

Analysis of Key Performance Indicators of Electric Bus Systems in Helsinki and Comparison to Simulated Results

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Abstract

Operation of opportunity charged electric buses can be an economically feasible solution for public transport in cities. However, the operation requires more planning than the operation of conventional buses. The data obtained from a pre-commercial electric bus pilot project by Helsinki Region Transport with 12 electric buses are gathered and analysed. The key performance indicators, having both the PTA's and PTO's as well as the passengers in mind, are chosen. Simulations are performed on all bus routes using a simulation tool based on geographical information. The key performance indicators obtained from real operation are compared to the simulated results.

Keywords: Electric buses, opportunity charging, key performance indicators, simulation, data analysis

1 Introduction

Electric drivetrains are gaining popularity especially in passenger vehicles but also in heavy-duty vehicles such as buses. A large number of demonstration and pilot projects are on-going in Europe and elsewhere. In addition, some commercial tenders have already also taken place. A relatively good summary of different activities on electric bus systems has been collected by the ZeEUS¹ project. [1]

Electric buses have many benefits as compared to conventional buses – they are more energy efficient, produce less noise and pollution, and, hence, provide a more comfortable ride for the passengers. The purchase price of electric buses is much higher than that of conventional buses, mainly due to the battery and the fact that the cost benefits from volume manufacturing have not yet been reached. The two basic system-level concepts for electric bus systems are 1) overnight charging of buses with a large traction battery (typically about 300 kWh), and 2) opportunity fast-charging of buses with downsized batteries (typically about 60-70 kWh) in selected locations along the operational route, such as route end-points and terminals. It has been shown, that the overall cost of ownership of electric buses can be minimised by using a relatively small battery combined with opportunity fast-charging at the end bus stops. This type of electric bus system, when designed right reaches high reliability and system availability, can be both economically and environmentally superior to the conventional public transport with diesel buses. [2]

System-level operation of opportunity charged buses is more complex than operation of depot charging. Critical parameters at system level are energy management (charging, battery capacity and range), labour-intensity and size of the fleet. Enough time for charging at the end bus stop has to be reserved. On the other hand, too much time should not be reserved, as this will only bring additional costs if extra minutes for

¹ Zero Emission Urban Bus System, <http://www.zeeus.eu>.

charging are added into the timetable, or extra vehicles are added to the fleet. Adding battery capacity takes away passenger seats and increases the mass of the vehicle. The energy and charging management at fleet level need to be able to deal with disturbances, so there must be sufficient operational and capacity margins. The bus has to be able to operate normally also in the case of a broken charger, for instance.

Current research tasks on electric bus systems are mostly related to enforcing and validating system-level reliability and availability. Opportunity charged buses require preparation and a thorough analysis in advance in order to obtain a reliable system ready for large-scale roll-out. As entire bus lines are electrified, simulations can be used for this purpose. Real data collected from operating systems are crucial for the validation and deriving the metrics to assess their production capacity in comparison to conventional buses. Currently, electric buses are tested on several locations including the Helsinki region, and the experiences and knowledge based on these initial lines should, of course, be utilised. Data from three different bus lines in Helsinki is gathered for this purpose.

Following activities on electric buses since 2012, Helsinki Region Transport HSL has in 2016 launched a pre-commercial pilot project 'ePELI' involving operation of 12 fully electric buses and their opportunity fast-charging systems. [3][4] The purpose of the pilot project is to create readiness to move to commercial tenders in electric bus systems and services when commencing roll-out according to the strategy of HSL in near future. For the pilot, HSL has directly procured 12 buses from Linkker Ltd, and is lending them to four to five different commercial PTO's for operation within existing contracts in several different bus routes (2-3 buses per PTO). The first buses have been in real route operation since spring 2016, and the last buses will enter operation during autumn 2017 or early 2018. Totally five different bus routes are planned for the pilot operation. The pilot also includes procuring and commissioning the opportunity charging stations for each of the piloted bus routes. This is done by the cities of Helsinki and Espoo in their respective geographical areas as part of the HSL region. Two different fast-charging equipment manufacturers are involved in the pilot: Heliox and Ekoenergetyka. The 'ePELI' pilot involves roof-mounted fast-charging pantographs in pre-commercial operation. The final decision on the type of the pantograph (roof-mounted or inverted²) will be made before the first commercial tenders.

Along with the HSL's ePELI project in Helsinki region, the electric buses are in Finland being piloted by the cities of Turku and Tampere. As a national co-operation, the system performance and experiences from the three pilots will be compared against each other. Each city is piloting a varying number of electric buses.

