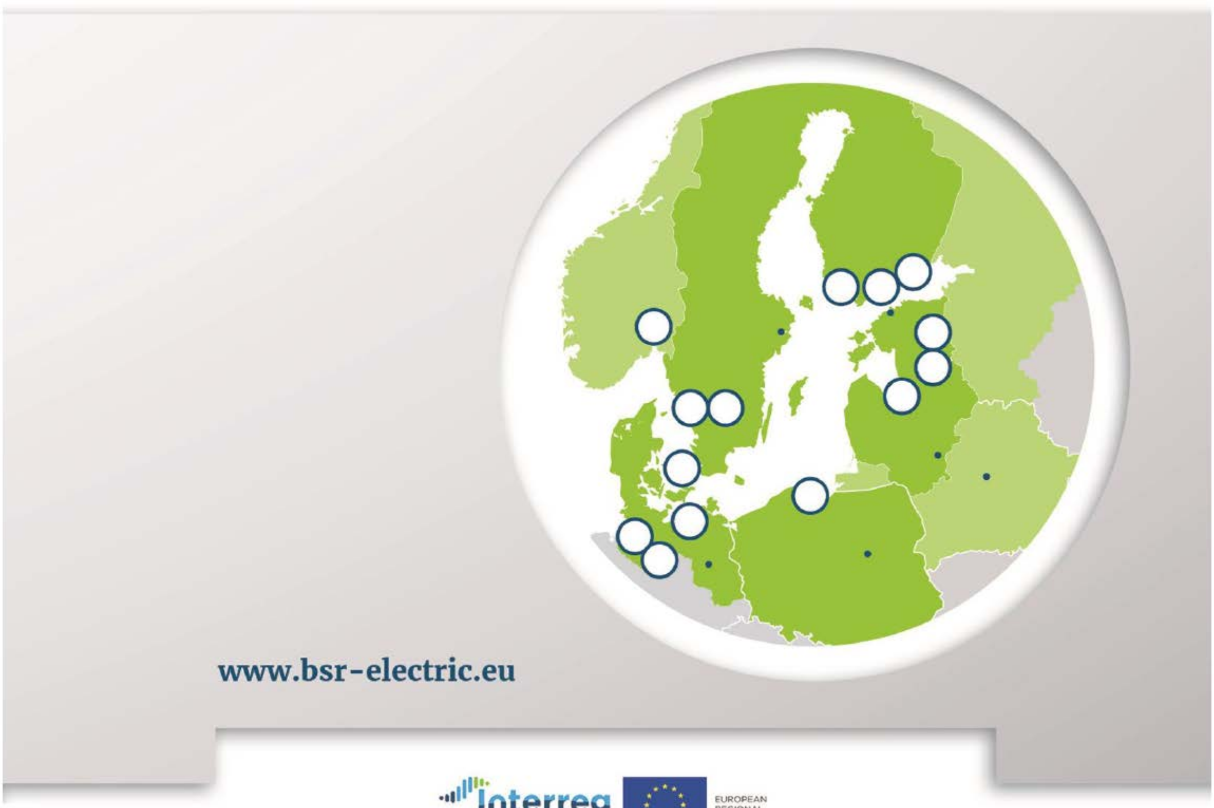
Use Case 3: E-Buses in Hamburg and Tartu



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1. Introduction

1.1. Background of the Use Case

Picture 1: E-Bus in Tartu, Picture by Tartu City Government (CC-BY-SA)

The transport of goods and passengers within urban environments is a major contributor to the emission of greenhouse gases (GHG) but also to noise, pollution and road congestion. In order to reduce negative environmental and health related impacts, the European Commission's 2011 White Paper on Transport (European Commission, 2011) defines cornerstones for a climate-friendly transformation of urban transport systems in Europe, aiming at a reduction of GHG in the transport sector by 2050 by 70 % compared to 2008. Thus, urban areas have to address the problems of congestion, noise, emissions of greenhouse gases, NOx and particulate matter to provide sustainable transport modes for increasing urban populations and increasing goods traffic within the next decades. Such a challenging transition within the given time frame requires a combination of various initiatives at all levels.

In spite of the various EU programs initiatives, the EU´s emissions caused by transportation have been mainly increasing over the last decades. This demonstrates that more effort and further initiatives on regional, cross-regional as well as local levels are required to achieve more sustainable transport systems. Necessary achievements include increasing the share of active mobility such as biking and walking, increasing public transport capacities, enhancing clean e-mobility solutions and very importantly, reducing the share of fossil-fuelled individual transport characterized by high emissions per passenger-kilometres and high space occupation.

