hence to the driving range. See Appendix X for more details on laboratory test code.

4.1 Influence of duty-cycle and ambient temperature

The development of the test protocol started with a series of in-laboratory testing on a Citroën C-Zero EV to address the influence of duty cycle on the energy use. Duty-cycles that were used included the European type-approval cycle (NEDC), as well as a few more realistic cycles including two proprietary cycles developed by VTT (Helsinki City, Finnish Road cycle), and some more commonly known real-world cycles (Artemis Urban, Artemis Road as well as Artemis Motorway). Table 7 lists the main characterristics of these cycles, and their speed profiles are presented in a conference paper of the early work in this project. Usually each cycle was driven at least three times to assess the energy consumption. However, in some cases even more repetitions were used to completely discharge the battery.

Table 7 Main parameters of the duty cycles.

cycle	Running distance km	Av. speed km/h	Max. speed km/h	Stops during cycle	Total time s
NEDC	11.007	33.6	120	12	1180
ECE15	4.052	18.7	50	12	780
EUDC	6.955	62.6	120	0	400
Helsinki City	6.600	19.1	55	17	1360
Artemis Urban	4.488	17.6	58	19	993
Road, FIN	24.800	81.3	120	1	1370
Artemis Road, EV*	16.641	60.3	111	1	981
Artemis Motorway, EV*	23.793	105.6	130	0	736

*EV denotes that warm-up part of the cycle is omitted

Apart from the effect of driving cycle, ambient temperature was also addressed in this initial laboratory testing phase. Cold temperature increases the density of the air over normal temperature. Thus, the average road-load was raised by 10 % at -20 °C compared to +23 °C to correspond with the 16 % nominal increase in air density and the air drag component. This ambient temperature effect varies between duty-cycles because of their different speed profiles and average speeds. The effect of temperature in theoretical work over the cycle was at most in Artemis Motorway cycle (+9.1 %) and lowest in Artemis Urban cycle (+1.4 %). Other additional resistances that are due to the low temperature were not simulated, because most of the effects like increased rolling resistance of colder and stiffer tyres as well as higher friction in the wheel bearings etc. occur in a cold-test chamber as they would in real-world driving. There-fore, it was not necessary to make any additional adjustments to the road-load model of the dynamometer.

Figure 22 shows the test set-up at VTT's test facility where in addition to the temperature control of the ambient air, near-realistic cooling effect of the driving thru cold air is also simulated with a blower delivering air blast thru a 1.0 m x 1.2 m duct with a speed following the simulated driving speed. However, due to the power limitations, the maximum air speed is limited to 100 km/h.

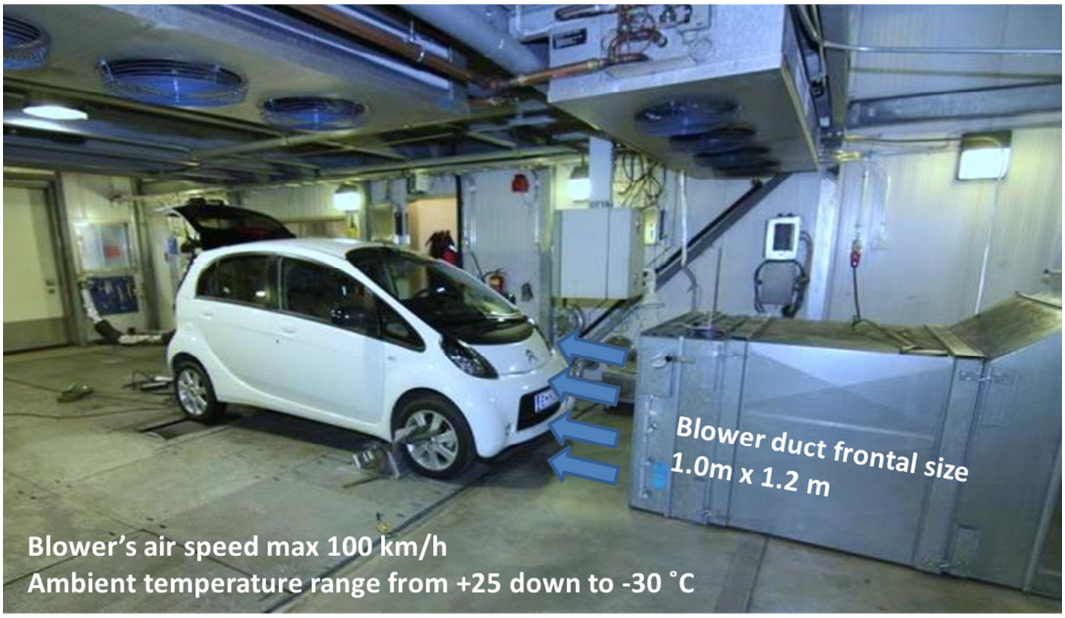

Figure 20 Laboratory test facility for electric cars and other light-duty vehicles at VTT, Finland

Table 8 lists the measured electricity uptake form the grid that was necessary to re-charge the battery after driving tests with the duty-cycle in question. The recharging was in all cases conducted also at the same ambient temperature as the driving had occurred.

Table 8 Measured energy uptake from the grid for each cycle and temperature.

	+23 °C	±0 °C	-20 °C
cycle	kWh/km	kWh/km	kWh/km
NEDC	0.141	0.160	0.192
Helsinki City	0.137	0.148	0.173
Artemis Urban	0.178	n/a	0.239
Road, FIN	0.189	0.214	0.251
Artemis Road, EV*	0.157	n/a	0.195
Artemis Motorway, EV*	0.244	n/a	0.329
average, urban	0.158		0.206
average, road	0.196		0.258
average, all cycles	0.174		0.230

Effect of temperature

cycle	ratio	ratio	ratio
NEDC	100 %	+14 %	+36 %
Helsinki City	100 %	+8 %	+26 %
Artemis Urban	100 %		+34 %
Road, FIN	100 %	+13 %	+33 %
Artemis Road, EV*	100 %		+24 %
Artemis Motorway, EV*	100 %		+35 %
average, all cycles	100 %	+12 %	+31 %

When we look at the relative impact that the ambient temperature had to the energy uptake we immediately notice how much more the energy use was increased over the theoretical workload that was calculated on the basis of higher air resistance alone.

The increased theoretical work in urban cycles was about 2 %, but the actual energy uptake was on average some 30 % higher. Furthermore, in road cycles the theoretical increase was some 8 %, but according to our measurement results the energy uptake increased by about 31 %. This must be due to the increased resistances of cold and stiff tyres and higher friction rates all over the drivetrain, as mentioned earlier.

It would have been interesting to measure separately the net energy drawn from the battery over the drive cycle but due to the limitations and difficulties in accessing the leads, we could not make this measurement. However, we deem that these gross values are equally valid to calculate the impact of increased energy use due to the cold temperature on driving range if we also use the gross energy uptake of recharging a fully depleted battery as the reference. In this case a fully depleted battery needed 17.8 kWh of grid electricity to reach 100 % SOC. It was noteworthy that we did not note this amount to be differentiated by the ambient temperature, but the same amount of energy could be drown from the battery and re-charged at normal and at low ambient conditions.

Table 9 lists the estimated ranges for each duty-cycle and ambient temperature. Based on these calculations, the driving range was 126 km in normal ambient temperature when using NEDC driving cycle. When using the Helsinki City cycle the range was even 2 % higher, probably due to the higher potential for energy regeneration that this cycle presents over the NEDC and Artemis Urban cycle that correspond to 100 km range. According to our measurements, road driving would yield to 94 km range on average.

When looking at the results measured at the intermediate temperature (±0 °C), we see that when driving like Helsinki City cycle, the range drops only by 7 %, but in Artemis Road cycle the impact was much stronger, as more than 30 % shorter figure was estimated.

At the lowest tested ambient temperature (-20 °C) the Helsinki City cycle sustained its position as in relative figures the range was only 18% shorter than for NEDC in normal ambient. Also the results for Artemis Road cycle show less than 30 % decrease in range. However, using the Artemis Motorway cycle lead to the strongest impact, as the estimated range for this cycle in this temperature was nearly 60 % shorter than the respective figure for type-approval cycle and normal ambient conditions.

Table 9 Estimated ranges for each duty-cycle and ambient temperature.

	+23 °C	±0 °C	-20 °C
cycle	km	km	km
NEDC	126	111	93
Helsinki City	129	120	103
Artemis Urban	100	n/a	75
Road, FIN	94	83	71
Artemis Road, EV*	114	n/a	91
Artemis Motorway, EV*	73	n/a	54

cycle	ratio	ratio	ratio
NEDC	100 %	-12 %	-27 %
Helsinki City	+2 %	-5 %	-18 %
Artemis Urban	-21 %		-41 %
Road, FIN	-25 %	-34 %	-44 %
Artemis Road, EV*	-10 %		-28 %
Artemis Motorway, EV*	-42 %		-57 %

4.2 Influence of road surface

Furthermore, the rolling resistance of various road surfaces were determined by coast-down tests on a track in north of Sweden during winter 2012 by TSS. Coefficients were determined for dry asphalt at ambient temperatures of +23 °C, ±0 °C and -20 °C, as well as for old snow and newly fallen snow at -20 °C.

These coefficients were then used to aggregate the effect of road surface on the total road load calculations. The increase in calculated theoretical work needed at -20 °C to complete the duty cycles that were used in this work varied between +6% (Artemis Motorway) and +12 % (ECE15), and the rest of the cycles fell between these figures.

Tests were performed at -20 °C with a subset of duty-cycles (NEDC, Helsinki City, Finnish Road Cycle) using rolling resistances simulating those three different road surface conditions. As in previous test phase, each cycle was run at least three times, and the electricity uptake from the grid was determined when recharging the battery after the test run. Table 10 lists the results in kWh/km, as well as relative to the value measured for clean, dry asphalt.

