Photo by Michael Dziedzic

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Procurement and piloting of electric buses in Turku

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This article is a summary of the report “Procurement and commissioning of electric city buses in Turku” made in eFöli project. The report highlights some of the most important aspects of introducing a modern opportunity charging e-bus system to operational urban mass transit system.

The city of Turku has an ambitious target to become a carbon-neutral city by 2029. Part of this plan is to electrify the majority of public transportation, which in Turku means mostly buses. The transition was started in autumn 2015 when Turku Region Public Transport, also known as Föli, electrified the bus line 1 with 6 Linkker buses aWnd two fast charging stations. Bus line 1 operates between the port and the airport and thus has more PR value that some other bus lines might have. This pilot was carried out as a part of TEKES-funded eFöli project. In addition to the procurement of e-buses and charging infrastructure, eFöli project contained adapting the route for e-bus operation and creating the operation model and contracts for different stakeholders. As a part of eFöli, Turku University of Applied Sciences (TUAS) carried out separate research that aimed to ensure the actual energy consumption of the system. This was done by acquiring and analyzing extensive amounts of data from the buses and charging systems. The experiences city of Turku gained during procurement and the results from TUAS research were documented in detail to be utilized in the future procurements in Turku and elsewhere.

Procurement and commissioning of the e-bus system

The procurement process was started in autumn of 2015. First, a public request for companies was issued to companies to express their interest in participating in the tendering and for companies to request additional information about the tendering. Six companies expressed their interest and out of those companies three (Linkker Oy, VDL Bus & Coach BV and Volvo Finland Ab) were selected for the final tendering phase. The target of the procurement was set to a turnkey solution of “six (6) new fully electric buses and one (1) charging system including two (2) fast charging stations and one (1) slow charging station” and a maintenance contract for those systems. The request for quotation was a 35-page document consisting of

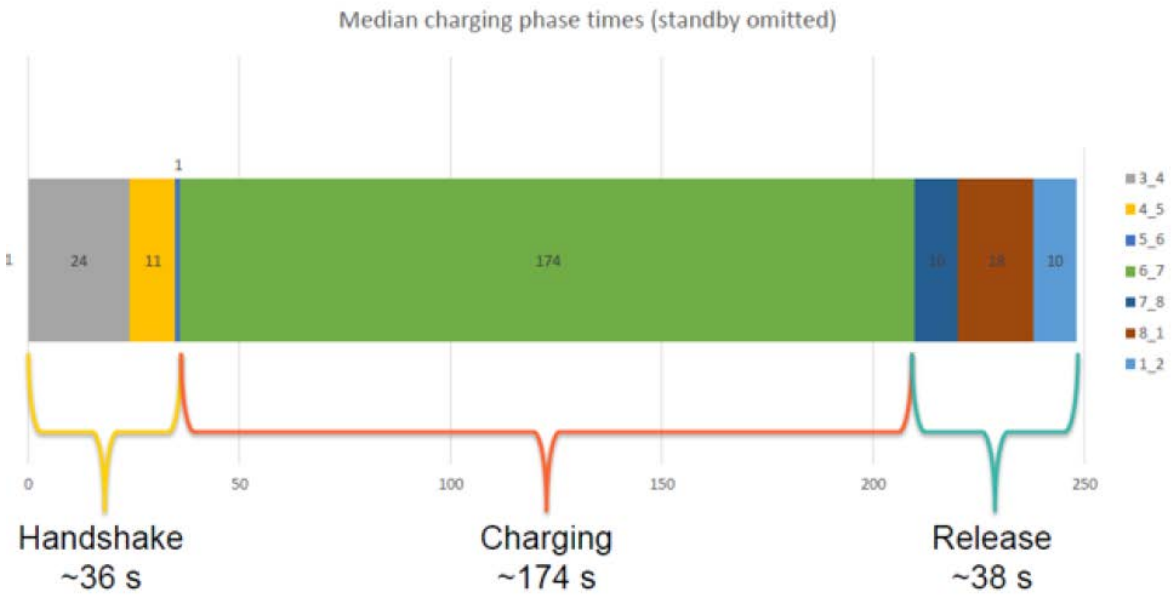
e.g. technical requirements, notes about delivery and commissioning and conditions about the maintenance of the systems. The participants were also provided information about the planned route, general description of the traffic, planned vehicle rotation scheme and planning documents, recorded velocity data from the route and illustrations of the planned charging stations. The city of Turku also organized an on-site visit where participants had a chance to familiarize themselves with the planned location of systems and asking questions.