The Interreg-funded project BSR electric addresses the mentioned topics and aims to enhance the use and integration of electric vehicles in urban transport systems in the Baltic Sea Region and beyond. In the course of the project, a set of seven use cases has been implemented, demonstrating the feasibility of integrating currently available, CO2-friendly e-mobility solutions into urban transport systems and, through this, increasing not only public awareness of sustainable urban mobility solutions but also providing real-life testing opportunities to experience new modes of urban mobility. The approach of the BSR electric project is to demonstrate the positive effects and technological as well as economic viability of sustainable transport solutions with small-scale pilot projects, which cover a broad range of applications from developing business cases for logistics companies to increasing the accessibility of public spaces.

An important component for the reduction of congestion, noise and transport related emissions is the fostering of public urban transport. The use case 3 is supporting the successful implementation of new battery electric buses into an existing fleet of local transport providers in Hamburg, Germany and Tartu, Estonia.

1.2. Aims of the use case in Hamburg

In Hamburg the associated organization 4 (AO4) Verkehrsbetriebe Hamburg Holstein (VHH) started the preparations for a large-scale implementation of e-buses into the existing fleet in 2016, which is envisaged to be completed in 2030, when only emission-free vehicles are allowed to operate in Hamburg (Verkehrsbetriebe Hamburg-Holstein, 2020). At the time before the start of BSR electric, only few zero-emission buses had been in pilot operation in Hamburg, thus experiences regarding large-scale deployment and operation of e-buses were practically non-existent. In order to include an academic perspective, the VHH is participating in the use case 3 of the BSR electric project. The aim is to evaluate the influences of different parameters on the range of the e-buses, such as ambient temperature or driver behavior by data acquisition and analyses, since knowledge of the influencing factors enables a more precise planning and optimization of the operations. For this purpose, systems for the acquisition of the bus data have to be implemented and the data sets have to be analyzed. Further, the procurement and implementation processes are being observed and lessons learned extracted.

1.3. Aims of the use case in Tartu

In Tartu, a sustainable and environmentally friendly transportation system is seen as a key element to creating a clean and human-friendly urban environment. In 2019 the Tartu City Government, project partner 10 (PP10) started a ten-year contract for public transport by gas buses. Nevertheless, for the next contract period starting in 2029, Tartu targets the implementation of electric buses running on renewable energy. In order to identify operational and logistic challenges of e-buses relevant for the transition of the transport system, Tartu procured an e-bus and tested it under real-life conditions in the frame of BSR electric. The aim of the use case in Tartu is to assess the feasibility for the city to procure a service contract that uses a fleet of electric buses once the current contract expires in 2029, evaluate present solutions for e-mobility and identify possible challenges in the implementation.

2. Procedures for the Implementation

2.1. In Hamburg

In 2016 the VHH started the preparations of a transition towards a zero-emission bus fleet, with the first intermediate target of procuring exclusively emission-free new buses from 2020 on. The first e-buses entering operation were 16 battery-electric eCitaros from manufacturer Evobus at the end of 2019, with a battery capacity of 230 kWh. The chosen strategy was overnight charging in the depot, since opportunity charging was estimated to have higher costs and more complicated infrastructure construction, especially due to the lack in space along the lines. After an initial test- and troubleshooting phase, the buses started regular operation in April 2020. The eCitaros were tested on various lines in the Borough of Bergedorf, with maximum lengths of around 170 km.

Some obstructions arose during the implementation of the BSR electric use case. Firstly, the drop-out of the initial implementer of the use case project partner 15, the Borough of Bergedorf. This was solved by the step-in of the VHH, which were preparing the implementation of e-buses into their fleet. Secondly, the VHH experienced delays in starting up the test phase of the e-buses by enduring problems with the procurement from several manufacturers. Thus the first e-buses could only be commissioned in late 2019, with a delay of several months. Other challenges regarded the production of the IT-systems for the acquisition of bus data, which also affected the BSR electric project. Due to the delays the automated acquisition of data could not be started during the project lifetime and data had to be logged manually by the bus drivers in specific standardized questionnaires, before and after every tour. The data from the questionnaires was then processed and analyzed with MS Excel by the BSR electric use case manager. This manual process involved a higher probability of mistakes and errors than by automated IT-based processes. Further, due to certain changes during regular bus operations, perfect conditions for data analyses where only one variable varies at a time could not always be established. Therefore, the data analyses performed in the course of the use case do not constitute precise evaluations, but are meant to provide indication for the correlations. Nevertheless, the gathered data are a valuable source of information and an opportunity to compare the results of Tartu and Hamburg.