Table 10 Measured energy uptake from the grid for each cycle and temperature

road surface ambient temperature	asphalt -20 °C	old snow -20 °C	new snow -20 °C
cycle	kWh/km	kWh/km	kWh/km
NEDC	0.192	0.196	0.201
Helsinki City	0.173	0.211	0.208
Road, FIN	0.251	0.267	0.267

cycle	ratio	ratio	ratio
NEDC	100 %	+2 %	+5 %
Helsinki City	100 %	+22 %	+20 %
Road, FIN	100 %	+6 %	+7 %

As seen from the figures in Table 11, road surface had only a minor effect (5 to 7 %) in those duty-cycles that have higher proportion of high-speed driving (NEDC and Road), whereas in Helsinki City cycle, which is a clearly urban "stop-and-go" type of cycle, the higher rolling resistance made a 20 % increase in energy uptake.

The effect of this increased energy consumption was also reflected in the estimated ranges figures for each tested case. Table 11 show the result of these calculations.

Table 11 Estimated ranges for each duty-cycle and road surface condition

road surface ambient temperature	asphalt -20 °C	old snow -20 °C	new snow -20 °C
cycle	km	km	km
NEDC	93	91	88
Helsinki City	103	84	86
Road, FIN	71	67	67

cycle	km	km	km
NEDC	100 %	-2 %	-5 %
Helsinki City	100 %	-18 %	-17 %
Road, FIN	100 %	-6 %	-6 %

Based upon the figures in Table 11, we can conclude that the relative shortening of the range due to the snow coverage on the road surface was quite small in NEDC and Road cycles, but nearly 20 % in Helsinki City cycle, corresponding directly to the increased energy use.

4.3 Cabin heating and ventilation

4.3.1 Electric-only heating

Cabin heating and ventilation is a substantial consumer of energy in a car. In a regular ICE-powered car, surplus heat is available to heat the cabin. However, in an EV the losses are so small that prime battery energy must be used for heating. Therefore, in addition to the energy needed for driving in cold and snowy conditions, the use of electric heater was separately addressed.

Based on the measurements and simulations, the conclusion was that the use of the 4.5 kW PTC heater that the test car (Citroën C-Zero) was equipped with, seriously increased the total energy use and subsequently cut down the range. Its impact was estimated by approximating the amount of driving energy on the basis of theoretical energy need, and adding some 10 % for parasitic losses.

Table 12 lists the measured and calculated total energy needs for driving as well as for heating at +20 °C and at -20 °C, as well as the effect of heater energy on total energy use and range for all tested duty-cycles at -20 °C.

Table 12 Estimated driving energy need and range at +20 °C and at -20 °C, and the effect of heater energy on total energy use and range for all tested duty-cycles

	+23 °C		-20 °C w/o and with PTC heater (4.5 kW)					
cycle	driving energy* kWh/km	est. range km	driving energy* kWh/km	est. range km	heater energy** kWh/km	total energy kWh/km	est. range km	relative impact %
NEDC	0.121	124	0.129	88	0.134	0.263	43	-51 %
Helsinki City	0.116	130	0.118	96	0.236	0.354	32	-67 %
Artemis Urban	0.143	105	0.145	78	0.256	0.400	28	-64 %
Road, FIN	0.169	89	0.184	62	0.055	0.239	47	-23 %
Artemis Road, EV*	0.129	117	0.137	83	0.075	0.211	54	-35 %
Artemis Motorway, EV*	0.205	73	0.224	51	0.043	0.266	43	-16 %
	*theoretical road load +10%				**calculated			

Table 12 shows that according to our measurements the car can reach up to some 130 km in urban driving and about 90 km on road in normal ambient. However, when the ambient temperature drops to -20 °C, and when the heater is turned full on to get the windshield defrosted and cabin heated, the range will drop by more than 60 % to only some 30 km in the slow urban driving. Thus the total relative effect is -67 %. In road driving the impact is less, some -25 %, but in mixed driving (NEDC) also about -50 %.

Furthermore, use of the heater was assumed constant at full power. However, in practice a PTC-type of heater will adjust its power according to the temperature, so full power may not be on anymore, when the cabin gets warmer. Therefore, the impact of the heater may not be as distinct as estimated here, but based on the measurement of cabin temperatures, the heater is by no means overpowered at ambient temperatures around -20 °C.

Figure 23 illustrates the combined effects that each key parameter has on the range in NEDC and Helsinki City driving.

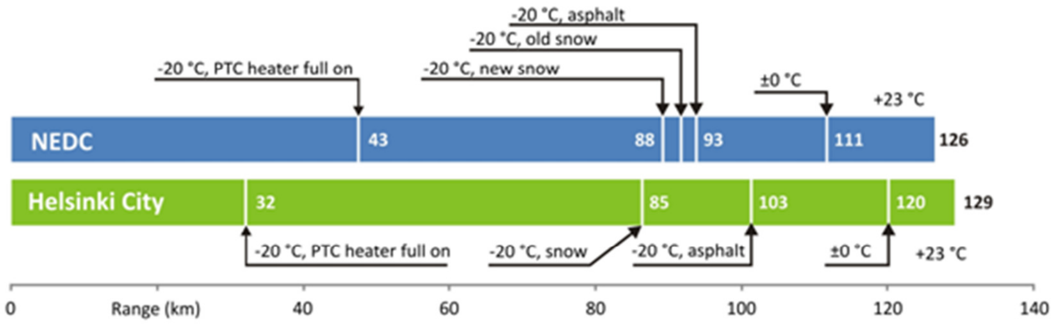

Figure 21 The influence of ambient temperature and road surface on range; NEDC and Helsinki cycles

4.3.2 Use of fuel-fired heater

In another series of tests the merits of a fuel fired heater use in an EV were evaluated. The test vehicle was regular 2012 model year Nissan Leaf, but fitted with an extra fuel-fired heater using petrol. A further more elegant solution could be to use bioethanol, such as in Volvo C30 electric that was measured by TSS in their field-test effort.

Table 13 lists the results of that exercise.

As we can see from the figures in Table 13, the measured grid energy uptake was at +23 °C some 15 to 25 % over the calculated theoretical work to drive the cycle. However, if the ambient temperature was lowered to -20 °C, and car's own heater was engaged by setting +23 °C as the target cabin temperature, this extra energy use jumped by 200 to 250 % in NEDC and Helsinki City cycle, and over 80 % in Road cycle with higher average speed and thus shorter relative running time per km, meaning also less running time for the heater.

Furthermore, when turning to the figures measured for the fuel-fired heater we can see that the electric energy uptake was markedly lower in the slower cycles, but less with the road cycle.

If we calculate the estimated ranges using the measured energy consumption figures, we can see that with the nominal 25.3 kWh battery capacity observed for this car, the range would suffer markedly, if the electric heater is on. If the range in normal ambient conditions is between 130 and 150 km depending on the type of duty-cycle, it shall drop at -20 °C with heat on to only about 50 to 75 km, i.e. roughly to a half.

However, if the fuel-fired heater is used instead, the range is much higher, between 85 and about 115 km. The "gain" from the extra fuel-fired heater is at best in slow-speed Helsinki City cycle (65 km), but not significant in Road cycle, only 10 km. If most of the driving takes place in urban environment at low temperatures, the extra fuel-fired heater would definitely be a valuable asset in fighting the loss of range.

Table 13 Energy use and estimated range using electric or fuel-fired heater, Nissan Leaf 2012

ambient	+23 °C		
	no heat		
	theor.	measured	diff.
cycle	kWh/km	kWh/km	%
NEDC	0.135	0.168	+24 %
Helsinki City	0.146	0.184	+26 %
Road, FIN	0.170	0.198	+16 %

ambient	-20 °C		
	own electrical heater		
	theor.	measured	diff.
cycle	kWh/km	kWh/km	%
NEDC	0.142	0.439	+209 %
Helsinki City	0.147	0.522	+254 %
Road, FIN	0.186	0.340	+83 %

ambient	-20 °C		
	fuel-fired heater		
	theor.	measured	diff.
cycle	kWh/km	kWh/km	%
NEDC	0.142	0.258	+82 %
Helsinki City	0.147	0.224	+52 %
Road, FIN	0.186	0.299	+61 %

ambient	-20 °C		
	heater		
	electric	fuel-fired	gain
cycle	km	km	km
NEDC	58	98	40
Helsinki City	48	113	65
Road, FIN	74	85	10

Furthermore, the cabin heating and windshield defrosting was much quicker with the fuel-fired heater compared to the standard electric system. However, we must bear in mind that Nissan has announced that the 2013 updated model of Leaf shall have much better heating and ventilation system than the original version. Unfortunately, it was not possible within the present work to test the new model and compare results to the first-generation car.

5 Field-testing (TSS)

5.1 Test track for EVs in real winter

Part of the testing activity in the RekkEVidde project was conducted in Northern Sweden, where several test tracks are built for the use of the vehicle manufacturing industry. One particular track operated by Arctic Falls AB called “Vitberget” (White Mountain), situated in Älvsbyn, was used in this project. Figure 24 shows an aerial view of the complete track area.

Figure 22 Test track "Vitberget" in Älvsby, Sweden, operated by Arctic Falls AB. (Photo courtesy of Artic Falls, www.arcticfalls.se)

We can quite clearly see the large circular track that was used to our testing. This track has length of 3.140 km, width of 7 m, and the track is level within ± 0.5 m to facilitate steady engine load and vehicle speed. The track is built for a speed of 110 km/h and has a camber of 5%. However, for safety reasons and because of the lower friction of the track surface during the winter season, we limited the maximum speed during EV testing to 100 km/h. Thus, we could not correctly match the speed profile of the NEDC cycle, but had to revise it to use maximum of 100 km speed instead of the officially stipulated 120 km/h, for 10 seconds. As the highest speed is used only very shortly, this "peak shaving" only means some 2 % lower total effort over the cycle.

Apart from the test track, the facilities at Vitberget include also temperature-controlled garages for overnight soak at steady pre-set temperatures, as well as instrumentation for measuring accurately the electric energy during the recharging of the batteries after testing is completed.

In track testing two main data acquisition systems has been used. One system is based on an instrument called "VBOX", which is capable of determining speeds, accelerations and distances based on GPS-positioning, and stores data on a solid-state memory card for later at-desk retrieval and computer analysis. Furthermore, it was equipped with a module to accept thermocouple input for multiple simultaneous temperature measurements time-synchronised with the rest of the data. This was useful e.g. in measuring how the cabin temperature raises after a start in cold temperature.