City of Turku has six of the same Linkker buses, and similar charger arrangement, but Turku is utilising an inverted pantograph in the charging connection. City of Tampere has selected four Solaris 12 m opportunity charging buses with a slightly larger battery size (75 kWh vs. 55 kWh). Tampere has only a single charger at one end of the route, and the city has selected the roof-mounted pantograph connection.

In this paper, the key performance indicators of the operation of electric buses in Helsinki region are chosen, and the data gathered is analysed. The same lines are simulated using a GIS simulation tool, and the results of the simulations are compared to the results obtained from the real operation of buses.

2 Key performance indicators

Key performance indicators (KPI's) are used to measure the success of a process. They are measurable quantities that are easy to understand and represent the most important contributors to the success or failure of a process. For the process under study, the KPI's should be chosen with great care in order to really obtain the correct indicators. In a public transportation system, the KPI's of interest depend on whom you are asking. Three different reference or observer groups are briefly discussed in the following: the passengers (customers), commercial public transport operators (PTO), and public transport authorities (PTA).

For the passengers, the most important aspect is that the bus arrives at the scheduled time to the bus stop and departs on time. It is also important that the service quality, including passenger comfort, is satisfying.

For the operator, the economic aspects are of utter importance as well as the practical considerations of operating electric buses instead of diesel buses. Reliability and availability of the electric buses is a

² The term inverted pantograph is here used for a system where the moving parts of the pantograph are installed on the stationary side and move downwards towards the bus.

cornerstone of cost-effective economy for the bus operator. Regarding operational flexibility, opportunity charging fully electric buses offer less operational flexibility than conventional buses or hybrids, for example, in terms of switching vehicles from one route to another. This is especially true in the early stages of roll-out when the fast-charging infrastructure has not yet been fully deployed. Also, the smaller the traction battery capacity is, the less operational flexibility and operative margins it offers to the operator.

For the PTA's, the reliability and economy of the system as a whole is of interest.

In the Helsinki region, the KPI's have been selected in discussions with all parties included in the public transportation system. An indicator space from the ZeEUS project was chosen as the base set of KPI's, which were then ranked in workshop sessions with the Helsinki Region Transport Authority (HSL). Each indicator was given a score between 1 (lowest relevance) and 3 (highest relevance). For the final set of KPI's, only the level 3 ranked indicators were chosen, and the most significant indicators were picked from the results to obtain a compact set of suitable indicators. The list of KPI's was later refined in meetings with all of the stakeholders, such as Public Transport Operators (PTO's), charging service providers and the cities of Helsinki and Espoo who own the charging infrastructure.

The KPI's have been selected to allow the assessment of the system-level performance in individual cities, and to enable comparison of the results in equal terms. The analysis provides information of the performance to the PTA's, PTO's and other stakeholders, but also to allow comparison of the different technology solutions in the cities' pilot projects, which will assist in the future decisions of for example charging connection type, battery sizing principles, charging arrangement etc. The list of the selected KPI's is shown in Table 1.

Table 1. Selected set of KPI's for electric bus systems in the Helsinki region

No.	Indicator	Description
1	Energy costs, driving (€/km)	Including electricity from the grid and the heater fuel
2	Operational driving distance (km)	Operational (on route) distance driven compared to the planned car circulation
3	Total electricity consumption (kWh/km)	Total charged external energy / kilometres driven
4	Time required to position the bus at the charger (s)	Time to maneuver the bus to the charger. From arrival at the proximity of the charger to the point when the driver initiates the charging
5	Total charging time (s)	Charging duration per sequence step from the charging start command to bus being ready to leave
6	Charging node utilisation (%)	Time when the charging position is occupied / time available. Time occupied includes the active and dead times
7	Depart on schedule (%)	Percentage of departures left on schedule
8	Availability of the vehicles (%)	Percentage of the time that the vehicles have been available for service
9	Availability of the infrastructure (%)	Percentage of time when charging service is available / calendar time

10	Additional maintenance time (h/a)	Additional/difference maintenance time compared to conventional vehicles, e.g. cleaning of pantograph contacts	in/unexpected time compared to
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It should be noted that, in addition to the KPI's listed in Table 1, a number of additional indicators and metrics from the entire system are collected and followed. These are used to produce relevant vehicle and system level info such as the dependence of energy consumption on temperature and traffic conditions. Selected technical and system parameters in the HSL region include: temperature and road slipperiness, the efficiency of the charging equipment and the battery system, efficiency of the total system (including idle losses etc.), efficiency of the drivetrain, auxiliaries and heating and ventilation system, minimum battery State of Charge (SoC), average window of SoC variation in the battery when operating the bus in the system and battery State of Health (SoH). The technical indicators can be of very high practical value when assessing the maturity of the systems upon entering roll-out to commercial production.

