Preferences of Electric Buses in Public Transport; Conclusions from Real Life Testing in Eight Swedish Municipalities

Sven Borén, Lisiana Nurhadi, Henrik Ny

***Abstract*—**From a theoretical perspective, electric buses can be more sustainable and can be cheaper than fossil fuelled buses in city traffic. The authors have not found other studies based on actual urban public transport in Swedish winter climate. Further on, noise measurements from buses for the European market were found old. The aims of this follow-up study was therefore to test and possibly verify in a real-life environment how energy efficient and silent electric buses are, and then conclude on if electric buses are preferable to use in public transport. The Ebusco 2.0 electric bus, fitted with a 311 kWh battery pack, was used and the tests were carried out during November 2014-April 2015 in eight municipalities in the south of Sweden. Six tests took place in urban traffic and two took place in more of a rural traffic setting. The energy use for propulsion was measured via logging of the internal system in the bus and via an external charging meter. The average energy use turned out to be 8% less (0,96 kWh/km) than assumed in the earlier theoretical study. This rate allows for a 320 km range in public urban traffic. The interior of the bus was kept warm by a diesel heater (biodiesel will probably be used in a future operational traffic situation), which used 0,67 kWh/km in January. This verified that electric buses can be up to 25% cheaper when used in public transport in cities for about eight years. The noise was found to be lower, primarily during acceleration, than for buses with combustion engines in urban bus traffic. According to our surveys, most passengers and drivers appreciated the silent and comfortable ride and preferred electric buses rather than combustion engine buses. Bus operators and passenger transport executives were also positive to start using electric buses for public transport. The operators did however point out that procurement processes need to account for eventual risks regarding this new technology, along with personnel education. The study revealed that it is possible to establish a charging infrastructure for almost all studied bus lines. However, design of a charging infrastructure for each municipality requires further investigations, including electric grid capacity analysis, smart location of charging points, and tailored schedules to allow fast charging. In conclusion, electric buses proved to be a preferable alternative for all stakeholders involved in public bus transport in the studied municipalities. However, in order to electric buses to be a prominent support for sustainable development, they need to be charged either by stand-alone units or via an expansion of the electric grid, and the electricity should be made from new renewable sources.

***Keywords*—**Sustainability, Electric, Bus, Noise, GreenCharge.

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I. Introduction

A. Background

MANY politicians in Europe are interested in more sustainable road transport solutions that contribute to societal goals such as greenhouse gas neutrality, energy use reduction, fossil fuel independence, and reduction of health problems related to emissions. Planning for sustainable development within complex areas such as transportation, which is greatly affected by development within other areas, calls for a structure that allows for a wide enough perspective to prevent sub-optimizations within certain areas, and where the development is guided by a robust definition of sustainability. The Framework for Strategic Sustainable Development - FSSD [1] is designed for such purposes and has been used on several occasions for development of transport towards sustainability [2]-[5]. In these and other studies, Electric Vehicles (EVs) are found to be a possible long-term solution for sustainable development, mainly because of high energy efficiency, very low emissions during drive, lower noise in city traffic, and the possibility to use renewable electricity for propulsion.

Meanwhile several European companies have started to manufacture electric cars and buses, some public authorities support projects aimed at increasing the share of EVs. GreenCharge, led by Blekinge Institute of Technology, is such a project in which municipalities, county boards, county councils, regions, companies and the Swedish Energy Agency collaborate to increase the share of EVs in a sustainable way. Electric buses powered by batteries have been available for public transport for decades and used in some cities worldwide to slow down erosion on old buildings and improve air quality. Research within GreenCharge has previously found that electric buses in urban public transport, when compared to combustion engine powered buses, are preferable not only from a sustainability perspective, but can also reduce the total cost of ownership with 25% when charged with new green electricity [6]. That study was based on simulations, but not real life data, of bus lines in Karlskrona, Jönköping, and Sundsvall. Assumptions were based on older vehicles, where the energy use was assumed to be 1,04 kWh/km. This excluded interior heating and did not account for Swedish climate. Moreover, available noise measurement studies were old. Stakeholders and researchers within GreenCharge therefore wanted to try out electric buses under realistic Swedish weather conditions and in real public bus transport systems. The need for charging infrastructure was also of interest, as well as opinions from passengers, drivers and other stakeholders.

B. Purpose of the Study

The purpose of the study was to test and possibly verify earlier assumptions and results [6], and assess whether key stakeholders find electric buses preferable to use in public transport.

II. Methods

A. Real-life Bus Testing Methodology

To get as real data and opinions as possible, the real-life testing required measurement of energy use and stakeholder opinions during a significant test period. Verification of the simulation study also required special focus on energy use in Karlskrona regarding line 1 and in Jönköping regarding line 1 and 3. Line 7 in Karlskrona that was part of the simulation study is today merged with line 1, and was therefore excluded from this follow up study.

B. Electric Bus Specifications

The tested Ebusco 2.0 battery powered electric bus measured 12 meters, and was manufactured in China in 2014 on commission of Ebusco Ltd in the Netherlands. According to the website [7], the battery capacity was 311 kWh (160 kWh/kg) and energy use 0,9 kWh/km, allowing a range of 300 km in urban traffic with 50% passenger load. The interior was heated by a diesel-powered heater, and cooled by air-conditioning that was powered by the 311 kWh battery pack. The test in Falun was an exception and was carried out with the older version Ebusco YTP-1. That older 12-meter bus had slightly lower passenger capacity, lower energy density in batteries, and thereby allowing for a range of only 250 km [8].

