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

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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. Project RekkEVidde is aiming at drafting a testing scheme to address EV driving in Nordic conditions, and produce realistic range estimates for the consumers to help them understand this raising technology and make successful purchase decisions. Both in-laboratory and field testing in actual winter weather conditions has been performed with almost all publicly available electric vehicles. The outcome of the project is a confirmation that in Nordic climate the adverse driving conditions and especially thermal management of the cabin for adequate driving comfort will seriously shorten the range. Therefore, additional testing to reflect this is definitely needed to complement the official regulatory test. However, it may not have to be very complex, as the testing workshop held in Northern Sweden proved. Already steady-speed driving with heater on and logging the cabin temperatures and energy consumption from the CAN-bus can provide valuable information on how the vehicle can perform in cold climate.

Keywords: EV (*electric vehicle), range, data aquisition, cold climate, energy label*

1 Introduction

Determining energy efficiency and energy consumption of a car is not a simple case. When switched on, a sixty watt light bulb will use 60 W of power, and in one hour, it will consume 60 Wh of energy. However, driving a car for one hour can give a host of different results. The result is depending on if is it a small or a large car, what kind of traffic environment – city or highway – the car is operated. Furthermore, also how is the season – summer or winter – makes a difference. These are just the few main parameters and an exhaustive list will contain many more.

Of course we are interested in the energy use from the economic perspective, but in the case of a battery-driven electric car, the results carry much more weight, as the most common question amongst the EV-users is "how far can I go" or better yet "can I reach my destination". This is the story, because in current vehicles the energy captured in one charge of the battery pack is very limited compared to the amount of energy available in liquid fuels.

Nordic countries can enjoy of relatively clean, low-carbon electricity because of a lot of hydropower in the common system. Therefore, using electricity to propel cars makes a lot of sense in terms of both lowering carbon emissions, but also increasing use of local energy. However, climate conditions in Scandinavia are far from ideal what comes to use of electric cars. For aforementioned reasons energy use in real driving conditions varies strongly, making it difficult to estimate how far the car will go with one charge. The official figures that are resulting from lab measurements according to ECE-R101 cannot serve the real needs, because the conditions in those measurements are far from those that drivers face in reality.

2 Co-Nordic project to address range

To give the potential users better understanding of the performance of present-day battery-powered electric vehicles the Nordic countries Finland, Sweden, Norway and Iceland joined in a collaborative project called RekkEVidde that addresses the topic. The objective of the work is to determine how the Nordic driving and climate influences energy use in EV's. The outcome shall also include a test protocol and list of procedures, how the performance of an electric vehicle should be determined in order to bring the consumers realistic and reliable data. Both in-lab as well as on-road testing was addressed. Furthermore, the work also encompassed drafting of the way the information shall be communicated, e.g. some kind of energy label that rates the vehicle in terms of various driving conditions.

Actual work has included gathering of data of the typical conditions encountered in Nordic countries regarding climate and driving, and testing of various EV's using set of driving cycles and ambient conditions. Testing has been conducted both in laboratory, but also on-road and on-track in real weather conditions. Figure1 depicts the laboratory facility at VTT.

3 Laboratory testing for Nordic Conditions

3.1 Duty-cycle and temperature

The project 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) and 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 1 lists the main characteristics of these cycles, and their speed profiles are presented in our previous paper [1].