The other data acquisition system was employing the vehicles own on-board diagnostics system. Plugging-in a logger in the EOBD-socket enabled us to log-on to the CAN-bus, and retrieve real-time values of many useful parameters like state-of-charge (SOC) of the battery pack. This was very useful in determining the energy consumption of different driving styles and cycles during one test series without the need to recharge between the cycles. Figure 25 shows a plot of power and battery SOC in a Citroën C-Zero driven according to NEDC-cycle (modified for 100 km/h top speed) on the circular track at -20 °C.

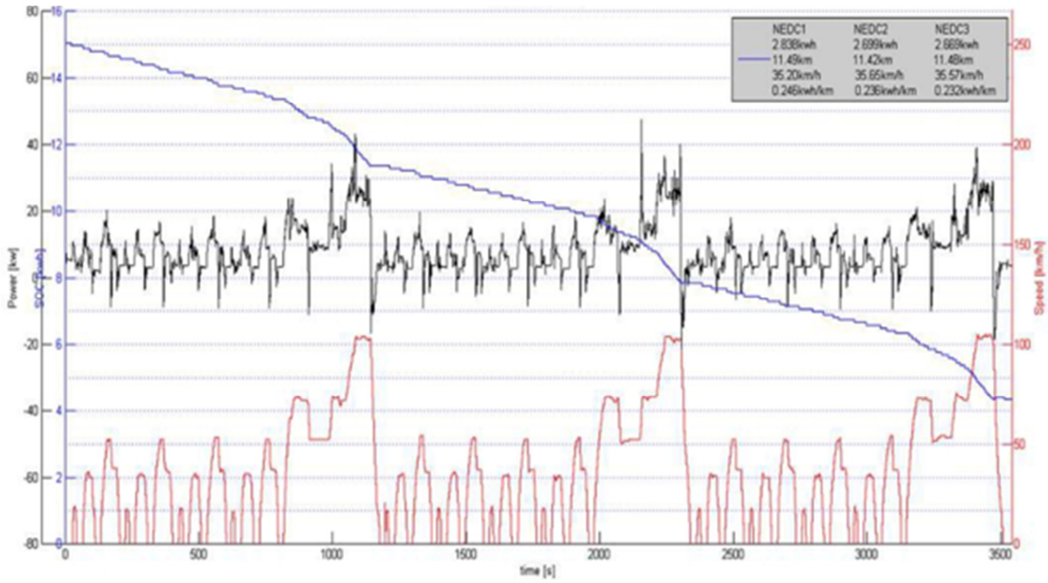

Figure 23 Power and SOC in three repetitions of NEDC-cycles driven with Citroën C-Zero on the circular track

When comparing the cycle-specific results we can see that the repeatability was fairly good. Distance-wised the results were on average some 4% longer (11.463 km) than the theoretical distance for NEDC (11023 m), but the cycle-to-cycle variation was less than ±0.5 %. Furthermore, in spite of the limited maximum speed, the logged average speed (35.47 km/h) for those three cycles in this test session was some 6% higher than the theoretical value (33.6 km/h). The average energy consumption recorded was 0.238 kWh/km, but the cycle-specific values were somewhat different. The first run of NEDC yielded to a figure 24.4% higher than the average, the second run was -0.8 % below the average, and the final third run was -2.5 % lower than the average. This is quite typical, because when you start the run with a fully charged battery the regeneration is at first almost non-existent, as the battery cannot accept energy. After some running the re-generation kicks in, and lowers the specific energy use. Especially in cold environment the third run is even more economical, as the tyres and the bearings in the car heat up, and subsequently the rolling resistance diminishes with a positive effect on the energy use.

We have collected in Table 14 average electric energy consumption figures determined on the test track using the instrumentation described above. For comparison we have taken results from in-laboratory measurements for similar cars, but none of them were the very same examples.

Table 14 Comparison of energy use figures, track measurements vs. in-laboratory results

	NEDC @ '-20 °C using heating at full		
	field	in-lab	
Car	TSS	VTT	TSS/VTT
	kWh/km	kWh/km	ratio
Citroën C-Zero	0.37	0.33	111 %
Nissan Leaf	0.46	0.44	105 %
Renault Kangoo	0.51	0.23 no heater	n/a

When comparing the results of the on-track and in-lab measurements we can say that track measurements seemed to give somewhat higher values. Furthermore, the correlation was not the same for all cars, but varied from case to case.

Use on heater was also evaluated in constant speed driving. Table 15 summarises this information.

Table 15 Comparison of energy use figures, track measurements vs. in-laboratory results

Citroën C-Zero			
	w/o heat	with heat	heater
km/h	kWh/km	kWh/km	impact
50	0.107	0.174	+63 %
70	0.136	0.187	+38 %
90	0.187	0.242	+29 %
120	0.232	0.289	+25 %
Nissan Leaf			
	w/o heat	with heat	heater
km/h	kWh/km	kWh/km	impact
50	0.154	0.231	+50 %
70	0.177	0.239	+35 %
90	0.219	0.253	+16 %
120	0.272	0.305	+12 %

According to the results, the heater in Nissan Leaf had slightly lower relative impact on energy use than the heater in Citroën C-Zero.

5.2 Workshop on winter testing of EVs

One of the key objectives for RekkEVidde was to establish test methods and protocols that can serve as a basis for more realistic and harmonised testing of EVs in Nordic climate and road conditions. Because motor magazines and other consumer-oriented media tests cars quite often, we concluded that a workshop targeted to this interest group was a good way of advancing our methodology and establish effective dialogue amongst the car testing community.

The event took place in mid-January 2013 at the same track as we used in our own measurements. It was attended by a dozen of media representatives or other persons specialised in vehicle testing. The work was led by the RekkEVIdde project team, and consisted of practical exercises using both the BFT (basic field test) and AFT (advanced field test) protocols.

Basic field test (BFT) protocol calls for testing using only the Vbox and temperature measurement module and the system for determining the electricity during recharging ("ChargeAlyser"). The Advanced field test (AFT) calls for the use of the EOBD/CAN data logging system, as well.

Test fleet included five battery-powered cars: Citroën C-Zero, Renault Leaf (2011 edition), Renault Kangoo Z.E., Tesla Roadster and Volvo C30 EV. Others were commercially available, but the Volvo C30 was from a pre-series, and not in production. Figure 26 shows all the tested vehicles.

Regarding the heating and ventilation system, the use of energy was not the only subject of interest, but also how well the heater performed in their duty. In the test fleet there were different heater concepts. Most were electric only, but Nissan, Volvo C30 and Renault offered also an option to preheat the car before start of the journey, while still plugged-in. Volvo C30 EV had a fuel-fired (E85 bioalcohol blend) heater that was very powerful. Figure 27 depicts cabin floor temperature vs. running time in NEDC driving on track at -15 °C. The preheat option was used, if available.

Unfortunately Volvo C30 did not arrive on time to participate the first tests pictured in Figure 27.

Figure 24 A workshop in real-world field-testing of electric cars was arranged in Älvsbyn, North-Sweden

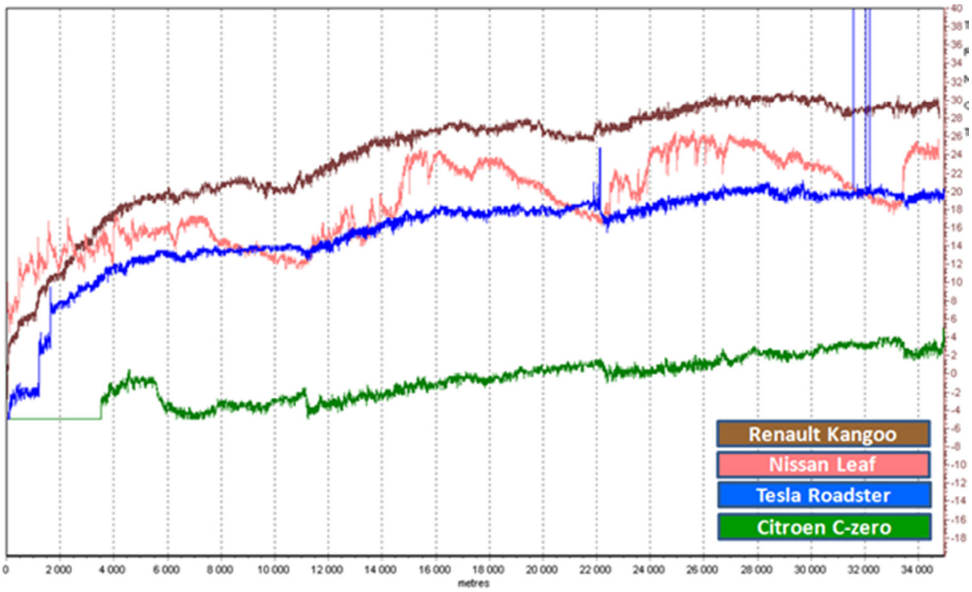

Figure 25 Cabin floor temperature vs. running time in NEDC driving on track at -15 ˚C. The preheat option was in use, if available

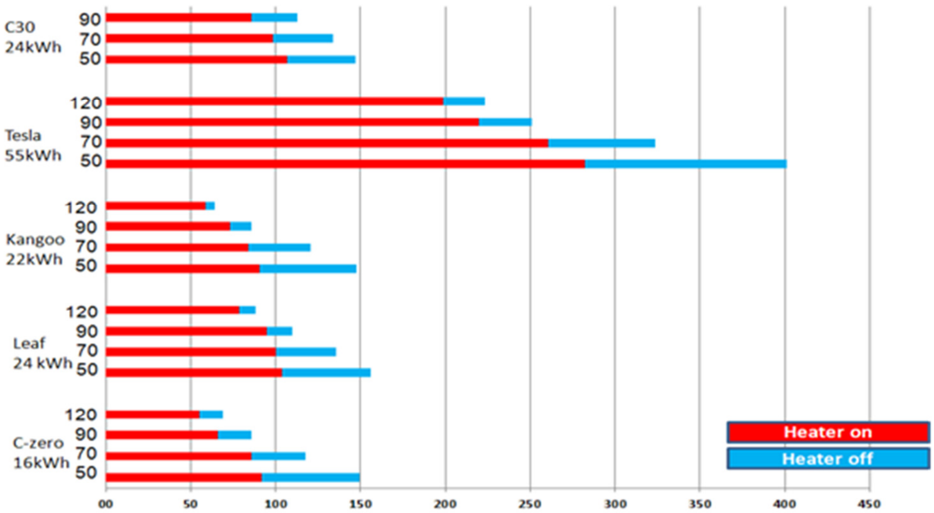

Figure 26 Estimated ranges for the tested cars at different steady speeds; energy use retrieved from the CAN-data; -20 ˚C; with or without heater on

As Figure 27 shows that cars equipped with the pre-heating option (Nissan, and Renault in this figure) were ahead at the beginning, but Tesla that had a relatively small (3 kW) but obviously efficient heater and a small cabin catches up quite well. However, the heater in Citroën was highly inadequate, as even after driving three full NEDC cycles (over 33 km) the floor temperature was barely above zero.