C. Energy Measurements

A literature review and an enquiry among bus operator stakeholders identified some main influencing factors on the energy use of an electric bus. These factors were:

- Topography,
- Number of bus stops and other traffic related stops,
- Urban/rural traffic,
- Average speed,
- Passenger load,
- Driver’s experiences,
- Climate, and
- Outdoor temperature (as the batteries where not stored in a temperature controlled environment inside the bus).

This study investigated which of the factors that seems to contribute most to the differences in energy use.

The bus was charged during nights in bus depots and the charging meter recorded how much electricity the batteries were charged with. This included losses related to charging and the batteries’ ability to keep the charged energy over time. This was double-checked by an internal energy meter in the bus. Energy use measurements were done on a daily basis and the distance meter was logged before the bus was leaving the depot each morning. To account for variations in the above-mentioned influencing factors the energy use figures from the simulation study were assumed to be verified if comparative figures could be measured as an average value over at least three days. Logging of mileage and amount of refueled diesel for the diesel powered interior heater was done at each refueling. The energy content of diesel was set to 9,96 kWh/liter. Recording of GPS-data was made for line 1 in Karlskrona to track the topography and verify the number of stops and the average speed.

The range was verified during real-life testing, but with a safety margin to avoid unwanted stops due to empty battery. Experiences from earlier testing by Ebusco revealed that driving during very cold days with less than 20°C below zero with heavy passenger load could require a maximum energy use of about 1,2 kWh/km, while very favorable conditions could require as little as 0,75 kWh/km. Lower energy use is probably caused by faulty logging of mileage or charging. The energy use from the simulation study was 1,04 kWh/km while Ebusco assume 0,9 kWh/km with 50% passenger load [7]. Measured daily energy use averages, which were not between 0,75-1,2 kWh/km, were therefore excluded.

D. Noise Measurements

This study measured and compared noise from diesel and hybrid buses currently in operation in Karlskrona and from the electric bus from Ebusco (Methods section B). The diesel bus was a Mercedes Citaro, and the hybrid a Volvo 7900, both meeting the requirements of Euro 6. The study was defined by the UN standard ECE 51-02 [9], and noise (dBA) was measured at constant speed 30 - 50 km/h, stationary mode, and during pressure release of compressed air by sound level meter type 1 RION NL-15 with microphone UC-53. The wind meter WS-10 recorded weather data during these noise measurements. The tires were not of the same type for the different buses, which could contribute to misleading results during constant speed measurements. The noise measurements did not include noise created during acceleration, but that was complemented by findings in a database from the Thomas D. Larson Pennsylvania Transportation Institute. These data came from the testing of buses for the US market since 1990, according to the United States of America vehicle noise measurement standard SAE J366 [10]. Three of the most recent tested 12-meter buses for public urban transport powered by Electricity, Diesel, and Compressed Natural Gas (CNG) where averaged and compared to each other.

In addition to noise measurements, it is also important to listen to the passenger’s opinion of noise (Results Section *C*.1).

E. Passenger and Driver Surveys

Surveys were created in English and Swedish to capture issues around noise and vibrations on-board, as well as noise and emissions outside the bus. A low inner temperature would reduce the total energy use and a control question was therefore asked about the perceived temperature on board to ensure that the interior heating had not been kept too low.

Questions were also asked about the overall experience of riding an electric bus. Demographic control issues on gender, employment and bus travel habits were added. The drivers' experiences during their work shifts were also important and questions were asked about weather, outside temperature, precipitation, driveability, passengers' opinions, load, and the ability to follow the time schedule. The surveys where handed out during testing to both drivers and passengers on-board the electric bus.

F. Stakeholder Interviews

The opinions from other key stakeholders within this study, e.g. passenger transport executives, bus operators and municipalities, were collected via non-structured interviews.

G. Methods for Initial Investigation About Charging Infrastructure

In combination with testing in each municipality, the study made an initial investigation of possibilities to, and the need for, a charging infrastructure for the public transport systems in the municipalities. Mapping and documentation was based on interviews and literature reviews of official information regarding lines, vehicles, bus operators, and conditions for different charging systems. Public transport executives and traffic officers within municipalities were also interviewed to get a grip of decisions, strategies and plans about future local traffic systems that might influence the public transport in each municipality. This was intended to form a knowledge base for general proposals of charging systems.

III. Results

The electric bus was tested according to Table I. The testing in Falun was restricted due to the change of bus type from Ebusco 2.0 to YTP-1, which would have provided the test with incomparable data. The first test period in Karlskrona was meant to include real-life testing, but was restructured due to administrative problems.

Urban traffic included speed limitations mainly up to 50 km/h, and rarely 70 or 80 km/h. In rural bus traffic, the speed was mostly limited to 70 or 90 km/h and had about 50% less stops than in urban traffic. The real-life testing at Lerum comprised a blend of urban and rural traffic; meanwhile testing at Orust was entirely in rural traffic.

The real-life testing was conducted during a rather mild winter with few snowfalls but mostly rain, and temperatures between -6 to +13°C [11].