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

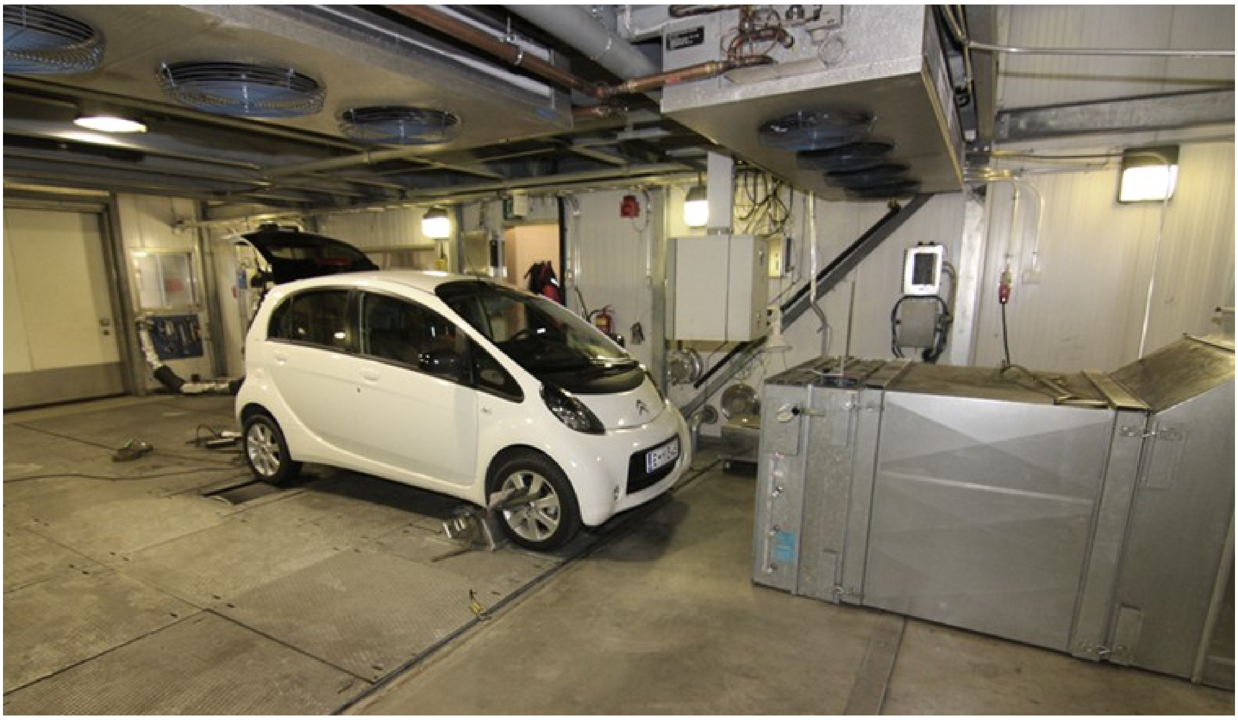

Figure 1: Laboratory test facility for electric cars and other light-duty vehicles at VTT, Finland.

Table 1. 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

16 % nominal increase in air density and the air drag component.

At first we wanted to compare the theoretical energy needs of the duty cycles. Table 2 lists the theoretical work calculated over the various cycles at normal ambient (+23 °C), as well as at ±0 °C and at -20 °C. The top section shows the calculated amount of work, the mid-section shows the figures relative to the amount of work NEDC-cycle at +23 °C, and the lowest section shows the relative impact of ambient temperature in each duty cycle case.

Table 2. Theoretical work over the duty cycles used.

Theoretical work	Ambient temperature		
	+23 °C	±0 °C	-20 °C
cycle	kWh/km	kWh/km	kWh/km
NEDC	0.110	0.114	0.117
ECE15	0.086	0.087	0.088
Helsinki City	0.105	0.106	0.107
Artemis Urban	0.130	0.130	0.131
EUDC	0.124	0.129	0.133
Road, FIN	0.154	0.163	0.167
Artemis Road, EV*	0.117	0.121	0.124
Artemis Motorway, EV*	0.186	0.198	0.203
The effect of temperature			
cycle	ratio	ratio	ratio
NEDC	100 %	103.5 %	105.8 %
ECE15	100 %	101.2 %	102.7 %
Helsinki City	100 %	100.9 %	102.1 %
Artemis Urban	100 %	100.6 %	101.4 %
EUDC	100 %	104.4 %	107.1 %
Road, FIN	100 %	105.7 %	108.6 %
Artemis Road, EV*	100 %	103.6 %	106.0 %
Artemis Motorway, EV*	100 %	106.4 %	109.1 %
Combined effect	of cycle and temperature		
cycle	ratio	ratio	ratio
NEDC	100 %	104 %	106 %
ECE15	78 %	79 %	80 %
Helsinki City	95 %	96 %	97 %
Artemis Urban	117 %	118 %	119 %
EUDC	112 %	117 %	120 %
Road, FIN	139 %	147 %	151 %
Artemis Road, EV*	106 %	110 %	112 %
Artemis Motorway, EV*	169 %	179 %	184 %

The relative figures in the mid-section of the Table 2 show the influence of the ambient temperature to range from +1.4% to +9.1%, depending on the duty cycle. The highest increase was calculated for the motorway, as it has the highest average speed, hence the influence of air drag is also the largest.