All data required to derive the values of the indicators were not available at the writing of the paper. For example, the heating energy consumption is a performance indicator, which has been seen to be rather significant in the Nordic climate conditions, based on the fuelling needs of the buses' fuel heaters. Not all electric buses use additional heaters running on conventional fuels. However, if such heaters are in place, their energy consumption needs to be reported alongside with the electric power consumption. The actual fuel consumption will be measured accurately as the fuel heater run information will become available in the bus IoT data.

Departure on schedule, and both vehicle and infrastructure availability require more information from the PTO's and the PTA IT systems. Regarding the additional technical indicators, some of them such as the battery health are not currently available, and some estimation algorithms will be developed during the project.

3 Simulation Tool

The simulation tool is here briefly presented, a more detailed description can be found in [5]. The tool is based on geographical information system (GIS). The routes in Helsinki region are depicted using the commercial software Mapinfo. Each route consists of segments including information about the segment length, slope, curvature, speed limit, and location of bus stops and stop lights. Chargers can freely be placed at the desired locations.

The dynamic bus model includes the mechanical forces acting on the bus, the efficiency of the powertrain, and the charging level of the battery. The bus model was validated in [6] by dynamometer tests. The equation of motion of the bus is given by

$$m \frac{dv}{dt} = \frac{1}{\rho_{rot}} \left(\eta_{dl} \frac{T_m f_d}{r} - mg \sin(\alpha) - F_{res} + F_{wb} \right) \quad (1)$$

where m is the total mass of the bus, v is the speed, and t is the time. The vehicle inertia coefficient is given by ρ_{rot} , the driveline efficiency coefficient is given by η_{dl} , the motor torque is given by T_m , the drive ration is given by f_d , and the radius of the tyres is given by r . The standard acceleration due to gravity is denoted by g and the angle of inclination of the road by α . The braking force of the wheel brakes is given by F_{wb} . In normal operation at sufficiently high speeds, a large amount of the energy can be regenerated during deceleration, but during rapid deceleration and lower speeds, the wheel brakes are used. The driving resistance force, F_{res} , consisting of the rolling resistance and aerodynamic drag is computed according to

$$F_{res} = f_r mg + \frac{1}{2} \rho A C_d v^2 \quad (2)$$

where f_r is the rolling resistance constant, ρ the air density, A the frontal area of the bus, and C_d the aerodynamic drag coefficient.

The battery, inverter, electric motor, and the mechanical driveline are modelled by simple efficiency factors. The efficiency of the motor is modelled by a look-up table dependent on the speed and the torque. All other efficiency factors are assumed to be constant.

Speed profile

In addition to having an accurate bus model, a realistic speed profile is of great importance in the simulations. City buses are characterised by numerous accelerations and decelerations as the bus stops for bus stops and traffic lights. Furthermore, the vehicle has to slow down when passing a crossing. Variations in the traffic and rush-hour congestions also have a big impact on the operation. At heavily trafficked segments, the average speed of the vehicle is low, and the energy consumption might somewhat decrease as the aerodynamic drag is lower as compared to higher velocities. On the other hand, the overall energy consumption increases as a longer time is needed for the route, and the power needed for heating and ventilation remains the same regardless of the speed. Furthermore, the efficiency of the machine is normally lower at lower speeds, and rapid variations in the traffic cause excessive accelerations and decelerations, which might increase the energy consumption.

In the simulations, the speed is generated dynamically according to

$$v_{set} = f_v v_{lim} (1 - f_{turn}) (1 - f_{traffic}) (1 + f_{hurry}) \quad (3)$$

The speed limit is denoted by v_{lim} , and the factor f_v can be used to adjust the average speed. The factor f_{turn} is used to make the bus slow down in curves. The value was determined based on measurement data from real buses in operation. The value is dependent on the steepness of the curve, a 90° curve leads to a 75% decrease in the speed. The traffic is modelled by the randomly varying factor $f_{traffic}$. A real duty schedule, including start and end times for each line as well as recovery time reserved for the terminal stop, is used as an input to the simulation. Based on the schedule, the target stop time for each bus stop can be computed. The factor f_{hurry} is used to increase the speed in case the bus is behind the schedule. In addition to (5), a limitation is set on the variation of the speed set point in order to avoid too harsh accelerations and decelerations.