TABLE I
Real-Life Testing Time Schedule

Municipality	Period	Test focus
Karlskrona	17 Nov - 6 Dec 2014	Test drives, pre-testing, vehicle registration, maintenance.
Kalmar	7 Dec - 27 Dec 2014	Real-life testing in urban traffic.
Jönköping	29 Dec - 13 Jan 2015	Real-life testing in urban traffic, energy use line 1 and 3.
Borås	14 Jan - 28 Jan 2015	Real-life testing in urban traffic.
Lerum	2 Feb - 12 Feb 2015	Real-life testing in urban and rural traffic.
Falun	14 Feb - 1 Mar 2015	Real-life testing in urban traffic. No measurements or surveys.
Eskilstuna	3 Mar - 13 Mar 2015	Real-life testing in urban traffic.
Orust	16 Mar - 28 Mar 2015	Real-life testing in rural traffic.
Stenungssund	1 Apr - 2 April 2015	Test drives. No measurements or surveys.
Karlskrona	4 Apr - 10 Apr 2015	Energy use line 1, noise testing, real-life testing in urban traffic.

A. Energy Use Measurements

According to the assumed data requirements in the Methods Section *C*, some days of the testing had to be excluded from the data set as the data was outside the range 0,75-1,2 kWh/km. Some days in Kalmar where not measured at all due to resource shortage and maintenance. The testing in Jönköping at line 1 and 3 would have required at least another day to verify the simulation study and is therefore not described in detail. The real-life energy driveline testing results (Table II) reveal that the bus used in average 0,96 kWh/km when tested in urban traffic, and 0,86 in rural traffic at the new line "Göksäterlinjen" Orust. A mix of rural and urban traffic in Lerum resulted in an average of 0,93 kWh/km.

TABLE II
Average Energy Use Results in Each Municipality and Average Results for Use in Urban Traffic

Municipality	Period	Drivers [a]	Line	Outdoors temp. (°C)	Rain/snow	Distance (km)	Average energy use (kWh/km)
Kalmar	17-18 Dec	5 [b]	401, 411, 412	+1 to +3	No	336	0,90
Jönköping	5-13 Jan	4	1, 3, 12, 18	-2 to +4	Some	1038	0,97
Borås	16-25 Jan	30	1	-1 to +3	Some	1235	1,02
Eskilstuna	3-5,10-12 Mar	3	1, 2, 4, 31	+1 to +10	No	900	0,90
Karlskrona	9-10 Apr	6	1	+10 to +12	No	514	0,96
Sum urban traffic				**4023**	**0,96**		
Lerum	2-11 Feb	1	525, 526, 532	-6 to +5	Some snow	1824	0,93
Orust	16-26, 28 Mar	1	Göksäterlinjen	0 to +5	Some	2123	0,86

[a] According to number of survey responses
[b] Total number of drivers that answered the survey during the entire test period

1. Topography Related to Energy Use

There seems to be a correlation between topography and energy use. The tested bus lines in Kalmar and Eskilstuna were rather flat, while the lines in Borås and especially in Jönköping were hillier. Lines 12 and 18 in Jönköping had about 60 meters height differences and line 1 in Borås about 100 meters. The tested lines in Kalmar and Eskilstuna were on the other hand flatter and smoother had less than 20 meters height differences, with a few exceptions in Eskilstuna.

2. Drivers' Driving Behavior Related to Energy Use

Another correlation seems to be related to the number of drivers in each municipality and the energy use. This is exemplified by testing in Lerum where a few drivers decreased energy use by about 10 % at the end of the test. There seems to be no differences in energy use due to the road conditions (wet/snowy/icy/dry) or temperature differences in the test. The latter is probably caused by the fact that air-conditioning was not used. The charging meter was not working in Kalmar, Eskilstuna, and Orust, but energy use was measured via logging of the energy meter inside the bus.

3. Driving Range and Battery Capacity Left

The range was tested several times, and the longest drive was done the last day in Karlskrona when the bus drove 272 km (Appendix 1), and the internal bus energy meter indicated 17% battery capacity left. Ebusco test personnel estimated the charging losses to be 4% for the whole test period.

4. Diesel Heater for Interior Heating System:

Logging of the diesel heater fuel use from the 23rd of December to the 13th of January revealed a use of 93,6 litres. With the bus driving 1,397 km during that period, this resulted in an average energy use of 0,67 kWh/km. According to SMHI [11] the measured temperature and rain/snowfall for that period (Appendix 1) can be regarded as average winter conditions. This implies that the measured energy use should be representative. Passenger survey responses (Results section C1), reveal that the interior temperature was by most passengers regarded as "ok" or "hot". This confirms that the diesel heater used enough energy and gave a satisfactory basis for energy measurements. The authors would like to highlight that the heater could use biodiesel to reduce CO_2 emissions.

5. Energy Use in Karlskrona

Line 1 between Saltö and Lyckeby in Karlskrona stretches 14.7 km and takes about 35-40 minutes to drive. The frequency is 10 minutes between each bus during peak time and this adds up to a total of 465000 km/year (93000 km/year/bus). The line has 38 bus stops in the longer of its two alternative routes. It has three traffic light stops, one railway crossing, and about 10 places where the bus has a duty to give way, which is slightly less than assumed in the simulation study. The average speed is 20-25 km/h and the topography (Fig. 1) is less hilly than the most frequently tested lines in Jönköping and Borås. Still, it was not as flat as the ones tested in Eskilstuna and especially not as those tested in Kalmar.