Furthermore, the relative numbers in the lowest section of Table 2 show that at +23 °C the work needed to drive thru the different cycles varies by some -22 % to +69 %, when compared to the driving cycle of the type approval standard that is used for assessing the official energy use, and is also the basis for the range figures. The same section also shows that the combined effect of driving type (i.e. duty cycle) and weather conditions (i.e. ambient temperature) can yield up to 84 % higher energy need (Artemis Motorway vs. NEDC).

Regarding actual energy use, the relations are somewhat different, because the efficiency of the system may not be the same in all test cases, because of different speed and power ranges entertained, when driving the particular cycle. This can be seen in Table 3, which presents the measured actual grid energy uptake after each duty cycle and ambient temperature used.

From the relative figures in the second section of Table 3 we can see that although the lowering of the ambient temperature increased theoretical net energy need from +1.4% to +9.1%, the actual energy uptake increased much more, between 26% and 36%. This suggests that also all the losses were increased due to the lowering of the ambient temperature. This includes also the losses in the charging process and battery management, as the charging was always performed at the same ambient temperature as the testing.

However, if we look at the relative figures reflecting the effect of driving cycle (third section), those are much closer to the relative numbers for the theoretical need. The combined effect can be seen in the numbers of the lowest section, where both effects are combined. Compared to the specific energy uptake needed after completing one NEDC cycle at +23 °C, we needed nearly 2.5 times the amount of energy per km after running Artemis Motorway cycle at -20 °C.

It goes without saying that this ratio is directly reflected in expected range with one charge. This is clearly seen in Table 4 that shows the calculated estimates for range in each combination of ambient temperature and duty-cycle that we tested. According to our measurements, the capacity of the battery pack was 17.8 kWh, and surprisingly not much dependent on ambient temperature. For this one charge the estimated range differs from a high of 129 km (Helsinki City at +23 °C) to a low 54 km (Artemis Motorway at -20 °C). In relation to the range calculated for the official NEDC cycle, this is nearly 60 % shorter.

Table 3. Measured grid energy uptake for different duty cycles and ambient temperatures.

Energy uptake from the grid			
	+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 %	114 %	136 %
Helsinki City	100 %	108 %	126 %
Artemis Urban	100 %		134 %
Road, FIN	100 %	113 %	133 %
Artemis Road, EV*	100 %		124 %
Artemis Motorway, EV*	100 %		135 %
average, all cycles	100 %	112 %	131 %
Effect of cycle			
cycle	ratio	ratio	ratio
NEDC	100 %	100 %	100 %
Helsinki City	98 %	92 %	90 %
Artemis Urban	126 %		124 %
Road, FIN	134 %	133 %	131 %
Artemis Road, EV*	111 %		102 %
Artemis Motorway, EV*	173 %		171 %
Combined effect of cycle and ambient temperature			
cycle	ratio	ratio	ratio
NEDC	100 %	114 %	136 %
Helsinki City	98 %	105 %	123 %
Artemis Urban	126 %		169 %
Road, FIN	134 %	152 %	178 %
Artemis Road, EV*	111 %		138 %
Artemis Motorway, EV*	173 %		233 %

Table 4. Estimated range with one full charge in different duty cycles and ambient temperatures.

Estimated range for a 17.8 kWh charge			
	+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 %

3.2 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. Coefficients were determined for dry asphalt for +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. Table 5 presents the calculated theoretical work needed to complete duty cycles that were used in this work assuming different road surfaces.

Table 5. Calculated theoretical work needed to complete duty-cycles assuming different road surfaces.

Theoretical work	road surface		
	asphalt	old snow	new snow
	-20 °C	-20 °C	-20 °C
cycle	kWh/km	kWh/km	kWh/km
NEDC	0.120	0.128	0.132
ECE15	0.090	0.098	0.101
Helsinki City	0.109	0.116	0.119
Artemis Urban	0.133	0.139	0.142
EUDC	0.136	0.145	0.149
Road, FIN	0.172	0.182	0.186
Artemis Road, EV*	0.127	0.136	0.139
Artemis Motorway, EV*	0.210	0.219	0.223
Effect of road surface			
cycle	ratio	ratio	ratio
NEDC	100 %	107 %	110 %
ECE15	100 %	109 %	112 %
Helsinki City	100 %	106 %	109 %
Artemis Urban	100 %	105 %	107 %
EUDC	100 %	106 %	109 %
Road, FIN	100 %	106 %	108 %
Artemis Road, EV*	100 %	107 %	109 %
Artemis Motorway, EV*	100 %	104 %	106 %
Combined effect of road surface and cycle			
cycle	ratio	ratio	ratio
NEDC	100 %	107 %	110 %
ECE15	75 %	82 %	84 %
Helsinki City	91 %	97 %	99 %
Artemis Urban	111 %	116 %	119 %
EUDC	114 %	121 %	124 %
Road, FIN	144 %	152 %	155 %
Artemis Road, EV*	106 %	113 %	116 %
Artemis Motorway, EV*	175 %	183 %	186 %