The delays and encountered problems in the use case 3 in Hamburg help to identify challenges and establish recommendations from which similar projects can profit. Reasons for delays in e-bus implementation can arise due to a number of reasons, such as the remaining technical immaturity of technology and production processes for the e-buses, charging infrastructure and IT systems required to operate e-buses. With ongoing development and consolidation of industry standards, these problems are likely to diminish in the near future, but at the present still have to be considered carefully. Availability and use of data is essential for successfully starting and optimizing e-bus operations. Therefore, a comprehensive data concept needs to be established already before the tender, which comprises the definition of the required parameters and how to acquire and integrate them into the depot management system. Due to the significant changes for transport providers by the transition to e-mobility, proper change management needs to be applied also to support the personnel to adapt.

2.2. In Tartu

Tartu procured a 12-meter Solaris Urbino Electric bus with a diesel heater and a 200 kWh battery and tested it under real-life conditions in the frame of BSR electric. The pilot operator was decided through public procurement and was won by the transportation company SEBE, which rented the bus directly from Solaris to provide the transportation service during the pilot. The bus was an older model that had been used as a test bus in other cities. The mileage at delivery amounted to around 50.000 km which equals around half a year of service for regular city buses. The charging strategy chosen was overnight charging at the bus depot. The e-bus was tested from 01.09.2018 to 31.08.2019, during this time data of e-bus operation was collected and analyzed. In the recent years many cities across Europe have piloted or procured e-buses, producing reports which provide valuable information based on the experience of other regions. Pilot projects in Turku, Edmonton, and Gothenburg were identified as suitable case studies to compare to Tartu.

Three bus routes were tested during the pilot phase, one between the Tartu bus station and train station with a length of 4,9 km, a longer one with an additional destination with the length of 9,1 km and one variation which included the airport. The number of kilometers on route per day was around

70-90 km, which was significantly lower than an average Tartu city bus (260 km). During the test phase approximately 90.000 passengers were transported over a distance of nearly 48.000 km.

The bus charging was solved without setting up permanent public infrastructure, as only one bus was used. A charger was provided in the frame of the rental contract and was set up at the SEBE bus depot just outside city limits, since at this location the bus would be stationed the longest and would hence have time charging. Alternatives in the city were considered, albeit no suitable alternative was found. Although the technology enabled three types of charging – fast, average and slow – the buses were always charged on an average regimen because the electric charge capabilities at the bus depot did not enable fast charging.

The overnight charging method had two limitations during the pilot. First, the remote location of charging resulted in some empty trips each day. While the average covered distance per day was 177 km, only 70 – 90 km of this was spent on route and providing the line service. Secondly, once the airport segment of the e-bus pilot was incorporated, overnight charging duration was obstructed as the bus could not get its needed 5 – 6 hours of charge. This had implications on the daily schedule where during a longer brake in between trains the bus had to return to the depot for some additional charging. This also explains the large amount of deadhead during the pilot.

The pilot project faced some challenges that limited the availability throughout the year, mainly due to technical malfunctions in the bus system. Although the repairs were generally no big issues and took a total of less than 20 hours, communication and the supply of spare parts increased the downtime significantly. During these days the e-bus was replaced with a diesel bus and the bus line was serviced as usual.

These obstructions and challenges are instructive in two ways. First, it shows how pilot projects that rely on a single bus or charger are at risk of significant hindrance of operation in case of technical problems. Pilots with a larger e-bus fleet and other infrastructure elements are more expensive but also more reliable. Second, the delays in Tartu were prolonged due to the lack of relevant mechanical and maintenance staff. As this was only a short-time pilot, there was no foreseen need to train local engineers in maintaining this specific bus model and instead a contractual agreement for all repair works was a part of the rent agreement with Solaris.

3. Results of the Use Case 3

3.1. Suitable technologies (vehicles, charging)

A main technological factor to consider for each specific case individually is the charging strategy, i.e. whether to choose opportunity charging, with pantograph charging stations along the bus route or depot charging, with a plug-in charger at the depot. The pantograph system has higher infrastructure cost and requires space and electric connection along the bus route. However, it extends the e-bus range, making them suitable for longer routes. Depot charging is less expensive but limited in range by the battery capacity of the bus. The question of charging technology is thus interconnected with the vehicle type. In the case of battery electric buses, the energy is stored in battery packs. Different sizes are available, depending on the desired range of the bus but the batteries can contribute to a significant amount of the costs of the bus. Other types of e-buses are trolley buses, which are powered by overhead power lines. In this case, the costs for the bus are usually lower due to the much smaller battery packs, but the infrastructure has to be constructed or be already in place. Information on different technologies were included in several information and dissemination activities and materials, such as the webinar "E-busses… yes, of course – but now what?", the Action Checklist for Municipalities and Public Transport Providers on e-buses or the open source online learning course "Fostering e-mobility solutions in urban areas in the Baltic Sea Region and beyond", which can all be accessed on the BSR results website (https://www.bsr-electric.eu/results).