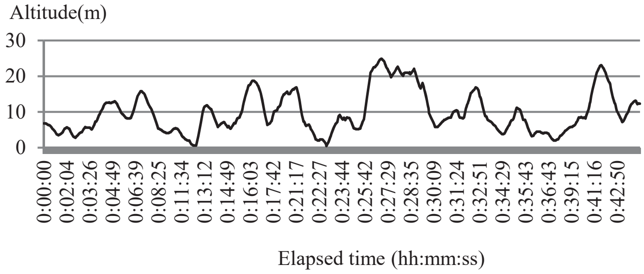

Fig. 1 Topography of Bus Line 1 in Karlskrona

Only the last two days of real-life testing in Karlskrona, with an average of 0,96 kWh/km, gave energy use results (Appendix 1) within the requirements set up in this study. This energy use is about 8 % lower than assumed in the simulation study. These two days where similar regarding passenger load and climate, and can be considered as acceptable data for verification purposes. Differences in energy use seem related to how the driving was executed, as there were different drivers both days.

B. Noise Level Measurement

The first section describes the estimated noise for accelerating buses. The next comings sections are summaries of the technical report produced for this test [12]. All these sections cover the noise measurements in Karlskrona as described in the Methods Section *D*, and thereby done accordingly to UN ECE 51-02.

1. Accelerating Vehicle Noise

As earlier mentioned, our tests do not include noise measurements during acceleration, but a test in Edmonton 2007 measured that an electric bus had 4 dBA lower noise level compared to a parallel diesel-hybrid bus when accelerating from 0 km/h and from 30 km/h [13]. In accordance with the methods section, a summary of recently tested buses (Table III) reveals that the electric buses had on average 9 dBA lower sound level than diesel buses and 12 dBA lower sound level than CNG-buses when accelerating from 0 km/h. When accelerating from 56 km/h, the electric buses had 6 dBA and 8 dBA lower sound levels, respectively.

2. Constant Speed Vehicle Noise

The constant speed noise measurements were done in Karlskrona on the 7th to the 8th of April at Klorgatan and Heliumgatan in Hattholmen, and on the 8th of April at Friluftsvägen in Bastasjö since the ambient sound levels were lower there. Two microphones were placed to the left and right from the centreline of the bus track, and one wind meter was placed a few meters away from the microphone, as illustrated in Fig. 2. The results were adjusted to compensate for the ambient sound level, which was more than 10 dBA lower than the measured results.

A relatively small difference was found between the buses (Fig. 3), but the electric bus was almost 2 dBA louder than the hybrid bus. It is not certain if these differences stem from the bus driveline or something else like differences in tires.

TABLE III
DIFFERENCES IN NOISE FROM TESTED ELECTRIC, DIESEL, AND CNG 12-METER BUSES WITHIN THE THOMAS D. LARSON PENNSYLVANIA TRANSPORTATION INSTITUTE DATABASE

Bus model and year of measurements	Energy Carrier	Length (meters)	Passengers Seats/Total	Average acceleration noise (dBA)	
				From 0 km/h	From 56 km/h
BYD electric bus 2014 [14]	Electricity	12,2	36/49	59,8	63,0
Proterra BE40 2014 [15]	Electricity	12,8	41/79	65,6	66,0
Designline Enhanced El. 2012 [16]	Electricity	12,8	38/81	62,9	67,6
		Average Electric		**62,8**	**65,5**
ElDorado ARRIVO 2014 [17]	Diesel	11,9	42/60	77,9	75,8
New Flyer NABI 40-LFW 2013 [18]	Diesel	12,5	38/72	67,7	68,5
New Flyer XD40 2012 [19]	Diesel	12,2	36/81	70,4	69,2
		Average Diesel		**72,0**	**71,2**
ElDorado Axess HD 2014 [20]	CNG	12,5	38/61	76,7	75,0
New Flyer XN40 2014 [21]	CNG	12,5	39/71	74,7	73,8
Nova (Volvo) LFS 40 2013 [22]	CNG	12,2	35/65	72,6	72,9
		Average CNG		**74,7**	**73,9**

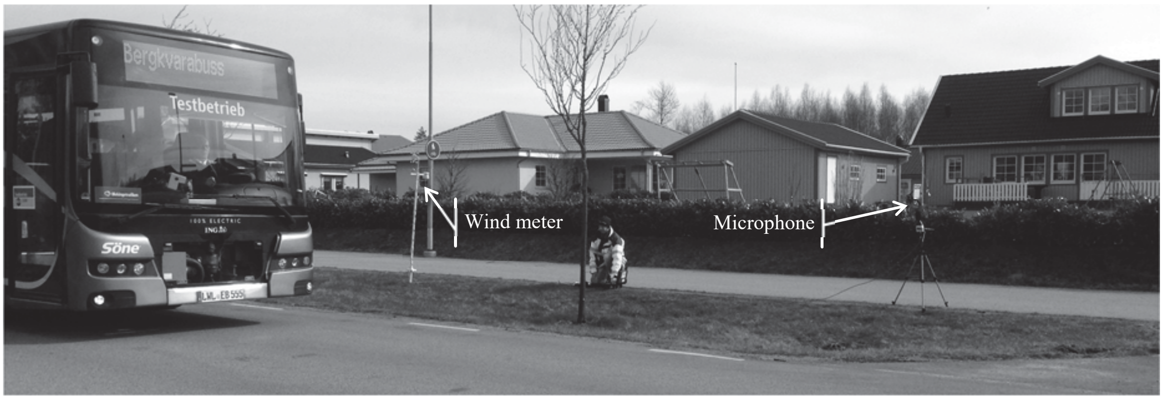

Fig. 2 Noise measurement of the electric bus when driving 30 km/h. Photo: Sven Borén