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

When we look at the relative ratios presented in the mid-section of Table 5, we see that on average old snow increases the rolling resistance of the road surface by 6 %, and newly fallen snow by 9 %. This ratio depends, of course, of the relative share of the rolling resistance of the total driving resistance.

The increased theoretical work needed is naturally reflected also in the amount of electrical energy taken from the grid while charging the batteries after driving the various cycles. Here we have not yet measured all cycles, but the results for those cycles that had been measured, are presented in Table 6.

Table 6. Amount of grid energy uptake while charging the batteries after driving various cycles.

energy use (grid)			
	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 %	102 %	105 %
Helsinki City	100 %	122 %	120 %
Road, FIN	100 %	106 %	107 %
cycle	ratio	ratio	ratio
NEDC	100 %	102 %	105 %
Helsinki City	90 %	110 %	108 %
Road, FIN	131 %	139 %	139 %

In relative terms, our measurements show that gross energy use was increased by 2 to 5 % in case of the type approval cycle (NEDC), and by some 6 % in the road cycle. However, for the more transient and slow-speed urban-type cycle (Helsinki City) the impact was as high as 20 %.

Using the measured gross energy use values presented in Table 6, we can calculate estimates for the effect of road surface condition on range. Table 7. lists those estimates for one full charge in different road surface conditions.

Based on the values in Table 7, the snow on the road surface had only a marginal impact on range. However, when using urban-type of cycle (Helsinki city), the snow shortened the range by about 18%, which is quite substantial impact.

Combined effect of all the parameters that were investigated in laboratory measurements are graphically depicted in Figure 2.

According to this graph, the range measured for NEDC-cycle at +23 °C is 126 km, but already lowering the ambient temperature to ±0 °C shortens the range by 15 km. Furthermore, at -20 °C the loss is more than doubled, and range is already cut back by 34 km, compared to normative conditions. Furthermore, if the road is covered with newly fallen snow, it slices off a further 5 km, and only 88 km is left. This means that the range is 30 % shorter compared to the normal conditions.

Table 7. Estimated range with one full charge in different road surface conditions.

Estimated range for a 17.8 kWh charge			
	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 %

With the other duty-cycle in the graph, Helsinki City, the lowering of the ambient temperature does not hurt the range as much as in the NEDC case. At -20 °C only 26 km is lost by the increased air drag induced by the cold and denser air. However, regarding the influence of road surface, the snow cover has more distinct impact in case of this duty-cycle, as 17 km is lost by the increase in rolling resistance. Thus, even if at normal conditions Helsinki City cycle yielded to slightly longer range than the type approval cycle, in wintery and snowy conditions the city driving cycle is more affected, and estimated range remains shorter than with the NEDC cycle.

Figure 2 presents also the ranges estimated with the use of the PTC-heater, but this matter is discussed more in detail in Chapter 4.

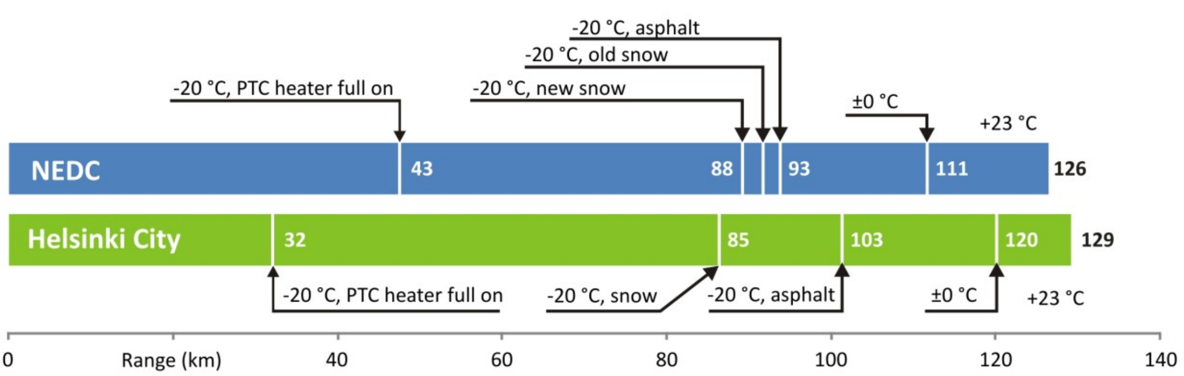

Figure 2: The influence of ambient temperature and road surface on range; NEDC and Helsinki cycles.