The motor torque is controlled based on the difference between the speed set point and the actual speed using a simple PI controller. Additionally, the torque is limited by the maximum battery current, and in the field weakening region, it is also limited inversely proportionally to the speed.

4 Results and discussion

4.1 Electric bus performance

Electric buses are currently in use on three different routes in the Helsinki metropolitan area. The electric bus operation started on Espoo route 11 (E11) in April 2016. Route 11 is a rather easy feeder-type route in a suburban environment. It is 10.4 km long, and has an elevation variation of only 14.8 m. The line is not prone to congestion and the mean speed of the line is typically around 24 km/h, being over 30 km/h in early morning or late evening. During the spring 2017, the electric bus pilot phase took a step further as the operation started on routes 23 and 55 in Helsinki (H23 and H55, respectively). These routes are slightly shorter than E11, but they are still much heavier. The routes start in the centre of Helsinki, which means that the passenger load is much higher than on route E11. The mean speed on route H23 is typically around 16 km/h, and on route H55 around 19 km/h. On each routes, two electric buses are used, and each route is served by one charging station at the time of writing. In September 2017, an additional charging node will be commissioned in the southern shared end-stop of routes H23 and H55 so that then both have charging at both end-stops.

Data from these buses are presented in the following. One of the buses running on route H23 is left out of the analysis due to missing data. All KPIs have not yet been analysed, but a few of the most important are included in the analysis. First, the distance travelled on the route (indicator 1) was studied. The results on all routes are shown in Fig. 1. Depending on the planned circulation, the expected distance per day on route E11 is about 140 - 250 km. A closer look at the two buses that have been operating on the line since April 2016 reveals that the buses reach the minimum daily target on only 75-79% of all days the buses have been in use. Furthermore, the buses were completely out of service during 35-37% of the days in the studied period.

During the pilot bus operation, the buses are occasionally taken out of service for laboratory tests, promotional rides, and exhibitions, and this partly explains the low commercial use of the buses. Technical problems with either buses or the charging stations are also part of the explanation. Based on the data gathered so far, it is not possible to get a complete picture of the reasons behind the low use. Currently ongoing discussions with bus operators and charging service providers will hopefully give a better picture. The results on bus routes H23 and H55 are similar. The buses should be used up to about 250 km per day on these routes, but the achieved distance is rarely that high. Electric buses have been used on routes H23 and H55 only for a short time, and the situation has improved during the spring.

The overall daily mean energy consumption and the traction energy consumption on different routes are shown in Figures 2-4. The influence of different seasons (temperature, driving conditions) can be clearly seen for both the overall energy consumption and the traction energy consumption. The traction consumption is mainly affected by the load, stopping frequency and the driving style. During the winter months, the amount of passengers is higher and the traffic is more dense. The regeneration capability is slightly smaller during the cold season as the roads are slippery. At most and in good conditions, about 45 % of the traction energy was regenerated, whereas in the winter time, the rate occasionally decreased down to 30 % or even lower. All of these factors can be seen as a higher energy consumption in the winter. The overall energy consumption includes not only the traction energy, but also the energy needed for heating, ventilation and auxiliary systems. Last winter was very mild in Finland, and the temperature was mostly around 0°C with only a few days having temperatures below -10°C. Still, the energy consumption clearly increased during the winter. The energy consumption of all buses as a function of the temperature is shown in Fig. 6. Compared to route E11, the routes H23 and H55 are characterised by a higher energy consumption. The passenger amount is larger, and the traffic conditions are completely different as the routes start from the centre of Helsinki.