For the future e-bus implementation in Tartu, a battery electric bus with opportunity charging combined with overnight depot charging was identified as most effective operating strategy. While opportunity charging was not tested in Tartu, it seems reasonable for the Tartu bus network considering the average length of bus routes of approximately 13 km. This length is suitable for buses that carry small batteries and get quick charges at the end of the route. Still, strategic charging points will need to be identified for pantograph stations and the network of bus routes will need to be considered. It is possible bus routes may have to be changed to accommodate charging systems. Therefore, it is recommended that Tartu City performs an additional analysis of the bus system, considering the bus line network and locations where chargers should be integrated in order to identify the best strategy for the city.

For Hamburg depot charging was established as preferred solution already before the beginning of the BSR project. The implementation of quick chargers for opportunity charging was rejected by the VHH based on high investment costs, insufficient technological maturity and reliability, insufficient space and complicated planning to integrate the chargers into the existing bus routes.

3.2. Effective procurement procedures

In the early phase of the project, procurement of e-buses was a highly dynamic area, and e-bus manufacturing was not in a state of serial production. Even though technology and processes advanced in the last years, e-buses are still in a phase of development parallel to the operation. The process of procurement is very lengthy, due to the necessary EU-wide calls for bids. Additionally, the tender process is quite complex, since a variety of different solutions and strategies are available, such as battery electric buses, trolley buses, opportunity charging, depot charging and differently sized batteries. Therefore, extensive assessments of the specific frame conditions are required in order to define the operational concept and strategy and choose the best long-term solution. Also a comprehensive data concept is required already before the tender, and the availability of relevant data should be made a requirement in the tender procedure. Due to the observed delays which often originated from quality issues from the OEMs, the terms of procurement for all systems (buses, charging infrastructure, IT systems, etc.) should include sanctions if the quality of the delivered e-buses is deficient. Recommendations regarding the procurement were included in the theme-specific action checklists, available on the BSR electric results website (https://www.bsr-electric.eu/results).

3.3. Influence of different climate and weather conditions on EV performance

For assessing the impact of climate on the e-bus performance, data analyses in Hamburg as well as in Tartu were performed. Based on the gathered data, a linear regression method was used in Tartu to find out the relationship between energy consumption of the e-bus and ambient air temperature. The data points of the dataset and the regression result are represented in the following figure.

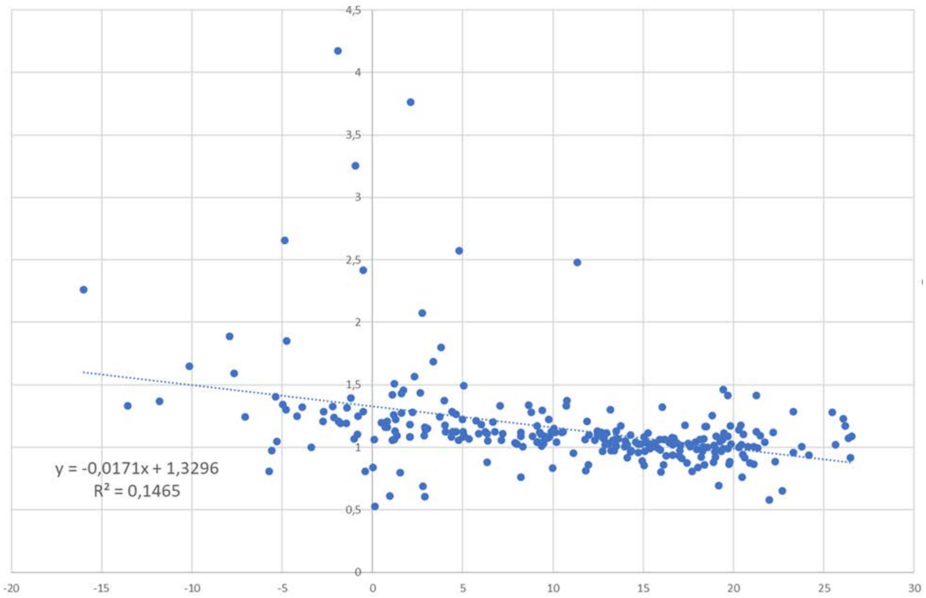

Figure 1: Energy consumption (kWh/km) vs daily average temperature in Tartu

The formula for linear regression is y = -0.0171x + 1.3296, where independent variable x is the air temperature (in °C) and dependent variable y is the energy consumption (in kWh/km). The model indicates that for every degree of air temperature decrease the energy consumption increases by 0,0171 kWh/km. The model's R^2-value of 0,1465 shows that the model may only describe 14,7 % of the variation in y by the x, which is not very precise and (based on the current dataset) the relationship between temperature and energy consumption is rather weak.