3.3 Cabin heating and ventilation

3.3.1 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 we must use prime energy for heating. Therefore, in addition to the energy needed for driving in cold and snowy conditions, we have separately addressed the use of electric heater.

Based on the measurements and simulations, we can conclude that the use of the 4.5 kW PTC heater that the test car (Citroën C-Zero) is equipped with, will seriously increase 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 (Table 2), and adding 10% for parasitic losses. 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 temperatures around -20 ˚C.

Table 8 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 %.

3.3.2 Use of fuel-fired heater

In another series of tests we had an opportunity to evaluate the merits of a fuel fired heater use in an EV. 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. Table 9 lists the results of that exercise.

Table 9. 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

Table 8. 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			

As we can see from the figures in Table 9, 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.

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.

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 has not yet been possible for us to test this new version.

4 Field testing of EVs

4.1 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 3 shows an aerial view of the complete track area.

Figure 3: Test track "Vitberget" in Älvsby, Sweden, operated by Arctic Falls AB.
(Photo courtesy of Artic Falls, www.arcticfalls.se)

We can quite clearly see in the middle of the photo 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. 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.

4.2 Methodology for track testing

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.

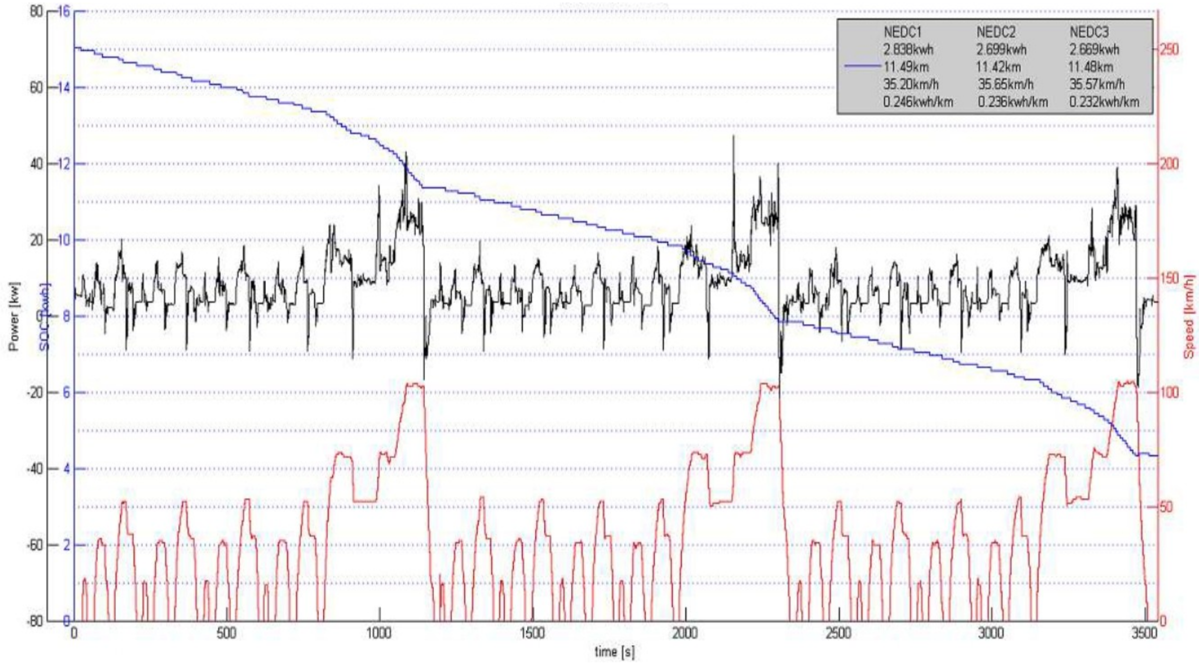

Figure 4: Power and SOC in three repetitions of NEDC-cycles driven with Citroën C-Zero on the circular track.