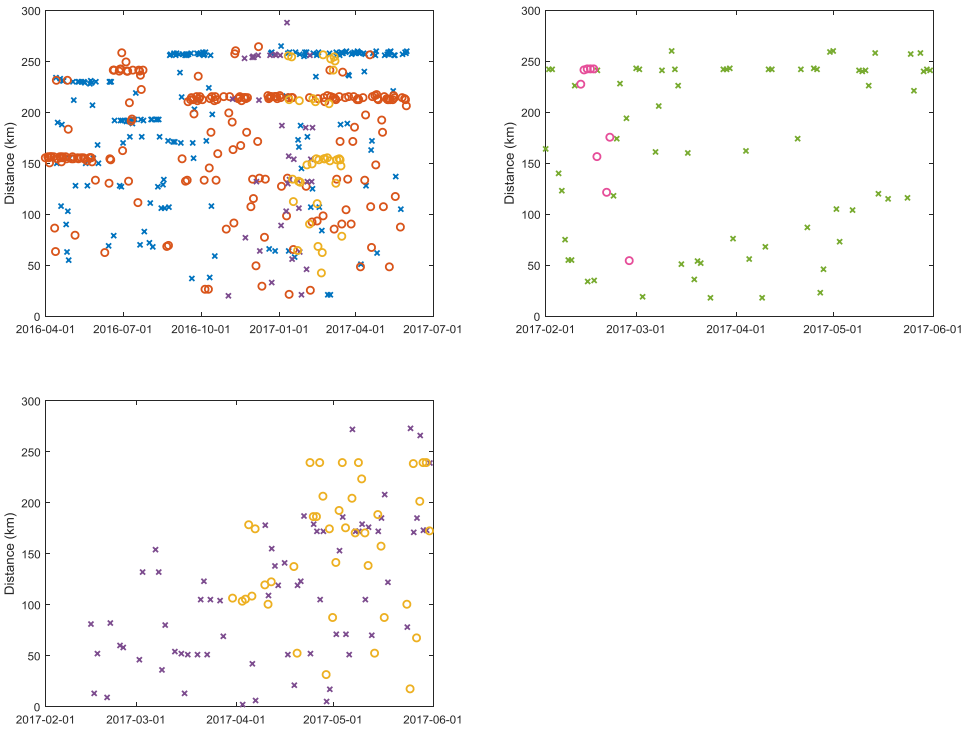


Figure 1. Daily distance travelled on route E11 (upper left), route H23 (upper right) and route H55 (lower left). Each bus is presented by a separate color and symbol. Each line is operated by two buses, except for route E11 that was temporarily operated by four buses in beginning of year 2017.

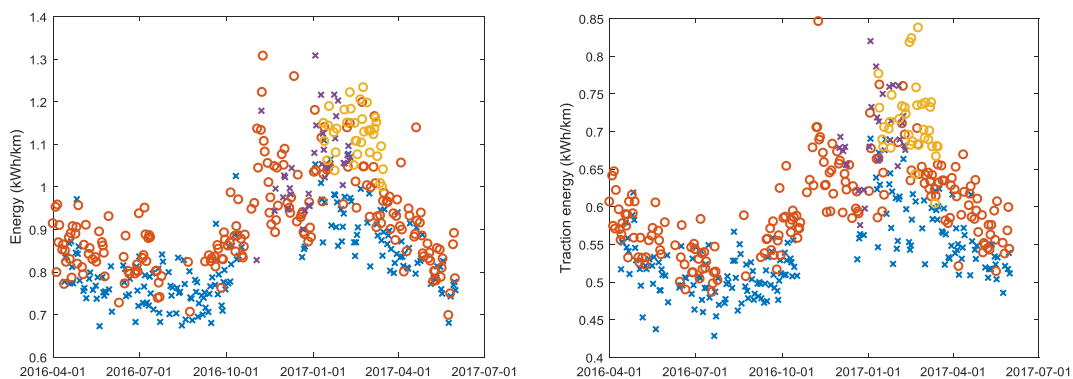


Figure 2. Total energy consumption and traction energy consumption on route E11 between April 2016 and July 2017.

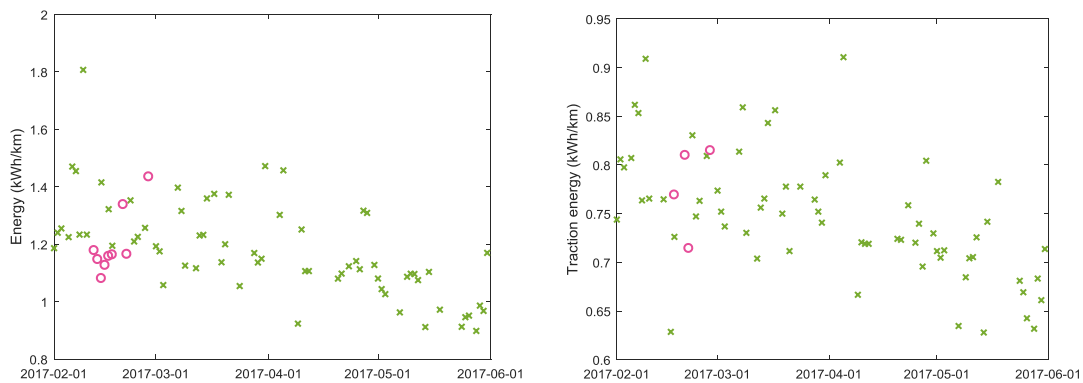


Figure 3. Total energy consumption and traction energy consumption on route H23 during February-June 2017.