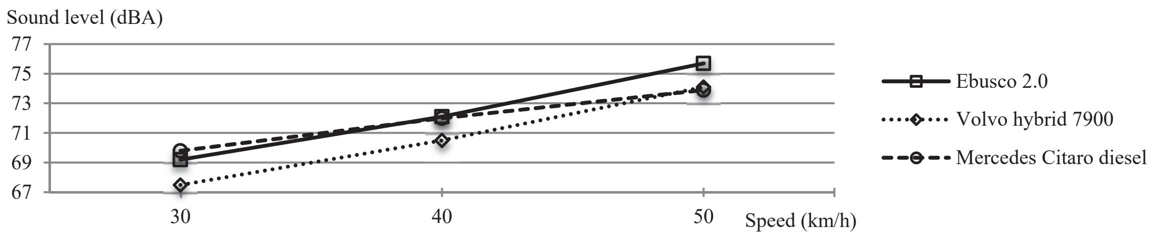

Fig. 3 Results of constant speed noise measurements of electric, hybrid, and diesel bus

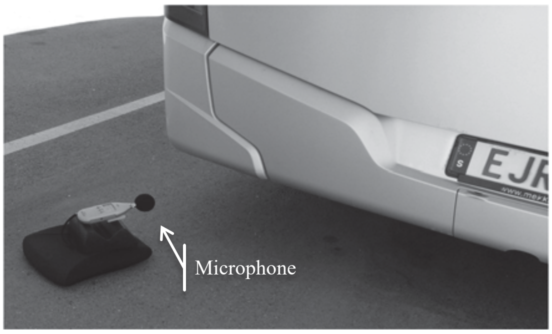

Fig. 4 Stationary noise measurements of the diesel bus. Photo: Sven Borén

3. Stationary Vehicle Noise

The noise from stationary vehicles was measured on the 8th 2015 of April in the bus depot in Torskors, where engines in the diesel and hybrid buses were revved to slightly more than 2000 rpm. The noise was measured behind the gas exhaust pipe as illustrated in Fig. 4. The noise of the diesel bus peaked at 95,7 dBA and the hybrid bus peaked at 90,2 dBA. The electric bus did not exceed the ambient sound level, which was less than 60 dBA.

4. Compressed Air Noise

The buses sometimes release the over-pressure in the braking system at bus stops, which can be perceived as noise by passengers or people nearby. This compressed air noise was measured on the 8th of April 2015 beside the bus as illustrated in Fig. 5. The levels were 69.2 dBA at the right side and 68.0 dBA at the left side of the diesel bus, 68.1 dBA at the right side and 65.7 dBA at the left side of the hybrid bus, and 64.7 dBA at the right side and 65.4 dBA at the left side of the electric bus. These results were adjusted to compensate for the ambient sound level that was more than 10 dBA lower than the compressed air measurements.

C. Driveline Related Opinions

1. Passengers Opinions

In total, 1,303 survey responses were collected from passengers during the entire test period [23] and the results are summarized in Fig. 6. Most of the survey responses came from Borås (84%). The question about comfort was included in an updated version of the survey before testing in Kalmar, but unfortunately the earlier version was used occasionally throughout the field test due to a misunderstanding. That resulted in 71% no-answers (n.a.) for that question. The conditions behind the 43 replies from November in Karlskrona are slightly different as the heating system was not working, and the bus was pre-tested with students who were curious to ride the electric bus. Other people were not picked up at the bus stops. The results clearly show that most passengers felt that the electric bus, in comparison to diesel buses or CNG buses in normal regular service, is quieter inside and outside at bus stops, produce less emissions at bus stops and is more comfortable (mainly regarding vibrations and ride comfort).