However, in another test session at -30 °C (not pictured) the heating system of Nissan Leaf became stressed during the high speed sections of the cycle, and temporal drops in temperature were registered. However, Volvo C30 with the fuel-fired heater was almost too hot, if the heater was fully on.

The workshop also performed some exercises using the advanced protocol and access to the real-time data in the CAN-bus. Figure 28 plots estimates of range for each of the five tested cars based on their nominal, advertised battery capacity and using the energy consumption values retrieved from the CAN-bus. All tests were run at -20 °C with and without the heater on.

The plots clearly depict that Tesla with its high battery capacity is in its own league, reaching 200 to 250 km even with the heater on. The other cars were roughly in the 75 to 150 km bracket without the heater, but barely can go 100 km, if the heat is on, and driving speed is 90 km/h or more.

6 Energy label for EVs

The plans for the RekkEVidde also called for an outline and a draft for an energy label that could be used to inform the EV buyers of the range in different conditions and various other performance figures. Such labels are widely used in home appliances. Furthermore, in the United States EPA has produced an EV-dedicated version of their fuel economy label that is compulsory for all cars.

Figure 29 shows the present draft of the label, and some comments we have received from the representatives of various interest groups and people working with labelling issues. We hope to be able to improve the layout and design and towards the end of the project (Q4 of this year) come up with an improved version.

Some final words regarding the label design and the need for a simple test protocol to follow for green car organisations and automotive magazines. One key observation from the workshop and the field tests in January 2013 was that a constant speed test, like the one presented in Figure 29, will actually give the customer a fairly good picture on the range for their own estimations. To implement this on the label as a complement to a range based on a duty cycle needs to be done, as no duty cycle in the world will match more than a few applications. Or as we wrote in the introduction: "because the conditions in those measurements are far from those that drivers face in reality", the most common question is: "can I reach my destination" will probably remain for a while.

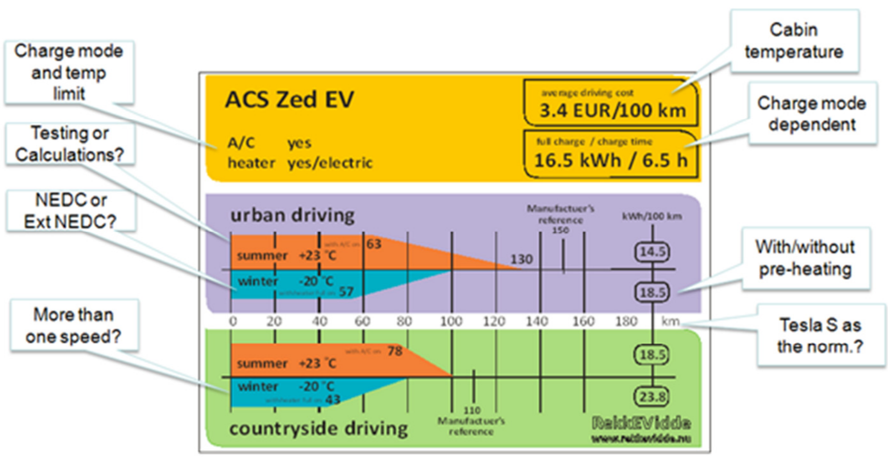

Figure 27 A draft of the "RekkEVidde" energy label for EVs with comments received from the interest groups

7 Milestones

The main milestones of the project were:

- Report of EV user groups and applications and duty cycles December 2011
- Winter test January 2012 and testcode 1.0
- Presentation at EVS26 Los Angeles May 2012
- Summer test August 2012 and testcode 1.1
- Winter test January 2013 and testcode 1.2
- Workshop at Arctic Falls in march and testcode 1.5
- Presentation at EVS27 Barcelona November 2013
- Final report November 2013 and testcode 2.0

8 Assessment of the results of the Project

The main results of the RekkEVidde –project are:

- Most selling EVs in Scandinavia have been range tested in the laboratory conditions and verified in the field tests both cold (-20 °C) and normal temperatures (+23 °C).
- List of additional measures and procedures that are essential in EV testing, when testing in laboratory environment and using ECE-R101 as the basic test protocol.
- A complete test method with protocol, recommended test equipment and a checklist are documented as a Testcodes for Basic Field Test, BFT, and Advanced Field Testing, AFT.
- A draft of the "RekkEVidde" energy label for EVs with comments received from the interest groups.
- Information to media, customers, official authorities about winter performance of EVs and proof that the can endure in a Nordic context.

9 Conclusions

The project has demonstrated that Nordic climate challenges the use of EVs in many ways. Cold weather and adverse road conditions increase driving resistances. Thus the range becomes shorter. Furthermore, cold weather necessitates slower charging and battery warming. Otherwise the battery lifetime will shorten or it may become damaged. Heating and ventilation (HVAC) of the cabin space consume also high amounts of prime battery energy that has an adverse effect on range. However, heating and ventilation must be properly supported; otherwise EVs will not enjoy great success in sales. Only a few motorists are willing to compromise their driving comfort, and if the windows are not properly de-frosted, traffic safety is also negatively affected.

According to our measurements, with a Nissan Leaf on a cold January morning when the temperature is at -20 °C you can reach in road driving a range that is more than 70 km, and still have the heater on in the car. However, when using the car in urban areas and according to NEDC with quite low average speed the heater starts to dominate the picture. A conclusion from that fact is that the customer needs some kind of information about the loss of range when queuing as additional information to the normal average consumption and the range figures.

On the other hand a set of steady-speed measurements ranging from 40 up to 100 km/h gives fairly good additional information to the customer to make their own range-calculations. Regarding the criticised NEDC driving cycle we believe that it probably will be still used for some years more. The upcoming VLTC will probably give a better estimate in total, but regarding repeatability during field testing, we think that NEDC will work fine for a long time.

The RekkEVidde steering group believes that the RekkEVidde test codes and protocol are a fair step towards a good and customer-oriented way to present range and energy consumption figures. There is also a growing interest from different stakeholders to make further steps with the basis in RekkEVidde. Car magazines have been pointing out that we need to enhance the customer information. Also authorities like "Konsumentverket in Sweden" are about to start up a study on how to improve information to the automotive customers and the OEMs themselves are looking for statistics showing that their products will do the job.

If we take in the main picture in to the conclusions and talk about the phenomena of electro-mobility and EVs in a Nordic context one way to put it is that there is an urgent need for larger batteries or, perhaps even better, additional biofuel heaters like the Volvo C30 solution. But on the other hand, with all the conclusions that we made from the tests performed and with the loss of range taken in to the picture, one can still claim that EVs works well in a Nordic context and during winter time.

Furthermore, by comparing the results from the RekkEVidde project with statistics from the driving behaviour in Nordic countries and the results from the over 130.000 trips with normal ICE-cars that were logged in parallel to this project by TSS, we can say that an EV will be suitable for a reasonable large share of a Nordic population. The average daily driving for the average citizen in Sweden is much shorter than the 70 km range that the Nissan LEAF is now providing. We know that the average speed is 53 km/h and that 35-50 km trips are the trips producing most mileage, and even if the driver is commuting at a speed at 100 km/h the Nissan LEAF can still make 58 km on a cold January morning at -20 °C. The extensive statistics received as a valuable contribution from Norway shows more or less the same picture. In Nordic countries the average daily driving for most people is far less than our worst range test case with a 58 km range for the example with the "high speed commuting LEAF". And one thing to remember here is that when keeping a speed of 100 km/h the range loss with a LEAF, caused by the cabin heater, is less than 15 %. So there is really no reason to say that EVs can't perform in a Nordic context. They just have to be tested in a customer oriented way.

10 Policy recommendations

With the tests performed within this project we can say that we know more about EVs range and that we have a method to both perform test expeditions and to present test results in a way that should meet the increasing interest concerning EVs and their Nordic performance.

We would like to stress that EVs are quite suitable for the Nordic area. Nowadays cabin heating is the weak point of EVs during the winter time when the journey takes a lot of time. Most EVs are used in urban areas where average speed of the traffic is quite low during rush hours.

- By accepting EVs to use bus and privacy lanes this problem can be avoided to some extent.
- Pre heating of EV's passenger compartment during charging can be seen as part of the solution.
- Usage of the fuel heaters is practical solution to increase range in winter time.

What should be done as a next step after RekkEVidde is to test all EVs coming in to the Nordic market and develop the test method one step further, including a test protocol for PHEVs. Heat pumps as EV cabin heater can also give a remarkable longer range and this should be studied further.

By doing this we believe that the market for Electro-mobility will grow in an even higher phase than Norway managed until this date. And by introducing the RekkEVidde test code as a guideline for range testing in the Nordic area the OEMs will both be able to benchmark and perhaps also be motivated to enhance their product mix with a Nordic perspective (Warmer, more heat-effective and with optional battery size).

11 Dissemination: Information activities and conferences

RekkEVidde project has arranged 3 seminar/workshop events, two in Sweden and one in Norway. Results have presented in several events in Norway, Sweden, Iceland, and Finland. Major electric vehicle symposium EVS have selected twice RekkEVidde paper to oral presentation. At EVS26 in USA there were only two presentations on this topic and EVS27 in Spain two sessions which tells growing importance of EV range issues.