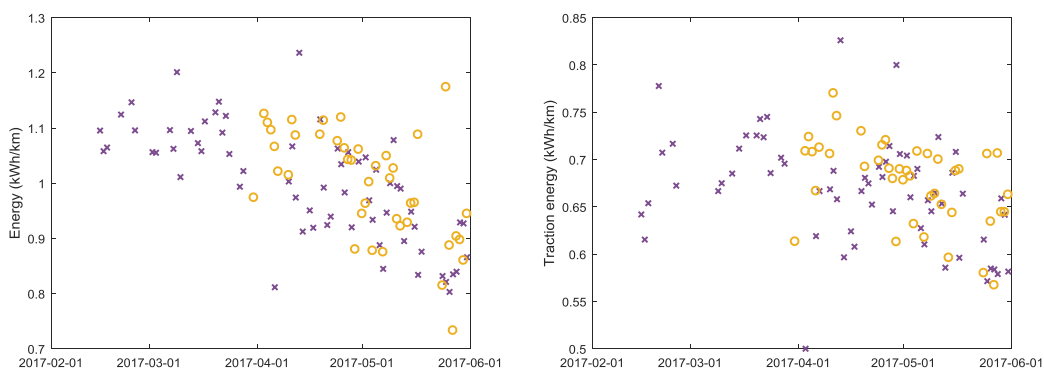


Figure 4. Total energy consumption and traction energy consumption on route H55 during February-June 2017.

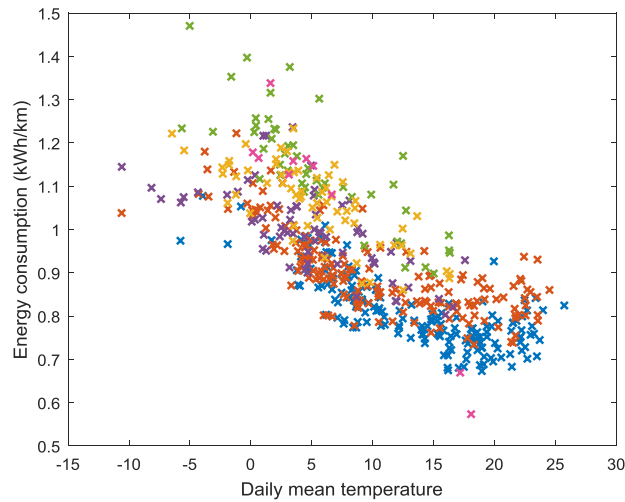


Figure 6. Total energy consumption of all buses as function of daily mean temperature.

4.2 Simulations

Simulations of the electric buses on all routes were performed using the system simulation tool previously described. Different scenarios were simulated by varying the passenger amount, frequency of stopping at bus stops along the route, and the driving style. The mean passenger amount was assumed to vary from 15 to 45 persons, corresponding to a load weight of 1000 - 3100 kg. The stopping frequency was varied from stopping at every bus stop to stopping at only 20 % of the stops. Variations in the driving style were modelled by adjusting the maximum level of acceleration and deceleration in the range 0.6 - 1.1 m/s². The simulated traction energy consumption is compared to the measured values in Table 2. With these settings, the simulator slightly overestimates the energy consumption. On route E11, 89 % of the measured values fall in the simulated range. On routes H23 and H55, much less measurement data are available as the operation of electric buses started later. On route H23 all measured values fall in the simulated range, and on route H55, the portion is 95 %.

Table 2. Simulated and measured traction energy consumption

Route	Simulated traction energy (kWh/km)	Measured traction energy (kWh/km)
E11	0.50 - 0.89	0.43 - 0.85
H23	0.60 - 0.97	0.63 - 0.91
H55	0.58 - 0.93	0.50 - 0.83

In the actual bus operation, it is obvious that the circumstances vary during the day. During early morning, for instance, the bus has only a few passengers and does not need to stop very frequently, while both the passenger load and the stopping frequency increase during rush hour. In the simulations, the traction energy consumption increases with up to 20 % just by increasing the number of passengers or the stopping frequency. As these factors are correlated and vary simultaneously, the variation in the energy consumption changes even more. The driving style also naturally has an impact on the energy consumption. Energy can be saved by applying a smooth driving style and by avoiding harsh decelerations. It should be noted, however, that it is quite difficult to model different driving patterns, and the influence of the driver cannot be fully analysed by use of the simulations.