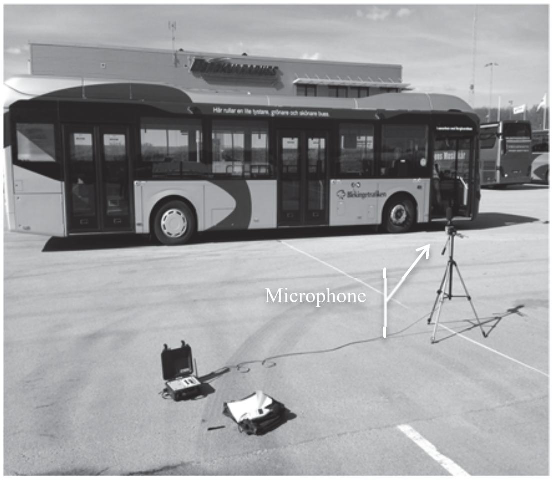

Fig. 5 Compressed air noise measurements of the hybrid bus. Photo: Sven Borén

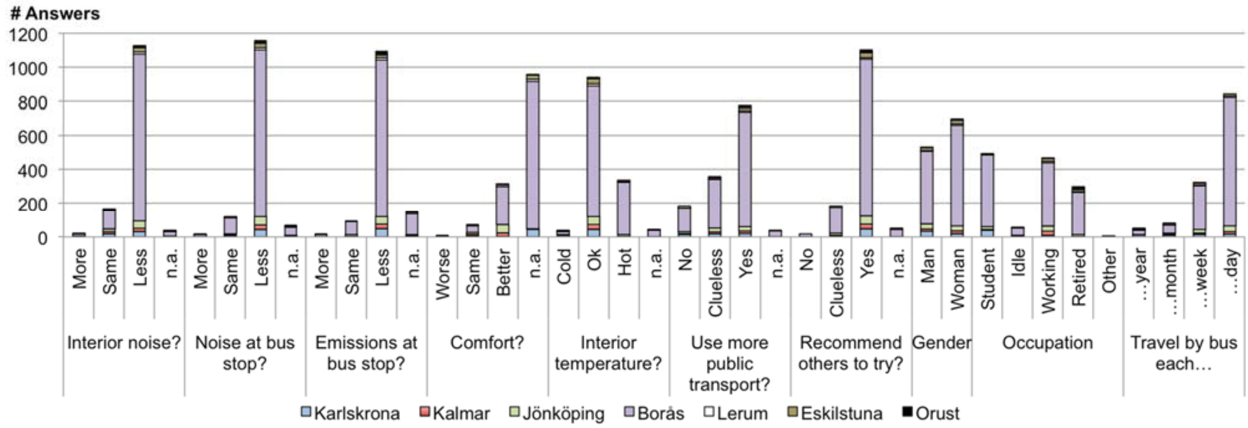

Fig. 6 Passenger survey responses from the entire test period [23]

In addition to the questions in the surveys, passengers were asked to provide additional comments. The most common driveline related positive answers, in descending order, were that passengers…

… liked the bus,

… appreciated the environmental friendliness provided by the electric drive,

… appriciated that the bus had a low noise level,

… regarded the ride as a pleasant and comfortable experience, and appreciated a fresh and pleasant interior.

Some non-driveline related negative comments, in descending order, were about:

- sudden braking (which can be adjusted by software settings),
- narrower seats than usual and narrow passage backward from the driver,
- hard seats,
- only one space for wheelchair or stroller, and
- fogged windows when the heater did not work.

2. Drivers' Opinions

During the entire test, 77 drivers out of about a hundred answered the driver survey [23] and the number of respondents varied a lot in each municipality. Borås had 49 driver responses, but Orust and Lerum only one answer each. The comments from the drivers who drove the electric bus can be summarized as follows:

- **Charging:** The majority of drivers did not charge the bus as the mechanics at the bus depots and/or Ebusco staff did this. A few of the drivers took part in the charging and felt that it worked well.

- **Time schedule:** Almost all drivers answered that they managed to drive according to the timetable. A few of the drivers who drove only short distances expressed a fear that the electric bus would have problems to drive according to the timetable.
- **Drive-ability:** Almost all drivers answered that they favor the electric bus drive-ability and some stated that the electric bus was even better to drive than other buses. Some drivers thought that the electric bus was quick at the start from standstill. About a third of the respondents mentioned that the bus brakes were hitting hard over 30 km/h, and that the bus was blunt, particularly in steep inclines. This is possible to adjust in the bus software, but can limit the range. In addition to the survey, direct conversations with drivers revealed that the electric bus was a bit weak when speeding over 50km/h, which is also possible to adjust in the bus software, but might limit the range.

Most drivers have given positive feedback about the electric bus, but some have complained about things that are not related to the driveline, such as the absence of stop braking, poor rear visibility, a modest driver environment with few personal adjustment possibilities, the absence of rear mirror inside the bus, and misplacement of the door mirrors.

3. Stakeholders' Opinion

Discussions have been held primarily with the stakeholders in the study, the participating municipalities, passenger transport executives, and bus operators. The following comments emerged in meetings during the study with drivers and representatives from the bus operator Bergkvarabuss in Karlskrona, and representatives from Blekingetrafiken, Region Blekinge, Karlskrona municipality and the local energy company Affärsverken, [24]:

- The electric bus from Ebusco was perceived as good and the use of hybrids was perceived as superfluous.
- The electric bus has the potential to fit into the operator's business if the need for charging within one or two circulations of vehicles can be solved in a simple way for the driver, without involving high costs.
- For future use of electric buses in public transport, bus operators' potential risk relating to the uncertainty about the new technology and expertise needs to be taken into special consideration. Several major European bus manufacturers have not started the production of electric buses yet, which some bus operators who have established cooperation with them consider to be a disadvantage. It is therefore important to make public procurement design specifications that are tailored for electric buses and the supporting charging infrastructure.
- The simulation study revealed a 25% lower total cost of ownership for electric buses compared to diesel buses for urban public transport. This is received with caution by stakeholders, but gives a positive impression of electric buses.
- The introduction of electric buses need to be preceded by some type of projects where electric buses are tested over a longer period to raise the level of competence for all parties.

Conversations with other stakeholders involved in the project confirmed the above views, as well as most of the comments from the passenger surveys. The issue of grid related capacity for depot charging of several electric buses during nights has been raised several times, as well as whether they should invest in electric buses with less battery and lower purchase costs, which would require a more advanced and expensive charging infrastructure. Once stakeholders have tested the electric bus and have seen how it can work in urban areas, the question of charging often appears, and how it could be solved in each municipality.