Seminars, workshops and selected presentations:

RekkEVidde Workshop 14th December 2011 in Stockholm:

- Volvo presentation Mats Hilmersson
- Energy marking Carlos Lopes

Rekkevidde Mini EV-seminar/Workshop 15th May 2012 in Oslo:

- RekkEVidde presentation Arto Haakana
- Grønn Bil - rekkEVidde - may 15th 2012
- Conclusions Czero 2012 Robert Granström

Electromobility in the North Atlantic Regions 4th of October 2012 in Reykjavík;

- Jonas Ericson, Clean vehicles Stockholm, Sweden Clean vehicles in Stockholm
- Arto Haakana, Green net Finland RekkEVidde – measuring actual range of battery vehicles
- Juhani Laurikko, VTT, Finland Electromobility in Finland – policy and status

Energy & Transport mid-term event 17-18 October 2012 in Helsingborg;

- RekkEVidde Presentation Arto Haakana

Älvsby RekkEVidde Result Workshop 18-19 March 2013:

- Summary wintertesting 2013 2 TSS Robert Granström
- Rekkevidde 18.3.2013 VTT Laboratory test results Juhani Laurikko
- Test codes Robert Granström

Scientific papers:

EVS-26 Los Angeles May 6-9, 2012

- Assessing range and performance of electric vehicles in Nordic driving conditions – Project "RekkEVidde"

EVS-27 Barcelona November 17-20, 2013

- Realistic estimates of EV range based on extensive in-laboratory and field-tests in Nordic climate conditions

Press conferences:

- October 10 2013 in Helsinki Press material
- Article Kauppalehti October 10, 2013

Other dissemination activities:

2011 International Electric Vehicle Pilot City and Industry Development Forum

April 21-22, 2011 Shanghai, China

- Arto Haakana presentation

Publications:

- Erik Figenbaum Marika Kolbenstvedt TØI report 1281/2013 Electromobility in Norway - experiences and opportunities with Electric vehicles

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13 Appendices

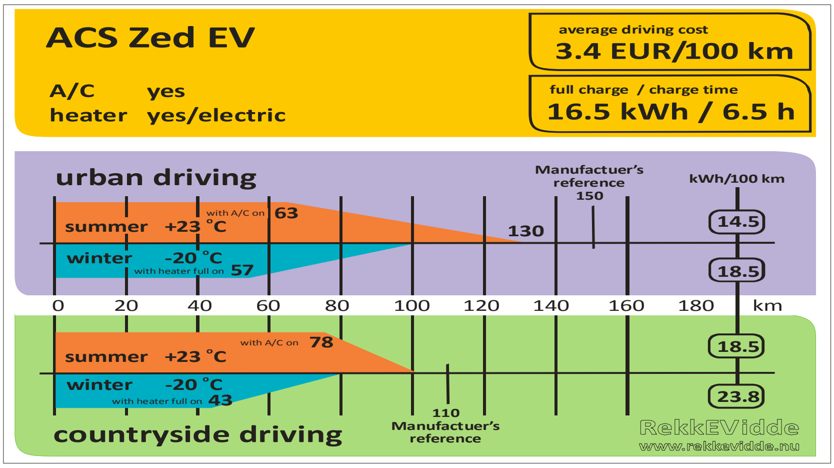
- Appendix 1: Test code strategy
- Appendix 2: BFT Basic Field Test
- Appendix 4: AFT Advanced Field Test
- Appendix 4: Additional Measures And Procedures In Laboratory Testing of EVs Using UN-ECE Regulation No 101 as the Basic Protocol.

APPENDIX 1: TEST CODE STRATEGY 2.0

1 Test Code Purpose

1.1 Background

Within the RekkEVidde project, financed by “Nordic council of ministers”, a series of tests is evaluated and chosen to define actual driving range for Electrical Vehicles “EVs” in the Nordic region. The focus for the test codes is customer oriented testing and the actual work done within the project comprises of both development of test-methods as well as customer oriented data presentation ideas. The main purpose with this “Nordic Test code” is to be seen as a first step on the development of a guideline. This first release of that guideline shows how to test out EV’s winter performance and how inform the potential EV-customer about the vehicles range and ability to operate and serve in a Scandinavian context with winter and cold weather. The condensed result from this work in the data presentation perspective is the suggested “RekkEVidde sticker” for EV-performance, (perhaps in the future enhanced and known under the name “Nordic range sticker”).



This sticker is to be seen as a beacon in need of further developed in dialogue within the Nordic countries.

This document, “Test Code Strategy”, describes the purpose with the test guideline as well as it gives an overview of the entire test procedure with its different steps and expected outcomes. In addition to this document three separate test code documents are available to conduct and to document each test step.

The method is separated in three different modes:

- BFT “Basic Field Test”. A nonintrusive field test mode aimed for “Green car associations”, automotive magazine testing and industrial “24 hours benchmarking” (for instance performed by a test facility for their customer). BFT is designed to perform a simple field test but still in a similar way as OEM perform their normal tests.

- AFT, "Advanced Field test". A test code mode where access to CAN-bus information opens up a wider perspective of data acquisition and test efficiency. This test mode is aimed mainly for industrial field evaluation and tests to produce a product declaration on range, efficiency and thermal comfort. It gives a full picture of information to produce a RekkEVidde-sticker but not with an official authority perspective with the extra high demands on repeatability following with that condition. AFT is a good complement to get input to lab testing. This test mode is also recommended to be used on annual benchmarking activities where Green car associations, magazines and others cooperates to give a picture on best practice in the EV area. The RekkEVidde group believes that AFT's would be a valuable link between field tests and lab tests for harmonizing OEMs and magazine testing.
- ALT "Advanced Lab test" mode with the target to complement industrial- and official authorities testing in the winter range perspective. The primarily field for this test mode is testing within automotive engineering companies and OEM's as well as further test code development in dialogue with certifications bodies. Note that with ALT both winter performance with cabin heater and summer performance with air conditioning can be performed on the same test expedition. A opportunity to test out summer performance testing as a complementary reference testing in the same area as the winter test facility is identified but, due to lack of time and financial resources, not ever conducted within the RekkEVidde-project. The ATF setup could in the future, and based on those ideas be divided in a certification test code and a complementary test code.

1.2 Guideline user scoop

The user scoop for the testing guidelines is as follows:

1.2.1 Winter conditions and temperatures

- The test codes described in this strategy document and the test code documents belonging to this test code strategy is only focusing on winter testing. Therefore the field tests performed according to this guideline is called BFT-Winter and AFT-Winter.
- The RekkEVidde project is addressing costumer information on range with an idea of data presentation on a sticker as a way to give condensed information about EV-range in one picture. (Reference figures about summer range and consumption is to this date recommended to be based on OEM information and/or additional testing indoors according to lab tests (ALT).
- Range is illustrated graphically and energy efficiency is given in numerical format as kWh/km.

- During a next step of the RekkEVidde project we might be able to introduce BFT-Summer and AFT-Summer involving range loss impact caused by A/C. The main obstacles in this area are repeatable temperature and humidity in summer-time.
- The performance on the sticker is initially declared in two levels (+23° and -20 °C) But we have an on-going dialogue about three different temperatures: (+ 20 °C, -7 °C and -20 °C) for AFT and ALT.
- The plan for the future is to add an algorithm for conversion of test results from field testing in outdoor temperature other than the reference temperatures. This algorithm is also planned to be used to calculate a theoretical lowest outdoor temperature to keep a thermal comfort (+20 °C) in the car.
- Thermal comfort is till this date measured only on the drivers side and only on to spots. Close to the left feet and above right shoulder. This needs to be developed in a coming phase to ensure that the temperature is sufficient in the back seat.

1.2.2 Start up conditions

- All tests starts with the car parked, plugged in, and fully charged outside or in a “freezer garage” for 12 hours. This soak down phase shall be done at the target temperature of -20 °C (+/- 1 °C).
- The car is allowed to be driven in “normal use” the before the soak down phase and it is supposed to be a winter day driving with no parking or recharging in-doors.
- The test is supposed to start within 30 seconds from engine on.
- Thermal comfort tests is performed with the ACC [Automatic Climate Control?] activated and at a +20 °C setting
- Cars with no ACC is tested with a maximum heater setting
- Stand by and preheating information is important information that needs to be tested and analysed/communicated to the customer.
- If the vehicle has preheating capabilities, preheating is allowed for one hour and encouraged. No external cabin pre heater (Calix, Defa or similar) is allowed. To prevent battery draining during pre-heating a connection with 16 amp 1-phase and 230Volts is allowed.
- Pre-start consumption is measured for 11 hours of the total 12 soak down hours. This is to ensure 10 whole hours of standby logging, with no charging activities, (if the car needs to be moved (driven) from outside a workshop to the soak down area).
- The test code accepts use of embedded additional fuel heaters to enhance the winter driving range. Winter range extension by additional heater (bio-burner, fuel cell or similar) is tested and declared as external fuel consumption. The total fuel consumption should be measured and presented parallel to the range figures. (This issue need further development. Top-filling is not a reliable solution).