The data analyses from Hamburg show a very similar tendency and is shown in Figure 2. The data is based on the operation of 16 e-buses by a total of 77 bus drivers over a duration of 6 month, resulting in a mileage of almost 90.000 km.

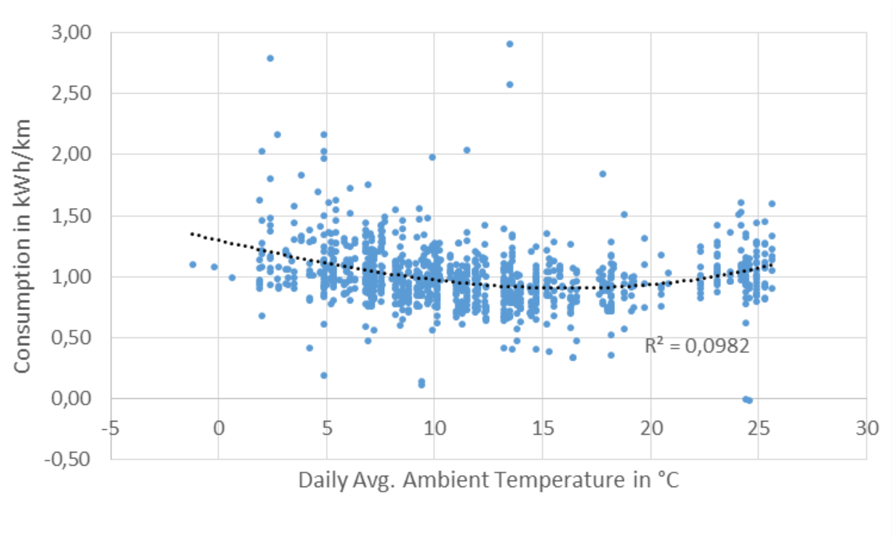

Figure 2: Energy consumption (kWh/km) vs daily average temperature in Hamburg

Due to a number of hot days in August with daily average temperatures of about 22 to 26 °C, the assessment was supplemented by data sets from 6th to 13th of August 2020. The data indicates an increase in energy consumption with increasing temperature, which might be due to the increased energy requirements of the air conditioning system.

When evaluating the impact of ambient temperature on the energy consumption it has to be considered that the e-buses in Hamburg and Tartu are equipped with a supplementary diesel heating system, supporting the main electrical heating system. This is reflected in the diesel consumption of the Tartu pilot in Figure 3.

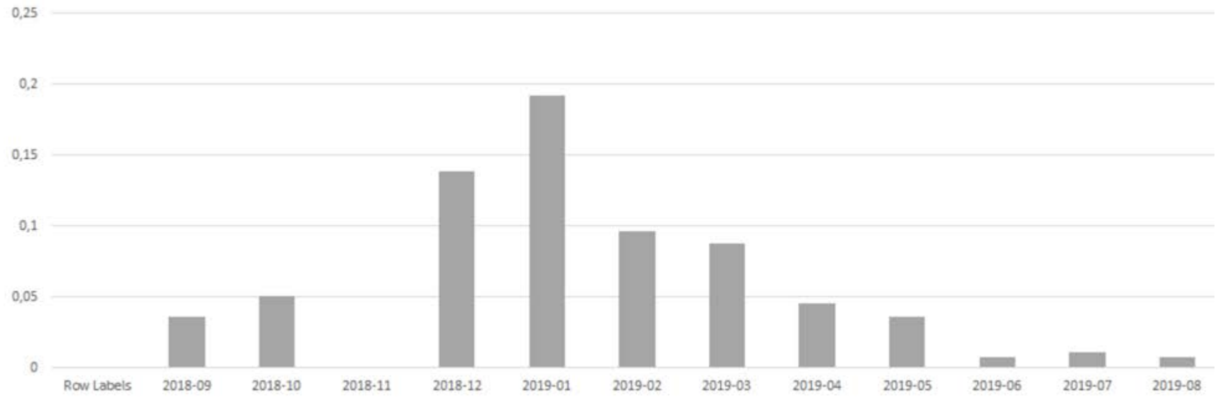

Figure 3: Relative diesel consumption for heating system of Tartu pilot (l/km) by months