D. Initial Charging Infrastructure Investigation

Interviews with representatives from municipalities and passenger transport executives revealed that they believe something has to be done to decrease transport emissions and lower noise levels within cities, and that use of electric instead of diesel buses has a great potential to contribute to such development. One problem they are facing when planning for such development is the palette of electric bus systems and which configuration of bus and charging system that would fit their local public transport. Should the buses have a large battery pack that allows long range and maybe only slow charging at depots, or a smaller battery pack that might require strategically placed fast charging equipment? These tissues were studied, including charging stations powered by the electricity grid, which need to allow for charging without effecting existing and future nearby electricity grid users (an overhead fast charger needs about 350-600 kWAC, while a handheld slow charger needs about 25-100 kWAC).

It was found that most bus lines included in the study had a great possibility to host electric buses and charging stations at either line end stations or at line crossing points, depending on the bus lines traffic intensity and the choice of battery pack size. For example, bus line 1 and 3 in Jönköping has a high traffic load and run with 18-meter buses each 10 minute. The end station in Råslätt beside a shopping mall, could host an overhead charging station, as there seems to be enough grid capacity and a possibility to host an electric charging station for cars as well. Another high traffic line example is line 1 in Karlskrona that ends at Saltö, which could be suitable to host an overhead fast charger because a grid substation is located about 20 meters from the bus stop. If electric buses with large battery packs (typically over 300 kWh) were chosen, it might instead be interesting to install a fast charger at the future common bus station located beside the train station at Blekingegatan, which could fast charge buses on most lines in Karlskrona. This second alternative might also be suitable for Kalmar at the bus station beside the train station for charging a part of the bus fleet that passes the city center. Even if fast charging seems feasible, slow charging at depots during nights should be the base for a local bus charging system, as it is the cheapest alternative and keeps the batteries in a better condition. Electric buses with large battery packs seems like an interesting alternative when traffic load is low as in Orust, where the rural traffic with low energy use allows longer ranges than urban traffic.

As stated in the simulation study, electric buses should use new sustainable generation electricity capacity to contribute prominently to sustainable development. This is possible and energy companies that deliver electricity to the charging infrastructures have some incentives from the government and the customers to buy shares in or build new renewable electricity production (based on flow-based energy such as wind, solar, and streaming water).

IV. Discussion

A. Main Message

The findings of this study indicate that it is preferable to use electric buses in public transport. The main reasons for this are:

- Almost all passengers perceived the electric bus to be more silent and comfortable than today's diesel and CNG buses. Most of the drivers enjoyed driving the electric bus, and representatives from municipalities, passenger transport executives and bus operators were positive too.
- Electric buses tested in the USA have more than a 6 dBA lower noise level than diesel and CNG buses during acceleration, which is perceived as a 75% noise reduction by the human ear. This indicates that noise levels in cities with bus traffic could be reduced significantly.
- The energy use turned out to be 8% lower than assumed in the simulation study [6], which supports the conclusion that electric buses used in urban public transport are up to 25% cheaper when compared to diesel buses.
- Almost all of the studied bus lines can be operated by electric buses, and are possible to equip with charging infrastructure that is powered by new sustainable electricity generation capacity. Renewable fuels could also power the interior heater.

B. Critical Assessment

Some issues that could have improved the real-life:

- Energy measurements would have included charging and battery losses during the whole test if the charging meter had been used regularly. This was unfortunately not possible as the charging meter broke down from time to time. The energy use (battery to wheel) was anyhow displayed at the drivers' seat and thereby continuously measured throughout the test.
- Energy use for interior heating and cooling could have been measured for a longer period to get more accurate average data. The testing was limited to Swedish wintertime, and the southernmost part of the test area had typical winter conditions. The northernmost part less so. If the testing had included all seasons, an average of the whole year would have been achieved to also include the use of air conditioning during warm days.
- Testing in Jönköping should in line with the study ambitions have included at least one more day on line 1 and 3 in order to be able to fully verify the simulation study. Testing in Falun could have contributed better to the results if the Ebusco 2.0 would have been used.
- The noise measurements could have been done with more buses available for the Swedish market, if there had been more time and resources available. They could also have been tested during acceleration. An interior noise measurement would also have been valuable to see if there might be any difference between passenger's perceptions and measured noise levels. A more thorough analysis of possible differences in noise performance during acceleration regarding the US or the European market for the tested buses would give the analysis more accuracy.

C. Comparison with Other Studies

Bus testing by the Thomas D. Larson Pennsylvania Transportation Institute (Results section B1) applied the SAE standard, but this is slightly different to the UN standard used in this study (Methods section D) as the SAE standard includes noise measurements during acceleration. The tested electric bus from BYD is similar for the USA and European market, but the other tested buses cannot be purchased in Europe and it is therefore some uncertainty about the accuracy when using results from bus tests for the USA markets in European cities. The same applies for a bus noise study in Edmonton [13].

A study about feasibility of electric buses in small and medium-sized cities in the USA [25] uses less updated data from the same source as used in this study (Results section B1). They found noise from accelerating electric buses to be surprisingly much lower than in this study, probably because they believe the ambient level can be excluded from the measurements, which is not in line with the UN standard used in this test and neither with the presented results via the above-mentioned reports from the Thomas D. Larson Pennsylvania Transportation Institute. In line with this study, Wang and González also believe that electric buses are ideal for use in small and medium-sized cities if the buses are charged with renewable energy.