4.3 Electric bus charging

Besides the performance of the bus itself, the capability and efficiency of the bus system is extremely dependent on the charging events. Four out of the ten KPI's selected are directly derived from the charging systems. Furthermore, if the charging systems are not working properly, many of the KPI's measured from the vehicles will be immediately and severely affected.

Ideally, positioning the vehicle correctly at the fast-charging node is simple and fast, and the connection and disconnection times of the pantograph are minimised. The vehicle positioning time was not yet available for analysis at the time of writing. The dead time in charging was analysed based on a data set of one and a half months for one of the buses. A rather short time period chosen for this analysis as the data have to be recorded with a sufficiently high frequency. The charging events from the time period selected were analysed by comparing a charging status indicator recorded by the vehicle to the battery charge current. The charging indicator indicates the time the vehicle spends at the charging node position, i.e. the time when the driver manually initiates the charging event from the bus, until the moment when the pantograph has been released and the vehicle is ready to drive again. The total charging time therefore also includes the movements of the pantograph and all necessary communication between the vehicle and the charger. Of the total charging time during one charging event, active time is the part when charging current is on, and the idle time is used in pantograph movements and communications.

Based on the data, the time consumed for the connection and initialisation of the charging is typically around 17-18 seconds. The time used for disconnection is slightly less, about 14-15 seconds. However, these times only hold for successful charging events. Different charging scenarios can be seen in the data recorded. In some cases, the charging itself is successful, but the time for connection of the pantograph and initialisation of the charging is for some reason longer than normally. During the time studied, 9.5% of the charging events had a connection time over 20 s. Another 11% of the charging attempts were totally unsuccessful, i.e. the battery was not charged at all.

Different types of charging problems can be observed from the data. In some cases, the initialisation of the charging is unsuccessful, and the bus driver has to make several attempts before the charging actually starts. In some cases, the initialisation is successful and the battery is charged, but the charging event is for some reason interrupted, and the charging has to be restarted in order to achieve the desired state of charge. In some cases, the charging restarts after achieving 80% state of charge, which is the predefined level for maximum charge for these buses. Based on the data, it is not possible to say conclusively, whether these unsuccessful, interrupted or incomplete charging events are caused by mistakes of the driver, or whether there is a technical problem. The number of unsuccessful charging events for the two buses on route E11 is shown in Fig. 7. In this figure, the charging was considered unsuccessful if the charged amount corresponded to less than 5 % of the total battery capacity. In other words, the charging is unsuccessful if no energy at all is received, or if the charging is interrupted after a very short time. As can be seen in the figure, problems with the charging occur quite often. Of all days with bus operation, only 38% had no charging problems at all. The number of unsuccessful charging events is mostly small, and the data merely indicates that the driver has to make a couple of attempts before the charging actually starts, or unintentional charging events are initialised. Occasionally the number of unsuccessful charging events is very high, indicating more severe charging problems. In further analysis to come, we will attempt to dig into the different reasons for unsuccessful charging and the related root causes.

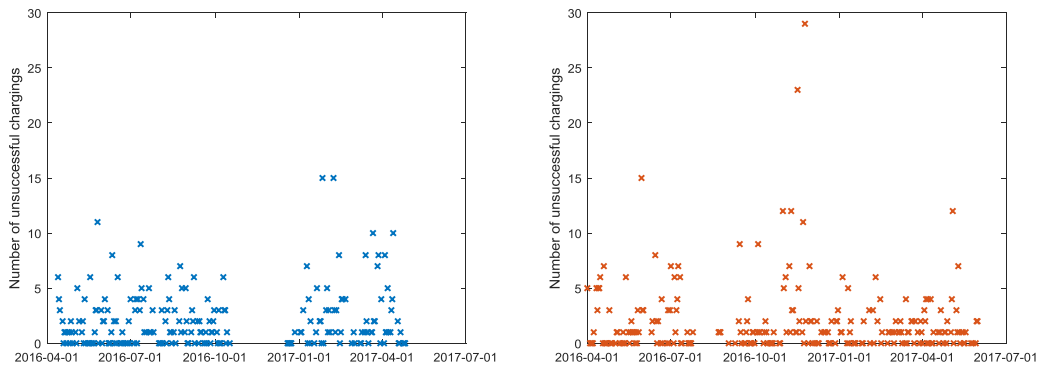


Figure 7. Number of unsuccessful charging events per day for the two buses running on route E11.