All three companies submitted a quotation before the deadline. The quotations were evaluated using a weighted scoring system, which was provided to the participants beforehand. The largest weight was assigned to the price and other criteria were involved e.g. the maintenance contract and the energy consumption. The winning tenderer was Linkker Ltd., a Finnish startup company. Linkker's offer included six 12.8-meter fully electric buses, two 300 kW fast charging stations and one slow charging station.

The original delivery schedule of the buses was delayed multiple times. As only one electric bus was delivered at the beginning of the operation (10/2016), Linkker supplied Turun Kaupunkiliikenne diesel buses to replace the missing electric buses, until they would be delivered. The last bus was delivered in summer 2017. One of the fast charging stations was also delivered a few months late. After the operation started, several problems and issues were detected in buses and charging systems. One of the most significant challenges was how to make the charging process as reliable as possible from a driver's perspective. These problems were clearly seen in the gathered data as prematurely terminated or otherwise unsuccessful charging attempts. The charging issues decrease the effectiveness and reliability of the system and cause stress and frustration for the drivers. The root cause of the problem varies and many of those reasons were not related to electric power train or charging system. For instance problems with doors, LCD displays, interior heating or other accessories can in principle be encountered equally well in traditional diesel buses as well. None of the six buses reached the planned km-output during the pilot phase.

Analysis of consumption, the total cost of ownership and emissions

The fast charging process in the charging stations is highly automated, in principle the driver needs only to position the bus correctly below the overhead pantograph and bus the button to initiate the charging process. Then a handshake data transmit takes place and the pantograph connection is established. After the identification, the charging is initiated. After the charging phase, there is a release phase where the process is finalized and the pantograph connection is detached. It is important to include handshake and release phases when estimating charging time. Durations for the different phases were analyzed utilizing data from the CAN bus of the buses. From the data analysis, it was estimated that the median for so-called dead time (preparation and release) is approximately 30 % of the total charging time.