D. Conclusions and Further Work

This study has clarified that electric buses have low energy use and low external noise levels, and receive positive opinions from passengers, drivers and other stakeholders in real-life use during wintertime in the south of Sweden. It also seems like the urban public transport system can rather easily host a charging infrastructure generated from renewable sources. An update of earlier studies about total cost of ownership [6] confirms that electric buses are up to 25 % cheaper than diesel buses when used in public urban transport and charged with new renewable energy. In all, this supports the conclusion that electric buses are preferable for use in Swedish public urban and rural transport, which can probably be applied also to other European and especially Nordic areas with similar climate.

Further studies within should include testing throughout a whole year to get a yearly-based average energy use. To support the development of a business model tailored for electric buses in public transport, further studies should reveal data for likely costs, and also develop training of bus drivers, maintenance personnel, and planners to use the electric bus in an optimal way. In this context, deeper correlation analyses on what factors that are the most influential on energy use could be useful to increase the validity of our conclusions.

APPENDIX 1

TABLE IV
ENERGY MEASUREMENT AND PARAMETER LOGGING PER DAY

Municipality, Date	Line	Passenger load [a]	Road surface	Temp (°C)	Rain/ snow	Distance (km)	Energy use (kWh/km)
Kalmar							**Average 0,90**
17th Dec	401, 412	Medium-low	Dry	+1 to +3	No	150	0,92
18th Dec	401, 411	Low	Dry	+3	No	185	0,87
Jönköping							**Average 0,97**
5th Jan	Mix	Low	Dry	-2	No	147	0,88
7th Jan	12, 18	Low	Dry	0	No	224	0,99
8th Jan	Mix	Low	Dry	+3	Rain	114	0,98
9th Jan	12,18	Medium	Wet	+2	Snow	159	0,92
10th Jan	1, 3	Medium	Snow-dry	+4	Little Snow	131	1,05
12th Jan	12, 18	Medium	Wet	+3	Rain	172	1,05
13th Jan	18	Medium	Dry	+3	No	79	0,91
Borås							**Average 1,02**
16th Jan	Mix, 1	Medium-high	Wet-dry	0	Little Rain	100	1,06
17th Jan	1	High	Wet-dry	2	Little Rain	150	0,92
18th Jan	1	Medium	Wet	0	Rain	101	1,02
19th Jan	1	High	Wet	1	Snow	154	1,09
20th Jan	1	High	Wet	0	Snow	143	1,09
21th Jan	1	High	Wet	-1	Snow	107	0,99
22th Jan	1	High	Dry	0	No	167	1,01
23th Jan	1	High	Dry	-2	No	153	1,00
24th Jan	1	Medium	Wet	-1	Snow	98	0,98
25th Jan	1	Medium	Dry	-1	No	117	0,98
Lerum							**Average 0,93**
2nd Feb	Mix, 525	Low	Snow	-4	No	227	1,00
3rd Feb	525, 535	Medium	Snow	-4	No	121	0,99
4th Feb	525, 535	Medium	Dry	-4 to -5	No	220	0,97
5th Feb	525, 535	Medium	Dry	-3 to -6	No	220	0,96
6th Feb	525, 535	Medium	Dry	-2 to -5	No	220	0,93
9th Feb	525, 535	Medium	Dry	5	No	234	0,88
10th Feb	526, 531	Medium	Dry	3	No	243	0,84
11th Feb	525, 535	Medium	Dry	4	No	236	0,86
Eskilstuna							**Average 0,90**
3rd Mar	1	Medium	Wet	2	No	61	0,97
4th Mar	2, 31	Medium	Dry	4	No	110	0,90
5th Mar	3, 1	Medium	Dry	1	No	156	0,95
6th Mar	2, 3	Medium	Dry	2	No	99	0,79
7th Mar	6	High	Dry	4	No	79	0,75
10th Mar	1, 2	High	Dry	10	No	134	1,03
11th Mar	3, 1	Medium	Dry	12	No	293	0,80
12th Mar	2, 30	Medium	Dry	9	No	146	1,03
Orust							**Average 0,86**
16th Mar	Göksäter	Medium-low	Dry	0	No	193	0,85
17th Mar	Göksäter	Low	Dry	1	No	193	1,02
18th Mar	Göksäter	Medium-Low	Dry	3	No	193	0,84
19th Mar	Göksäter	Medium	Dry	5	No	193	0,80
20th Mar	Göksäter	Low	Dry	3	No	193	0,88
21th Mar	Göksäter	Low	Dry	0	No	193	0,86
23th Mar	Göksäter	Low	Dry	0	No	193	0,96
24th Mar	Göksäter	Medium-low	Dry	1	No	193	0,82
25th Mar	Göksäter	Low	Dry	3	No	193	0,84
26th Mar	Göksäter	Low	Dry	5	No	193	0,79
28th Mar	Göksäter	Medium-low	Dry	0	No	193	0,81
Karlskrona							**Average 0,96**
9th Mar	1	High-medium	Dry	+10 to +13	No	242	0,99
10th Mar	1	High-medium	Dry	+10 to +12	No	272	0,94

[a] High passenger load indicates that the bus is full and halt at each bus stop, and medium a bus filled with passengers to 50 % that halt every third bus stop, meanwhile low a bus filled with a few passengers that halt every six bus stop.

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