In order to achieve energy efficient public transportation, the energy efficiency of the charging (technical indicator) also has to be analysed. The daily mean efficiency of the charger on route E11 during the first half of year 2017 is shown in Fig. 8. The efficiency was calculated by comparing the energy taken by the charger from the grid to the energy received by the battery in the buses. As can be seen, the efficiency is mostly 70 - 80 %. The charger consumes up to 70 kWh per day in standby. The efficiency, therefore, rarely goes above 80 % and is dependent on the utilisation of the charger. The efficiency was slightly higher in the beginning of the year, as four buses used the charger at that time. During the last months, only two buses have actively used the charger. Very low efficiencies can be seen on days when the charger has been used only one or two times, and the charged amount of energy has been even smaller than the standby consumption. The electric buses on route E11 do not operate at all on weekends during the pilot phases, resulting in 0 % charger efficiency. Another part of this topic is the actual efficiency of the charging event when the current is flowing. This has not yet been measured and will be reported later.

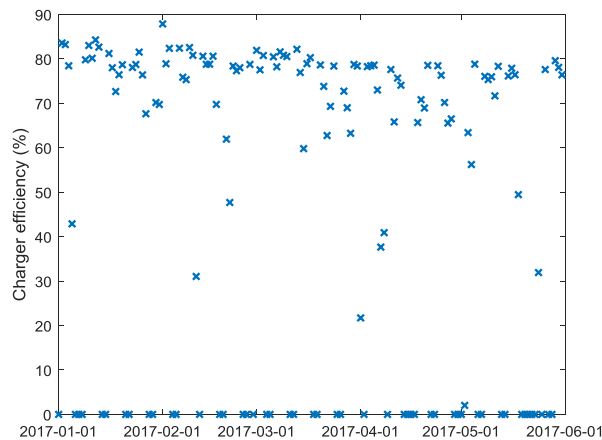


Figure 8. Daily mean efficiency of the charger used on route E11.

4.4 Availability of the KPI's

The availability and calculation methods of the KPI's at the time of the writing is presented in Table 3.

Table 3. Availability of the KPI's

No.	Indicator	Calculation	Availability
1	Energy costs, driving (€/km)	Electricity (from grid) and heater fuel consumption costs / kilometres driven	Not available yet; Heater fuel consumption missing

2	Operational driving distance (km, on route)	Operational distance driven compared to the planned bus circulation	Data available; Requires manual work. Work in progress to automate
3	Total electricity consumption (kWh/km)	Total charged external energy / kilometres driven	Available
4	Time required to position the bus at the charger (s)	Time to maneuver the bus to the charger. From arrival at the charger proximity to the point when the driver initiates the charging	Not available; requires additional measurement arrangements
5	Total charging time (s)	Charging duration from the charging start command to bus being ready to leave	Available
6	Charging node utilization (%)	Time when the charging position is occupied / time available. Time occupied includes the active and dead times	Available
7	Depart on schedule (%)	Percentage of departures left on schedule	Data available; not being visualized yet
8	Availability of the vehicles (%)	Percentage of the time that the vehicles have been available for service	Not available yet; Requires more data from PTO's
9	Availability of the infrastructure (%)	Percentage of successful charging events / all charging events	Not available yet; Requires work with the CPO
10	Additional maintenance time (h/a)	Additional maintenance time compared to conventional vehicles, e.g. cleaning of pantograph contacts	Not available yet; Requires more data from PTO's

Conclusions

A set of key performance indicators was processed for the assessment of performance of the the electric bus system being piloted by Helsinki Region Transport. A tentative list of 10 KPI's has been identified and the derivation of the numeric values based on system-level data through IoT systems and partially also input from the PTO's is underway. The first results from real operational data were presented here. Work will continue to analyse this pre-commercial electric bus system pilot in a systematic and open way. The purpose of this is to bring the whole HSL region to the status of readiness to commence commercial tendering phase. Of key importance in this work is the seamless interoperation of charging systems and the electric bus fleet. Reasons and root causes need to be understood so that necessary corrective actions can be done. At the moment, the pilot is still in the early stage and the system does not yet reach the availability and productivity targets set. A positive trend in most of the indicators can be observed, however. Close follow-up of system performance will continue.

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