1.2.3 Driving and type of cycles

- The test code is addressing daily work commuting in two different perspective: Urban driving and rural driving. Both with a perspective of a high daily mileage. This is due to the fact that we are aiming for the maximum range in harsh conditions and that ROI and EV-profitability for the customer, compared to a traditional car, increases with the amount of daily mileage.
- In Urban driving test mode the NEDC driving cycle has been chosen to simulate urban driving conditions. Due to safety and repeatability priorities the top speed in the NEDC is reduced from 112 to 100 km/h. This lower the total workload for the NEDC-cycle with about 2 % and must be taken in to the picture when test results is presented.
- To assure a good repeatability a NEDC-app is developed for a windshield mounted Nexus7 to help the driver to keep a proper speed and still keep an eye on the road.
- By repeating the NEDC three times we reach 33 km of continuous driving and acquires data both from non regeneration driving (full battery) and from sequences with full regeneration of energy.
- In the future NEDC might be replaced by VLTC if we can assure a high repeatability during in field testing with VLTC. If not VTT have made a series of testing with a total of 7 different driving cycles and this data can be used to overview comparison and translation between different types of driving cycles.
- Added to the NEDC-driving simple constant speed tests is conducted. The strategy behind this is to help the customer to do their own range estimations based on what speed that is dominating their own driving. NEDC gives an average speed of 33 km/h and a typical average speed in Sweden is above 50 km/h.
- All tests are supposed to be performed on a circular track with a diameter of minimum 1 km. The road surface is supposed to be ice or asphalt with compressed snow on top.
- The test drive is supposed to be performed in low wind conditions. (Preferably on a cold January morning).
- BFT testing only contains a single battery depletion test simulating country road driving at 80 km/h constant speed. This test will only give one figure for country road driving but this “range stress test” also provides a good picture on the thermal comfort in the car and the limp home strategy. The strategy to drive until the battery is empty also neutralizes the effect of preheating and rewards good thermal efficiency on the road.

1.2.4 Different speeds

- All three test modes is using the two basic tests from BFT to simulate Urban driving and Country side driving.

- AFT testing contains both battery depletion and a reference test with a speed stair test. The AFT-mode involves CAN-bus data retrieving. This opens up for gathering of data concerning charger efficiency and, the state of charge information to the driver. This test mode includes a reference test procedure with a speed and consumption-stair going from 40 up to 100 km/h in steps of 20 km/h. With this test a picture on consumption with and without heater activated is provided as an input to driver estimated range calculations. This data also helps to adjust energy consumption figures from a test in a non specified test temperature.
- The country side BFT is chosen to be performed in 80 km/h constant speed due to the fact that this is a common speed limit in all Nordic countries. High speeds while driving on winter roads, shaped a circular track, hazards both the drivers safety and the test repeatability. And if the normal case of use is a one hour trip, an average speed above 80 km/h is quite uncommon in wintertime.
- For future calculations of range in higher speeds (highway driving is up to 130 in Denmark) the speed-stair in the AFT-modes could be complemented by decrease the speed stair steps to 10 km/h and stopping at 110 km/h. With the 10 km/h increment it should be possible to estimate consumption in 130 km/h.
- One other way to analyse is to switch to a straight lake ice track of at least 10 km and then drive the speed star with a start and stop setup. But this craves that the tests will be performed on a calm day and with a repetition both ways.

2. BFT, "Basic Field Testing"

BFT, "Basic Field test" is the easy way to compare different products in a given context. This test mode is performed in two steps on two different days with a preparations day called day 0:

Day 0:

- Installation of test equipment and testdriving
- Charge the car and park it for 12 hours.

Day 1:

- Pre heated car
- Register Standby and preheating consumption
- Contryside testing according to BFT1
- Charge the car and park it for 12 hours.

Day 2:

- Pre heated car
- Register Standby and preheating consumption

- Urban testing according to BFT2

2.1 BFT1

BFT1 is a battery depletion test at 80 km/h speed, performed on a circular track, With the car soaked down in -20°C ambient temperature, starting from the roadside and running until the battery is empty and the car stops completely. The actual range is evaluated after the test, defined to the moment when the driver can't keep a speed over 50 km/h. If the car drops below 50 km/h and retrieves a speed above 50 more than one time the range is evaluated as the second time it goes below 50 km/h. After the car is stopped the car should be towed with the gearshift in neutral to the charging site.

Used amount of energy is measured by recharging the battery up to 100% SOC with a ChargeAlyzer or similar equipment. Charging is performed outdoors or in a climate chamber if the outdoor temperature deviates from the reference temperatures (-20 °C +/- 2 °C). After the battery is recharges standby consumption is measured.

The output from this test is:

- Net charged energy from depleted battery when charging in outdoor ref. temp
- A calculated charger efficiency (compared to OEM's battery capacity declaration)
- Vehicle range in constant speed.
- Warm range in km (distance until the heater is shut down)
- Energy consumption
- Thermal comfort figures (feet and head/shoulders in Celsius)
- Pre heating consumption (kWh/hour)
- Stand-by consumption (kWh/hour)

2.2 BFT2

BFT2 is a simulated city driving cycle following NEDC-standard. Top speed is limited to 100 km/h as a safety first action in a winter road context. Ambient and soak temperature is -20 °C. The driving cycle is repeated three or four times (33 or 44 km) to smooth out problems caused by speed variations and friction losses. This will also reduce the effect of preconditioning. Every cycle (11 km) is ended with a 2 min stop. The first 11 km is supposed to gain less from regeneration due to a full battery.

The output from this test is:

- Theoretical range in City driving.
- City driving energy consumption
- Thermal comfort figures (feet and shoulders in Celsius)

Conditions

Both test is started with a fully charged battery (100 % SOC). The document Basic Field Test declares the complete picture on BFT-conditions.

It´s recommended to use a reference car (EV or non EV) for additional Coast down reference gathering. With this reference car data can be compared with data from earlier testing. Initial reference coast down was performed with a SAAB 93 -02.

Summing

The entire BFT is intended to be carried out during 24 hours if the weather is fine. To achieve the best possible conditions the test should be performed on a Circular track or perhaps on a public road with low or no interfering traffic.

A likely user scenario for this test code is a 24 hour benchmark mission performed by a winter test facility. In those situations and with access to climate-controlled garages the test repeatability and accuracy is very good. By adding a temperature compensation algorithm the test could easily be performed by a Green car association or an automotive magazine even in a non specified out door temperature.

The only test equipment needed is a VBox with a thermo measurement box and a high accuracy energy meter. If the car is equipped with an additional liquid fuel heater a solution to gather that data is needed.

3. AFT, "Advanced Field test"

AFT, "Advanced Field Test" is supposed to be a harmonisation between OEM and Magazines testing. This test mode is performed in three steps: AFT-ref. and AFT1, AFT2, and

Day 0:

- Installation of test equipment and testdriving
- Charge the car and perform AFT-ref
- Recharge the car and park it for 12 hours.

Day 1:

- Pre heated car
- Register Standby and preheating consumption
- Contryside testing according to AFT1
- Charge the car and park it for 12 hours.

Day 2:

- Pre heated car

- Register Standby and preheating consumption
- Urban testing according to AFT2

3.1 AFT-ref

This test is performed to sort out differences in road condition and rolling resistance caused by the winter road. By reference measuring's from this test the results from AFT1 and AFT2 are supposed to be comparable from different test expeditions and from one year to another. Note that a reference cost-down-test with an extra reference car is recommended to sort out road friction differences during day 1 and day 2.

The AFT-ref is starting with a constant speed sequence to acquire energy consumption in five different speeds (40, 60, 80, 100 and if possible 120). The speed stair prepares the car for the next phase and gives also the car a good conditional value for the coast down test that needs to be followed. The Coast down is measured from 100 down to 5 km/h. A V-Box is used for the registrations and data (length and time) is presented in a speed table from 100 down to 5 km/h in steps of 5 km/h.

3.2 AFT1

AFT1 is a battery depletion test at 80 km/h speed, performed on a circular track, starting from the roadside and running until the battery is empty. The range is defined in the same way as in the BFT till the car can't keep a speed over 50 km/h. The car is allowed to roll out by shifting to neutral. After the car is stopped the car should be towed with the gearshift in neutral to the charging site. In the AFT mode the battery depletion is used to calibrate data gathered from CAN-bus with data received from the Charged power from the grid.

Used amount of energy is measured by recharging the battery up to 100 % SOC with a ChargeAlyzer or similar equipment. Charging is performed outdoors or in climate chamber if the outdoor temperature deviates from the reference temperatures (-20 °C +/- 2 °C). After the battery is recharged standby consumption is measured.

The output from this test is:

- Net charged energy from depleted battery when charging in outdoor ref. temp
- A measured charger efficiency (based on CAN-bus-logging on used energy)
- Vehicle range in constant speed.
- Warm range in km (distance until the heater is shut down)
- Energy consumption
- Thermal comfort figures (feet and shoulders in Celsius)
- Pre heating consumption (kWh/hour)
- Stand-by consumption

3.3 AFT2

AFT2 is a simulated city driving cycle following NEDC-standard. Top speed is limited to 80 km/h as a safety first action in a winter road context. The driving cycle is repeated three times (33 km) to smooth out problems caused by speed variations and friction losses. This will also reduce the effect of preconditioning. By gathering data from the CAN-bus all the NDC repetitions can be monitored separately. This increases the possibility to make compensation calculations, for instance due to frictions losses, if one NED-C lap is unsuccessful. The test will also show the higher energy consumption during the first NED-C run and it will indicate the consumption increment when the effect of the pre-condition is fading and the cabin heater needs to kick in.

The output from this test is:

- Actual energy consumption in City driving
- Range span in City driving caused by preheat, cabin heater etc.
- Thermal comfort figures (feet and shoulders in Celsius)

Conditions

All tests are started with a fully charged battery (100 % SOC). The document Advanced Field Test declares the complete picture on AFT-conditions.

Summing

The entire test is intended to be carried out on a circular track with low or no interfering traffic.

In those situations and with access to climate-controlled garages the test repeatability and accuracy is very good and verified in LAB-testing according to the ALT-procedure.

By using a temperature compensation algorithm the test could easily be performed by a Green car association or an automotive magazine in other temperatures than the reference temp of -20 °C.

No additional testing have been performed to verify if it is possible to get a decent repeatability on this tests by using public roads at late or early hours with low traffic.

Equipment needed is:

- a VBox with
- a thermo measurement box and a high accuracy energy meter
- Temperature range

- a CAN-bus logger.

If the car is equipped with an additional liquid fuel heater a solution to gather that data is needed. To this date the only solutions tested is top filling and use of a scale for accurate measuring but this isn’t good enough.

APPENDIX 2: BFT "BASIC FIELD TEST"

1. Purpose

The purpose with this test document is guiding and documentation of Energy-consumption and range testing of EV's in a Scandinavian climate. The test is a two-step field-test to verify both constant speed and city driving. City driving is simulated by the NEDC driving cycle.