These figure shows, that diesel consumption for the Heating Ventilation and Air Conditioning (HVAC) system went up during the colder months. The average diesel consumption in Tartu for the HVAC system across the pilot year was 0,04 l/km. Therefore, the total increase in energy consumption is the sum of electric energy and energy from the combustion of diesel fuel. Mere battery powered HVAC systems would thus result in a much higher effect on the battery in winter. The authors of the Edmonton analysis (Marcon, 2016) used for comparison estimated, that in the case of electric heating the range of the e-bus decreases between 15-25 percent. Since all the buses used by VHH and Tartu used an additional fossil heating, this could not be confirmed. But from the experiences and data analyses in Hamburg and Tartu it can be concluded, that providing a supplementary fossil heater can effectively limit negative effects of cold ambient temperature on the range, with the downside of a relatively small amount of CO_2 emissions due to the heating. Another measure is the preconditioning of the vehicles before departure. This means, that the HVAC systems of the e-bus are starts some time before leaving the depot, while the bus is still plugged into the charging station. This way, the temperature can already be adjusted, heating the bus in winter, cooling it down in summer, without draining the battery. While this has to be done manually at the moment, with bus depot management systems in place, the preconditioning can be conducted automatically and optimized regarding departure time and ambient temperature.

3.4. Driving habits, influence of driver performance on EV range

The driving style or driving performance is comprised of a multitude of actions which can influence the energy consumption, such as acceleration behavior, anticipatory driving and use of brakes. An optimum driving style is also dependent on vehicle specific features. The eCitaro for example enables a driving mode called “sailing” or “gliding” which holds the current velocity with minimum energy expenditure and should thus be used as much as possible, while extensive acceleration or braking increases the energy expenditure and reduces the driving efficiency. E-buses from other OEMs might have other characteristics.

In Hamburg, the influence of drivers or respectively driving styles was examined in detail. Data of 77 different drivers was included in the assessment, with the main indicator being the specific energy consumption in kWh/km. Figure 4 shows the average energy consumption for specific drivers (F1 – F29) with the highest mileage and the respective number of trips recorded. The average consumption varies between 0,85 kWh/km and 1,17 kWh/km, which represents a significant difference, especially when considering large-scale implementation of a high number of e-buses and drivers. Additionally, operational costs of e-buses are mainly driven by energy costs.

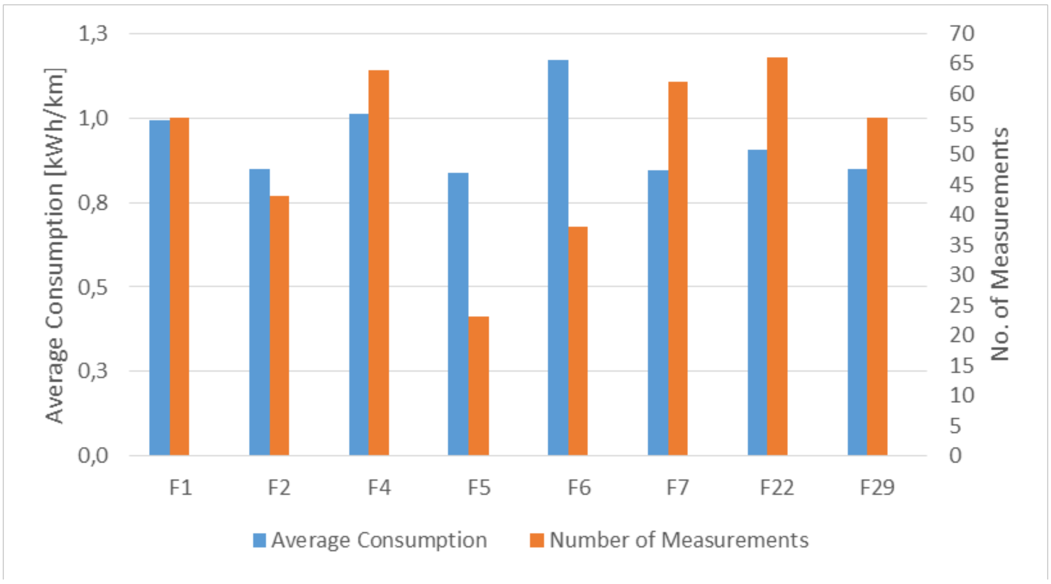

Figure 4: Average specific consumption of different e-bus drivers

The distribution of energy consumption over all trips is reflected in Figure 5. On the y-axis the number of trips in the respective bins are listed and the x-axis shows the energy consumptions bins, ranging from <=0,8 to >=2 kWh/km. The arithmetic mean of the energy consumption for the assessed trips equals 1,09 kWh/km.