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 4 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.

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 (11.007 km), 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 3.4% 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 regeneration 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 10 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 10. 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 11 summarises this information

Table 11. Comparison of energy use with or without heater in constant-speed driving

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.

4.3 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 5 shows all the tested vehicles.

Figure 5: A workshop in real-world field-testing of electric cars was arranged in Älvsbyn, North-Sweden.

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 6 depicts cabin floor temperature vs. running time in NEDC driving on track at -15 ˚C. The preheat option was used, if available.

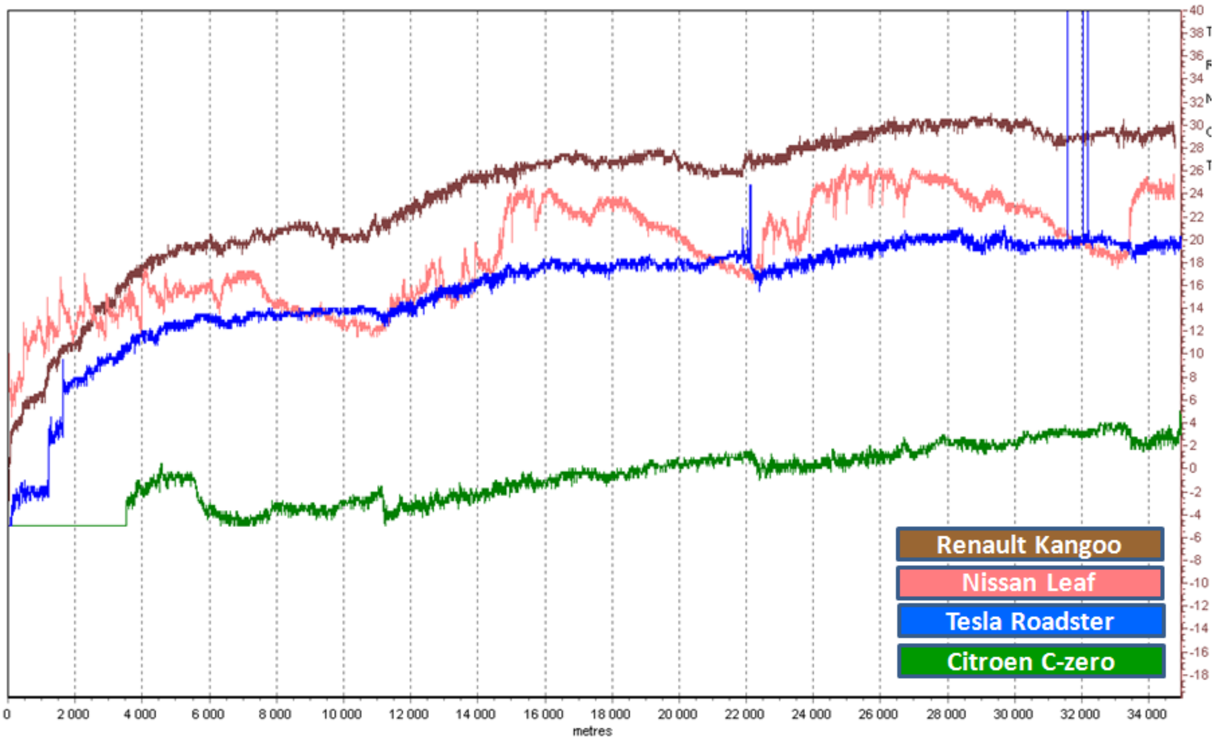

Figure 6. Cabin floor temperature vs. running time in NEDC driving on track at -15 ˚C. The preheat option was in use, if available.