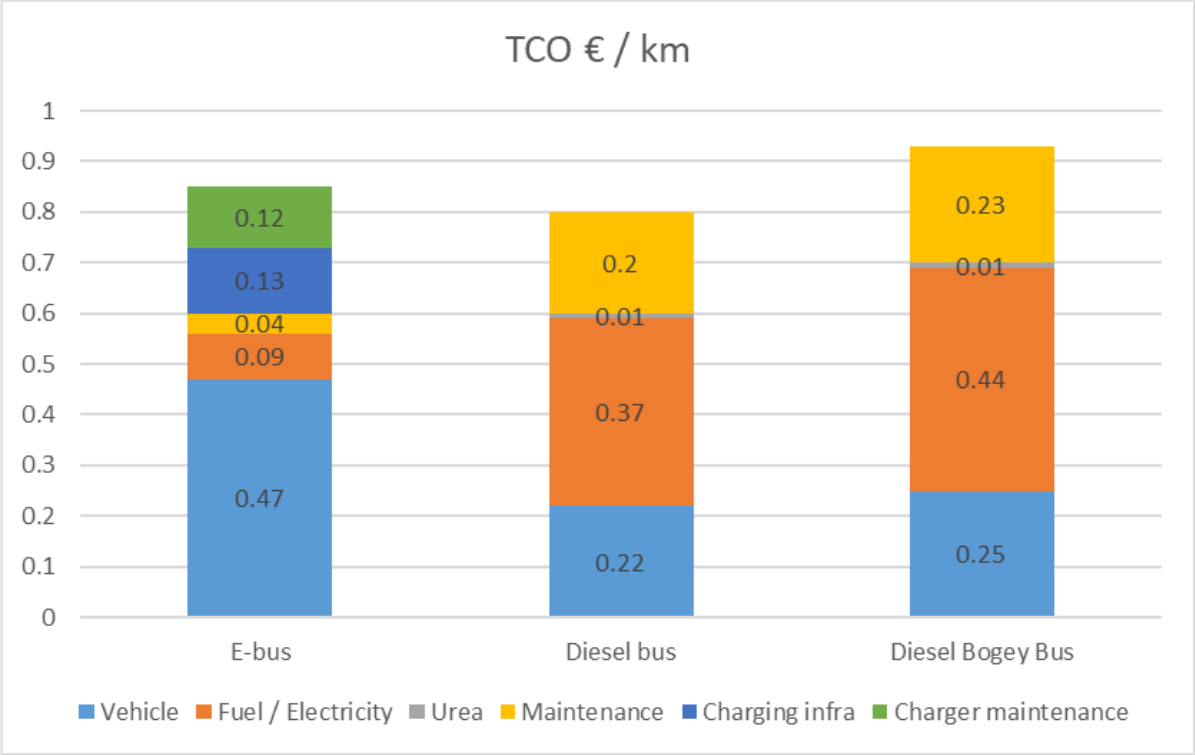


The median durations of the different phases in the fast charging events

Consumption

The energy consumption of the system has been satisfactory. Dynamometer consumption measurements were conducted at VTT Technical Research Centre of Finland in order to verify the information provided by the manufacturer at the time of tendering. The results from the standardized test was 0.825 kWh / km, which was in line with the values provided by the manufacturer. Real-world measurements from the buses and results suggest a mean consumption of 0.83 – 0.95 kWh / km depending on the vehicle, averaging to 0.89 kWh / km across the vehicles. These values are not considering charging losses or idle consumption of the chargers. The total amount of invoiced electricity is 20-25 % higher. The system-level energy efficiency is highly dependent on the idle consumption and can be improved by increasing the utilization rate of the charging stations. Linkker e-buses are also equipped with 24-kW diesel, which must be taken into account when determining the total energy usage for the buses. The fuel heater's consumption was approximated to be 0.32 kWh/km. With all these values, the system-level consumption adds up to 1.33-1.47 kWh/km.

The total cost of ownership on line 1 was compared with diesel bus operation in Janne Lankila's B.Sc. thesis that was a part of eFöli project. The data used in calculations was based in the City of Turku's procurement documents, energy consumption measurements from buses and expert statements. The baseline scenario presented was TSO metric of 0.85 € / km, which is in agreement with other literature. The baseline scenario is slightly lower than the corresponding value for 3-axis diesel bus and slightly higher than for 2-axis diesel. The TCO will greatly vary if operative parameters such as the yearly mileage and system lifetime deviate from the baseline scenario. Altogether, if operating goes as has been planned, this indicator suggests a competitive edge for e-bus systems from a financial standpoint, too.