The main purpose for the test code is to compare different cars during a 24 hour bench-mark. The main test objectives are:

- Range on a full battery
- Cabin temperature
- Energy consumption during use
- Energy consumption on stand by and during preheating

2. Equipment

A VBOX-system or similar equipment to acquire:

- Speed
- Driving distance
- Cabin temperature

A ChargeAlyzer or similar equipment to evaluate the amount of energy charged after performed test as a reference.

An external tank and a scale (+/- 1 gram)) to weigh used fluid fuel.

3. Preparation / Test arrangement

- The test is supposed to simulate winter use from a normal customer point of view on a cold January morning with the car parked outside, connected to the grid and preheated with the integrated cabin heater for a maximum of 2 hours.
- The ambient temperature is supposed to be -20 +/- 2°C and the car need to be soaked down during charging for 12 hours with the same temperature conditions.
- Stand by consumption is measured for 10 hours before pre heating starts.
- Internal extra heater (bio- or fossil-burner) is allowed to operate during driving but not during preheating phase.

- Tyre pressure and type of tyres should be chosen according to recommendations from the OEM. Friction-tires are preferred. Stud-tires are prohibited on some test facilities.
- Simulated normal cleaned winter roads with asphalt or compressed snow.
- The test is designed to be performed on a circular track with a diameter on 1 km and a deviance in altitude below 1 meter. (An alternative test track on public roads can be used during no traffic hours and after a reference test showing that this road increases or decreases the average consumption with less than 3%).

4. Test method

4.1 BFT 1: Country road driving (Battery depletion with preheated car and heater on).

4.1.1 Purpose

This test step gives the actual driving range on a country road in a normal use scenario, during a cold winter day. This test is also important to get a picture on the thermal comfort in the car in Scandinavian conditions, and how the car is behaving before and during limp home mode.

4.1.2 Conditions

- Compressed snow on asphalt is recommended. Avoid powder snow and polished ice to get repeatable rolling resistance from day to day.
- Climate control is set to on +20 °C and AUTO (or max heat if no ACC equipment).
- Lights on and no other consumer (radio etc.)
- Temperature-sensors are very important to get a picture on the thermal comfort in the car. In door temperature is measured on two positions:
  - Drivers right feet (Close to the accelerator and not directly in an air-outlet).
  - Drivers right Head (Close to right shoulder)

4.1.3 Method

The speed is expected to be kept at 80 km/h (+/- 2 km/h) until the car switches to limp home mode.

The car should be parked and charged close to the circular track to be able to accelerate with no interference up to 80 km/h in less than 30 seconds.

Total range is measured until the car stops.

The car is supposed to be towed with neutral gear to the charger.

4.1.4 Test 1: Registrations

Car type: Testday:

Start time	Start: ODO-meter (km)	Start: SOC (%)	Test track	Driver	Lights
Soak time	Soak and charge spot	Pre Heating	Climate control setting	Tyre pr. (Bar)	Tyre type
Start: temp in	Start: temp out	Road conditions	Weather observation	Pressure (mbar)	Humid (%)
Speed	Comments (problems)	Weather change	Road conditions	Sight (ice/moist)	defrost
80					
Stop time	Stop: ODO-meter (km)	Stop: SOC (%)	Charged energy (kwh)	Charge time	Comment
Duration	Name VBOX-file	Name CAN-file	Name: Photos	Charge spot	Comment

4.1.5 Evaluation output

- Actual range with heater (km)
- Calculated Consumption with Charging/power-conversion energy loss (kwh/km)
- Maximum feet temperature (°C)
- Maximum head temp (°C)

4.2 BFT 2: City driving (Simulation according to NED-C driving cycle)

4.2.1 Purpose

This test step gives the basis to calculate city-driving range by defining energy consumption at an expected use scenario for EV's on a cold winter day. The user scenario is work commuting mainly in city traffic on a cold January morning with no access to a warm garage.

It simulates:

- City driving by following the NEDC driving cycle
- Normal use in winter by having the car preheated.

4.2.2 Conditions

- Compressed snow or asphalt is needed. Avoid powder snow and polished ice to get repeatable rolling resistance from day to day.
- Climate control is set to on +20 °C and AUTO (or max heat if no ACC equipment).
- Lights on and no other consumers (radio etc.)
- Temperature-sensors in the car is optional if proper measurements was made during BFT1.

4.2.3 Method

Pre heating is allowed

The NEDC-cycle is repeated three times, with the exception to a limit in top speed at 100 km/h instead of 120 km/h for 10 sec, due to safety and repeatability reasons.

Average speed is expected to be 33.6 km/h (+/- 1 km/h)

Driving distance is expected to be 33.069 km (+/- 500 m) during three repetitions

The car should be parked and charged close to the circular track to be able to start the NED-C cycle in less than 30 sec from engine on.

The car is supposed to be towed with neutral gear to the charger after the complete test.

4.2.4 Test 1: Registrations

Car type: Testday:

Start time	Start: ODO-meter (km)	Start: SOC (%)	Test track	Driver	Lights
Soak time	Soak and charge spot	Pre Heating	Climate control setting	Tyre pr. (Bar)	Tyre type
Start: temp in	Start: temp out	Road conditions	Weather observation	Pressure (mbar)	Humid (%)
Lap	Comments (problems)	Weather change	Comfort feet/shoulders	Sight (ice/moist)	defrost
1					
2					
3					
Stop time	Stop: ODO-meter (km)	Stop: SOC (%)	Charged energy (kwh)	Charge time	Comment
Duration	Name VBOX-file	Name CAN-file	Name: Photos	Charge spot	Comment

4.2.5 Evaluation output

- Theoretical driving range in city traffic, based on battery size (km)
- Average energy consumption (kwh/km) for the total of 33 km driving
- Feet temperature (°C)
- Shoulder temp (°C)

APPENDIX 3: AFT: "ADVANCED FIELD TEST 2.0"

1. Purpose

The purpose with this test document is to guide and to provide a documentation of Energy-consumption and range testing of EV's in a Scandinavian winter/subarctic climate. The test is a three-step field-test to verify constant speed driving and city driving. City driving is simulated by the NEDC driving cycle.

The main purpose for the test code is a setup to evaluate EVs performance and to be able to compare tests, according to this test code, carried out at different times/occasions.

The main test objectives are:

- Range on a fully charged battery
- Cabin temperature by the feet and the head
- Energy consumption during use
- Energy consumption on stand by and during preheating

2. Equipment

A VBOX-system or similar equipment to acquire:

- Speed
- Driving distance
- Measured Cabin temperature

A ChargeAlyzer or similar equipment to evaluate the amount of energy charged after performed test as a reference.

An external tank and a scale (+/- 1 gram) to weigh used fluid fuel.

A CAN-bus logger to acquire data available via CAN-protocol:

- SOC, State of Charge
- Instantaneous voltage and amp. consumption
- Active subsystems (fan/heater, radio, light, etc.)

3. Preparation / Test arrangement

- First step of the test preparations is to ensure that retrieved CAN-bus-data is valid by driving the car down below 50 % SOC and recharge.

- The test is supposed to simulate normal winter use on a cold January morning with the car parked outside, connected to the grid and preheated with the integrated cabin heater for a maximum of 1 hour.
- The ambient temperature is supposed to be -20 +/- 2^{o}C and the car need to be soaked down during charging for 12 hours with the same temperature conditions.
- Stand by consumption is measured 10 hours before pre heating starts.
- Internal extra heater (bio- or fossil-burner) is allowed to operate during driving but not during preheating phase.
- Tyre pressure and type of tyres should be chosen according to recommendations from the OEM. Friction-tires are preferred. Stud-tires are prohibited on some test facilities.
- The test is designed to be performed on a circular land track with a 1 km diameter and a deviance in altitude below 1 meter. The road condition is supposed to be compressed snow. (A circular test track on a lake ice is an equivalent if the road surface is made by compressed snow).

3.1 AFT-Reference phase (Coast down and constant speed calibration)

3.1.1 Purpose

This test step gives reference key inputs to be able to compare results from tests, carried out at different times/occasions. The reference test is divided in two parts. A five step constant speed stair sequence followed by coast down tests.

This reference phase starts with the constant speed sequence with a total of more than 40 km driving. With the speed stair as the first moment the power train will be sufficient preheated before the coast down phase. To pre heat before the speed stair we recommend two initial extra laps on the circular track at the lowest speed and a reference runt at the end. The measurements from the speed stair gives useful reference data for coming tests and a good picture on wind speed impacts on range and consumption at different speeds. Added to that a heater- and powertrain-ratio in different speeds is provided by switching the heater on and off every 3 km (every lap on the circular track).

The coast down test is aimed to calibrate/compensate for road conditions. And the test is suggested to be performed on the circular track in two directions and with the test object and a reference car. Note that circular tracks on winter test sites are used to be one directional for safety reasons. A dialogue with test site management is needed.

This AFT-test-phase evaluates:

- The road friction impact on the test for this test occasion.
- Key figures on consumption in driving range at 40, 60, 80, 100 and if possible 120 km/h speed
- The loss of range while using the heater.

Below a detailed description and the protocol for documentation.

3.2 AFT-Ref1: Constant speed

3.2.1 Conditions Constant speed

Compressed snow or asphalt is needed. Avoid powder snow and polished ice to get repeatable rolling resistance from day to day.

The car should be parked and charged outside to keep tyres and transmission soaked down to ambient temperature. The parking/charging place should be close to the circular track.

Check tyre pressure.

The car can be preheated for up to 1 hour and the test starts with the heater on.

The climate control is set to off every second lap on the circular track to get an on/off ratio.

When the climate control is set to on the value +20 °C should be choosen (or max heat if the car don’t come with an ACC equipment).

No extra cabin heater (bio or fossil) during the test.

Lights on and no other consumers (radio etc.).

3.2.2 Method

Constant speed

This test method requires CAN-bus logging.

Start with a “heat up” phase with two laps at 40 km/h on the circular track.

The test starts at 40 km//h with heater on for one lap (approx. 3km) and with the heater off the following lap.

The speed should be increased every two laps with 20 km/h up to 100 (or 120 km/h if it feels safe to drive in that speed). Cabin heater of every second lap.