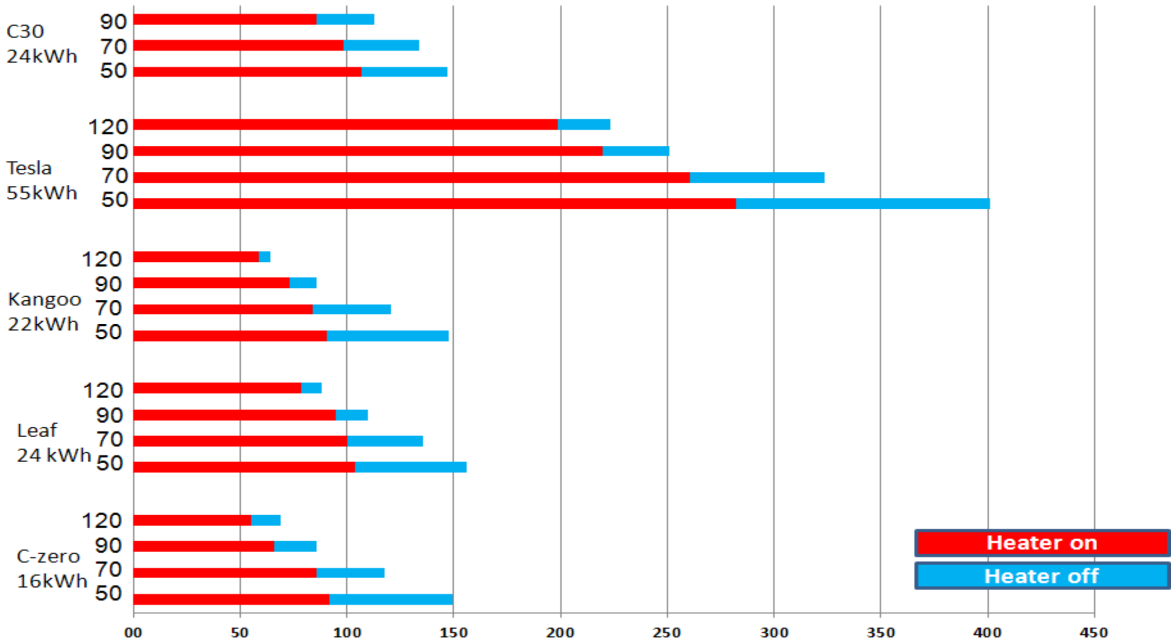

Figure 7: Estimated ranges for the tested cars at different steady speeds; energy use retrieved from the CAN-data; -20 ˚C; with or without heater on.

Unfortunately Volvo C30 did not arrive on time to participate the first tests pictured in Figure 6.

As Figure 6 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.

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 7 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.

5 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 8 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 7, 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.

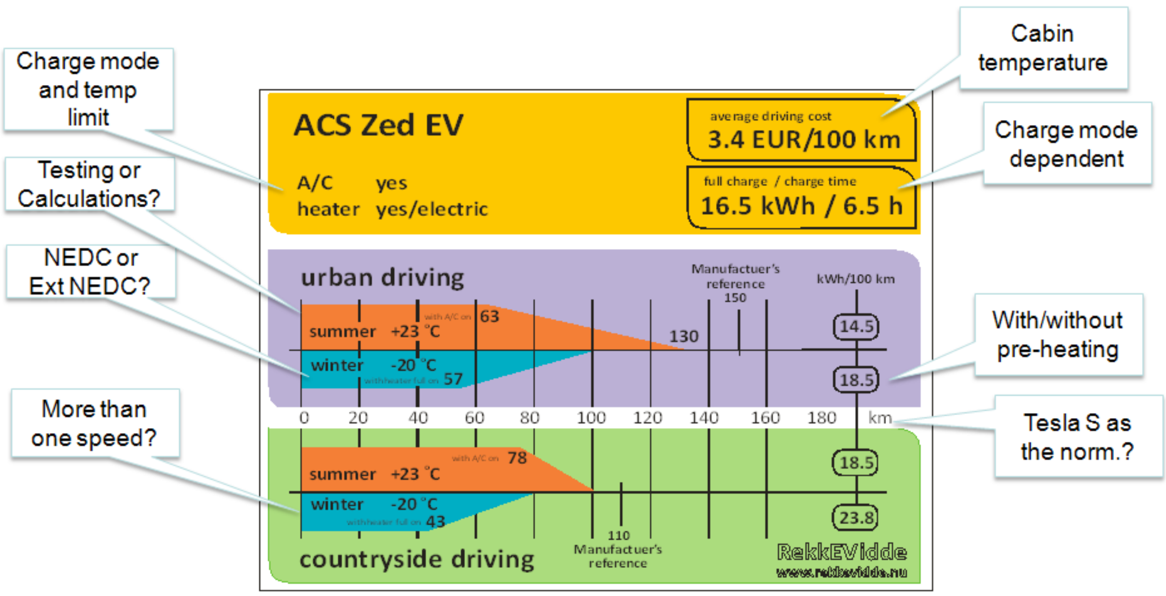

Figure 8: A draft of the "RekkEVidde" energy label for EVs with comments received from the interest groups.

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