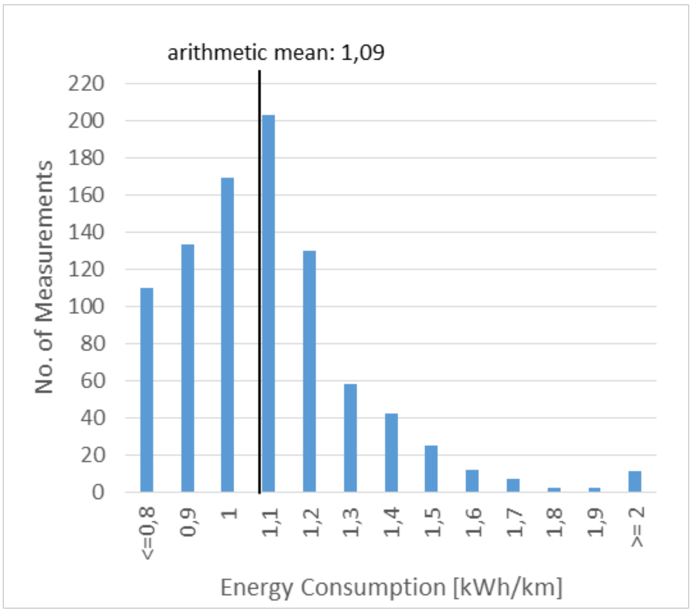

Figure 5: Distribution of energy consumption over all trips

The results indicate the great impact of driving style on the e-bus performance, especially since it is the only impact on the range which can actively be influenced. Measures for efficient driving are described in the following section.

3.5. Optimizing route plans and actions for efficient driving

As already mentioned, a variety of actions can be implemented to increase the driving efficiency. Concrete measures for efficient driving comprise proper training for the drivers, implementation of online feedback systems (indicators during driving), offline feedback systems (to be reviewed after driving) or the implementation of comprehensive telematics and data monitoring systems for in-depth analyses of the data, e.g. by specialized companies. A requirement of increasing the efficiency is measuring driving efficiency by acquisition of operational data from the e-buses. With proper data monitoring of the bus performance and charging infrastructure, defects, problems and optimization potentials can be identified significantly easier.

During the project it was found that the driving efficiency is a factor which is often neglected by transport companies but contains great potential for optimization. Therefore, the impact of driving style was the main subject of two initiatives directed at very specific target groups, an expert webinar as well as a video production for energy efficient driving. The webinar titled "The future of e-bus operations: Seizing the full potential of electrification" was held on August 7th 2020, featuring two expert speakers from leading companies in telematics and data monitoring of e-vehicles and 25 participants, which comprised professionals from public transport, academia, public authorities and consulting. The recorded webinar was uploaded on YouTube for continued dissemination and can be accessed on https://www.youtube-nocookie.com/embed/PRgXwgfLs0I. The video production realized in cooperation with the VHH aims at explaining background and implementation of energy efficient driving in practice to bus drivers and the general public. This is achieved by interviewing the use case manager in Hamburg and a driving instructor from the VHH. The video will be made available on websites of BSR electric and VHH in the course of September.

The optimization of route plans for e-buses is a highly complex process, depending on a multitude of different parameters, such as the chosen charging strategy, location of hubs, design of the different lines, distances covered by different buses or the range of buses. These aspects are also interconnected, e.g. the charging strategy is influenced by the required distance and the availability of spaces for charging infrastructure. In order to find a suitable charging and operation strategy, location dependent factors have to be considered, e.g. sufficient area for constructing charging infrastructure and with a suitable connection to the electric grid but also contractual aspects, with the contracting authority. When transitioning a bus fleet from diesel to battery electric, it is convenient to have a step by step approach. In a first step, the shorter routes can be operated via e-buses, because that does not require a complete re-planning of the routes. This is the approach chosen by the VHH. At the same time, the VHH is working to develop an IT system capable of predicting the precise remaining range, based on relevant factors, such as ambient temperature and route characteristics. This system will enable precise route planning and optimization of usage of the e-buses. For the future upscaling of e-bus operations it is worth considering to contract specialized companies which implement existing systems and processes for measuring driving efficiency and optimizing routes.

3.6. Surveys

In Hamburg a survey was performed with the aim to identify how passengers perceive e-mobility in public transport, both in terms of sustainability and practicability and which aspects are important to them in daily life. In the week from June 22nd to June 26th, a total of 167 passengers were interviewed in bus lines operated by VHH. To identify significant differences in perceptions, respondents were interviewed in both e-buses as well as in conventional buses. Findings clearly reveal that, from the passengers´ view, the most important aspects for public transport are punctuality and frequency of services, with 92 % and 80 % respectively regarding these aspects as very important. All other aspects surveyed were less important. However, compared to conventional buses, e-buses do significantly better in almost all evaluation categories e.g. in terms of environmental compatibility, overall acceptance and riding comfort. 95% of the interviewed passengers were very satisfied with the travelling experience in the e-buses, compared to 52% for the conventional e-buses. Passengers especially value the quietness of the e-buses and steadiness during the tours whereas the conventional bus rides were perceived as rather loud and bumpy. Most passengers do not consider e-buses as less reliable than diesel buses. It may be concluded that the vast majority of public transport users is in favor of electrification of public transport and appreciates the environmental benefits. The survey results suggests that BSR electric is on the right path with fostering the transition towards an electrified, emission-free public transport. Providing attractive, comfortable and economic means of mobility can create pleasant travelling experiences and may be regarded as key factor to literally get the passengers back “on board” after the Covid-19 heavily affected the entire public transport sector.