After the last step of constant speed (100 or 120) two reference laps at 40 km/h with the heater on should be performed and registered.

In door temperature is measured on two positions:

- Drivers right feet (Close to the accelerator and not directly in an air-outlet).
- Drivers head (Close to right shoulder)

3.2.3 AFT-Ref1: Registrations

Car type: Testday:

Start time	Start: ODO-meter (km)	Start: SOC (%)	Test track	Driver	Lights
Soak time	Soak spot	Charge spot	Climate control setting	Tyre pr. (Bar)	Tyre type
Start: temp in	Start: temp out	Road conditions	Weather observation	Pressure (mbar)	Humid (%)
Speed	Comments (problems)	Weather change	Road conditions	Sight (ice/moist)	defrost
40 Heater					
40					
60 Heater					
60					
80 Heater					
80					
100 Heater					
100					
120 Heater					
120					
40 Heater					
Stop time	Stop: ODO-meter (km)	Stop: SOC (%)	Charged energy (kwh)	Charge time	Comment
			No charging		

Duration	Name VBOX-file	Name CAN-file	Name: Photos	Charge spot	Comment

3.3 AFT-Ref2: Coast Down

This test step aims to compare the rolling resistance between different test occasions and at the same time acquire input data for future lab tests with dyno in climate chamber (ALT, "Advancd Lab Test").

3.3.1 Conditions Coast down 100 to 5 km/h

Compressed snow or asphalt is needed. Powder snow and polished ice gives extra input for lab test setup but should be avoided during the test-expedition if possible.

The car should be preheated according to the constant speed sequence above.

If no earlier Coast down data have been recorded, for the test object or any other car from the on-going test expedition, a reference car is needed (SAAB@Arctic Falls?)

The test needs a 3 km straight road or circular track with at least 1 km diameter.

The climate control can be set to any temperature.

Lights on (safety first action)

Use tyres and tyre pressure recommended from the customer

3.3.2 Method

Accelerate to 110 km/h

Put gearshift in neutral to get the car freewheeling down to zero speed.

Use the VBOX to keep right speed

Make at least 3 repetitions and in both directions to minimize wind disturbances.

(On a one-way circular track, and with winds lower than 1 m/s the coast down sequence can be performed unidirectional two times from a reference point on the track and then 1500 meters away from that point on the same track)

Print out rolling distance in a 100 to 5 km/h speed interval by using Vbox data.

3.3.3 Test 2: Registrations

Car type: Testday:

Start time	Start: ODO-meter (km)	Start: SOC (%)	Test track	Driver	Lights
Soak time	Soak and charge spot	Pre Heating	Climate control setting	Tyre pr. (Bar)	Tyre type
Start: temp in	Start: temp out	Road conditions	Weather observation	Pressure (mbar)	Humid (%)
Lap	Comments (problems)	Weather change	Comfort feet/shoulders	Sight (ice/moist)	defrost
1					
1 Return					
2					
2 Return					
3					
3 Return					
4					
4 Return					
Stop time	Stop: ODO-meter (km)	Stop: SOC (%)	Charged energy (kwh)	Charge time	Comment
Duration	Name VBOX-file	Name CAN-file	Name: Photos	Charge spot	Comment

3.3.4 Evaluation output

Rollout distance (m)

4. Test method

4.1 AFT 1: Country road driving (Battery depletion with preheated car and heater on).

4.1.1 Purpose

This test step gives the actual driving range on a country road in a normal use scenario, during a cold winter day. This test is also important to get a picture on the thermal comfort in the car in Scandinavian conditions, and how the car is behaving before and during limp home mode. By using CAN-bus data "Warm-range" (range until the heater is shut off automatically) can be calculated

4.1.2 Conditions

- Compressed snow on asphalt is recommended. Avoid powder snow and polished ice to get repeatable rolling resistance from day to day.
- Climate control is set to on +20 °C and AUTO (or max heat if no ACC equipment).
- Lights on and no other consumer (radio etc.)
- Temperature-sensors are very important to get a picture on the thermal comfort in the car. In door temperature is measured on two positions:
  - Drivers right feet (Close to the accelerator and not directly in an air-outlet).
  - Drivers head (Close to right shoulder)

4.1.3 Method

The speed is expected to be kept at 80 km/h (+/- 2 km/h) until the car switches to limp home mode.

The car should be parked and charged close to the circular track to be able to accelerate with no interference up to 80 km/h in less than 30 seconds.

Total range is measured until the car stops. The range-figure will be declared as two figures. When the car can't keep the speed above 50 km/h and when it stops.

The car is supposed to be towed with neutral gear to the charger.

Energy used during driving is measured both via the ChargeAlyzer and CAN-bus data to be able to calculate and compare energy use data for "battery to wheel" and "grid to wheel" after recharging.

By using CAN bus an AFT-Ref phase adjustments to previous test with the same or other cars can be made.

By combining data from AFT-REF1 and AFT1 a picture on range loss in higher and lower speed can be calculated.

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AFT2: Registrations

Car type: Testday:

Start time	Start: ODO-meter (km)	Start: SOC (%)	Test track	Driver	Lights
Soak time	Soak and charge spot	Pre Heating	Climate control setting	Tyre pr. (Bar)	Tyre type
Start: temp in	Start: temp out	Road conditions	Weather observation	Pressure (mbar)	Humid (%)
Speed	Comments (problems)	Weather change	Road conditions	Sight (ice/moist)	defrost
80					
Stop time	Stop: ODO-meter (km)	Stop: SOC (%)	Charged energy (kwh)	Charge time	Comment
Duration	Name VBOX-file	Name CAN-file	Name: Photos	Charge spot	Comment

4.1.4 Evaluation output

- Actual range with heater (km)
- Calculated Consumption with Charging/power-conversion energy loss (kwh/km)
- Efficiency figures for "battery to wheel" and "grid to wheel.
- Temperature graphs and maximum feet temperature (°C)
- Temperature graphs and maximum shoulder temp (°C)

4.2 AFT 2: City driving (Simulation according to NED-C driving cycle)

4.2.1 Purpose

This test step gives the basis to calculate city-driving range by defining energy consumption at an expected use scenario for EV's on a cold winter day. The user scenario is work commuting mainly in city traffic on a cold January morning with no access to a warm garage.

It simulates:

- City driving by following the NEDC driving cycle
- Normal use in winter by having the car preheated.

4.2.2 Conditions

- Compressed snow or asphalt is needed. Avoid powder snow and polished ice to get repeatable rolling resistance from day to day.
- Climate control is set to on +20 °C and AUTO (or max heat if no ACC equipment).
- Lights on and no other consumers (radio etc.)
- Temperature-sensors in the car is optional if proper measurements was made during AFT1.

4.2.3 Method

Pre heating is allowed

The NEDC-cycle is repeated three times, with the exception to a limit in top speed at 100 km/h instead of 120 km/h for 10 sec, due to safety and repeatability reasons.

Average speed is expected to be 33.6 km/h (+/- 1 km/h)

Driving distance is expected to be 33.069 km (+/- 500 m) during three repetitions

The car should be parked and charged close to the circular track to be able to start the NED-C cycle in less than 30 sec from engine on.

The car is supposed to be towed with neutral gear to the charger after the complete test.

4.2.4 AFT2: Registrations

Car type: Testday:

Start time	Start: ODO-meter (km)	Start: SOC (%)	Test track	Driver	Lights
Soak time	Soak and charge spot	Pre Heating	Climate control setting	Tyre pr. (Bar)	Tyre type
Start: temp in	Start: temp out	Road conditions	Weather observation	Pressure (mbar)	Humid (%)
NEDC-runs	Comments (problems)	Weather change	Comfort feet/shoulders	Sight (ice/moist)	defrost
1					
2					
3					
Stop time	Stop: ODO-meter (km)	Stop: SOC (%)	Charged energy (kwh)	Charge time	Comment
Duration	Name VBOX-file	Name CAN-file	Name: Photos	Charge spot	Comment

4.2.5 Evaluation output

- Theoretical driving range in city traffic, based on battery size (km)
- Average energy consumption (kwh/km) for the total of 33 km driving
- Average consumption for 11, 22 and 33 km driving. (for the three consecutive NEDC-runs)
- Feet temperature (°C)
- Shoulder temp (°C)

APPENDIX 4: ADDITIONAL MEASURES AND PROCEDURES IN LABORATORY TESTING OF EVS USING UN-ECE REGULATION NO 101 AS THE BASIC PROCEDURE

Today, regardless of their powertrain and fuel/energy options, all passenger cars need to be tested for fuel and electricity consumption using UN-ECE Regulation No 101 as the protocol. This is mandated by the type approval directive 2007/46/EC. All "official" figures that manufacturers release for their vehicles are based on this procedure.

All types of powertrains are nowadays included. Separate procedures are listed for IC-engine powered, autonomous hybrids (HEV), plug-in hybrids (PHEV) and battery-electric (BEV) cars, However, there are number of issues that should be addressed, if one aims at better accounting of Nordic conditions in testing.

Based on our experience gained in this project, the main issues are:

- **Basic test temperature is +20 °C to +30 °C**.

  Therefore, majority of the test cells used cannot set and maintain lower temperatures. However, as the IC-powered petrol-fuelled cars need to be tested also at -7 °C, there are at least some cells that could be used for this temperature, even if it is far from the needs of Nordic climate.

- **Heating and ventilation is not addressed**.

  As the test today is only for normal ambient conditions, neither heating nor ventilation or A/C is used during the test. However, according to our experience HVAC is most critical in electric vehicles, and should be included in the protocol.

- If and when lower test temperatures are used, **road load coefficients that describe the air drag and rolling resistance should be altered to match with the physical phenomenon like increased air density at low temperatures**.
- As duty cycle, the current **European Driving Cycle (NEDC) is not ideal, but sufficient**. Compared to more representative cycles that were used in this project, however, it may even be a good compromise, as e.g. Helsinki City cycle that is derived from actual driving in streets of Helsinki, has much higher transient dynamics and hence much larger potential for regeneration. Thus, the less-aggressive and slow-speed ECE15-cycle should give less optimistic energy consumption results for urban driving, as its regenerative potential is lower.