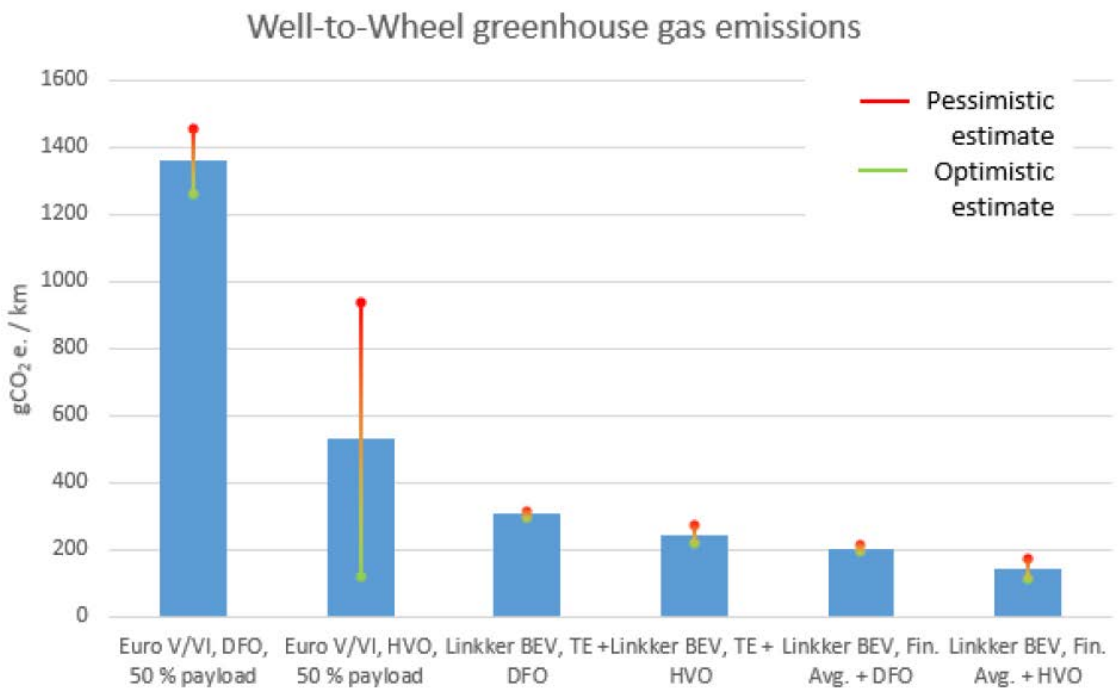


TCO analysis of an e-bus system compared to various types of diesel buses (Lankila 2017)

Environmental impact was analyzed by comparing computational emissions of e-buses with diesel bus emissions approximated from VTT's Lipasto-coefficients. No emission measurements of diesel buses were conducted. A tank-to-wheels (TTW) and well-to-wheels (WTW) analysis was conducted comparing Linkker buses to EURO V and EURO VI emission standard diesel buses. At the time of the pilot project, most of the diesel buses in Turku conformed EURO V standard. TTW analysis gave a result of emission savings of 500-800 t CO2 eqv during the pilot phase. WTW analysis was conducted using data analysis made during the project and LIPASTO-coefficients and WTW coefficients found in the literature. The WTW emission coefficients vary from source to source so two different scenarios for diesel buses were presented. Linkker emissions were calculated using average CO2 impact of the electricity used in Turku and the national average. The analysis showed that electricity is clearly a very competitive choice compared to conventional diesel, but with renewable diesel, good results could be obtained too.

Conclusions

During the first operative years, the reliability of the system failed to reach a Wsatisfactory level. In the future, the learning curve needs to be steeper to minimize the disturbance to bus operations when introducing e-buses on existing bus lines. From the technical point of view, all of the core components of the electrical power-train and battery system have functioned satisfactorily. In addition, from the energy efficiency point of view, the system has proved its competitiveness against traditional diesel buses. Problems have occurred with the charging system and with some of



Well-to-Wheel analysis of various fuels of transportation. Linkker values include the operation of the fuel heater.

the most critical auxiliary devices such as HVAC system. For general acceptance, it is important to have good PR management as when an e-bus is being maintained for whatever reason, the general public will blame the new technology.

The pilot has also shown the importance of sizing system components with sufficient redundancy to overcome slight distractions such as charging station malfunction. The overall efficiency and hence profitability is highly dependent on the utilization rate of charging infrastructure and the number and placement of the fast charging stations should be optimized carefully. The pilot project results show that the challenges of new technology should be addressed appropriately already in the tendering phase. Hopefully, the results of this pilot project will help Turku and other cities to avoid the most common pitfalls in the future e-bus system tendering process.

The complete report is available on the website of Turku University of Applied Sciences.