In Tartu user and operator experiences were assessed through interviews with bus users and operators. Although both the user interviews and online surveys had limited and non-representative samples, they both provided a favorable indication towards e-buses. The respondents saw e-buses as environmentally friendly and quiet alternative to diesel buses. Most respondents were in favor of moving towards a fully electric bus fleet in Tartu. However, there are citizens who are concerned with cost efficiency and environmental impact of e-buses, considering that oil shale is still the predominantly used energy source in Estonia. These concerns should be addressed by the city to assure a broader support from the public.

Operator experience was assessed by interviewing experts (N=3) who were closest to the e-bus pilot: The Head of the bus service provider SEBE that was responsible for the e-bus pilot, a Lead expert of public transportation at Tartu City Government and a Bus driver of the e-bus. The main message from the service provider and bus driver was that the operator experience was much better compared to a diesel or gas bus as it was not physically exhausting for the drivers. According to the interviews the biggest challenge in integrating a fleet of e-buses are technological, e.g. the current battery size and cost of investments. However, special attention should also be placed on training drivers to use the new technology.

3.7. Summary of the Results

As a result of both pilot projects, the implementation of systems for the monitoring and optimization of the bus and driver performance was identified as key factor for an economic operation due to energy savings. The driver performance is often unconsidered but the difference in energy consumption between a well-trained, efficient driver and an inefficient driver can reach up to 30 %, in some cases even 50 %. At the same time, driving performance can be monitored and improved relatively easy by measures such as implementing feedback systems, monitoring the drivers on their individual performance or providing specific driving training. Thus digitalization of the entire operations and implementation of advanced data-driven processes are essential for optimizing the business and saving money and energy. Also, training and sensitizing bus drivers to optimize their driving efficiency will be increasingly important, as the transformation of public bus fleets towards zero-emission fleets continues. The pilot projects further indicated the importance of having qualified maintenance personnel at hand in order to increase the operational availability especially for the first months. This avoids large downtimes when technical problems are encountered and decreases dependencies on reaction times of the equipment manufacturers. Technical problems are likely to occur at the early stages the industry is currently in, but will be less problematic with increasing maturity of the technology. Therefore, sufficient backup capacities should be provided during the implementation phase of e-buses. Nevertheless, appropriate reaction times of equipment manufacturers in case of technical problems should be specified in the terms of procurement including associated sanctions in case of infringement. In order to avoid problems of data availability with the manufacturers, free availability of the relevant data should also be specified in the procurement process. Finally, capacity building and knowledge transfer initiatives for public and private decision-makers are an important measure for disseminating the learnings within the stakeholders and speeding up the learning curve of bus fleet electrification.

Environmental impacts of e-mobility also depend on the primary energy source. In Tartu it is dependent on whether Estonia can reduce its dependence on oil shale for electricity production until 2029. Assuming that these targets are accurate and Tartu transitions to 100% renewable electricity use, integrating e-buses in 2029 will be environmentally feasible due to the lack of emissions in operation and related to the generation of electricity.

The results from the pilot project indicate that climate conditions will not have a significant impact on the performance of the e-bus if measures are taken, such as providing a fossil fuel heating for backup during the coldest season. In the Edmonton and Turku case study, neither city observed any significant decline in the performance of the e-bus battery in terms of energy consumption, charging rate, or discharging rate despite operating in cold ambient temperature, provided that an additional diesel or biodiesel heater is present to support the electric heating during especially cold conditions.

Tartu performed an assessment on the economic viability of e-buses compared to other bus types. This was performed based on an Excel model which allows to input cost data for different bus profiles and compare them over a longer period. Using this model, it was found that when comparing the costs of different bus types over an operational period of 15 years, both e-buses with depot charging and opportunity charging were less expensive than diesel and biogas. Further, research indicates that battery electric buses (BEVs) in combination with depot charging might reach price parity with biogas and diesel buses within between 9-10 years and BEVs with opportunity charging within 11-13 years. It is important to note that the model was not used to calculate the cost for a fleet of e-buses but for individual buses, because an assessment of Tartu’s current bus network and electrical grid capabilities would have been necessary to estimate the infrastructure costs. However, this constitutes an indication for the economic viability of e-buses.

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